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**Testimony Guide**

My name is Linda Green and I'm a member of Illinois People's Action and Fair Economy Illinois.

[Pick one of the IPA/FEI "Dirty Dozen" Comments and phrase it in your own words here. Try to pick a talking point that hasn't already been addressed by previous speakers. If possible, please explain why this is personal to you. For example, I am a (mother, father, student, health-care professional, farmer, teacher, etc.) and this is important to me because.... Translate the talking points into your own voice. Write it down so that you can submit it to IDNR at the end of the hearing]

## "Dirty Dozen" Comment Suggestions:

### (1) My comment is on Radioactivity

- One of the consequences of fracking in Illinois is that we can expect much of the produced water will be radioactive due to the fact that Illinois shale has above average levels of uranium. The US Geological Survey itself has found that produced water in Southern Illinois has radioactive Radium levels that are *67 times* the maximum contamination level of the EPA.
- The original legislation requires IDNR to comply with all "applicable federal, state, and local laws", but the rules make no mention of how regulators will ensure that fracking operators abide by the Illinois Low-Level Radioactive Waste Management Act.
- Unfortunately Sec. 245.850 only provides for testing of fracking fluids only once – during the early flowback stage – and only for "naturally occurring radioactive materials".
  - The proposed rules include no follow-up requirements or standards if testing shows radioactivity levels in flowback to be high. In other words, these proposed rules treat flowback the same whether it is highly radioactive or not!
  - The proposed rules do not include any standards or protocols to follow if testing of flowback water shows radioactivity.
  - The proposed rules do not require the testing of "produced water", which is the water produced from a well in conjunction with oil or natural gas production. This is where radioactivity is most likely to show up. It should be noted that while these Rules have been purported to be the strongest in the nation, PA law requires the testing of produced water at two separate intervals because, once again, that is where the radioactivity is most likely to show up. Testing only the flowback water is like saying, "We really don't want to find any radioactivity because then we'd have to do something about it, so we'll just test where we're pretty sure we won't find any."
  - The proposed rules do not require testing for added radioactive materials, like depleted uranium, which can be used during well-bore perforation in the fracturing operation and has a half-life of 4 ½ billion years.
  - The proposed rules do not test work areas for levels of radioactivity that would call for OSHA standards of occupational safety.
- These deficiencies, cumulatively or singly, would pose a significant risk to the public health and safety, property, aquatic life, and wildlife, in violation of section 1-75(a)(2) of the Hydraulic Fracturing Regulatory Act.
- **Solution**: We recommend testing produced water at least twice (the standard of PA) at $10\pm5$ and $75\pm5$; but because the law limits it to one test, we recommend the test occur at >21 days to obtain an accurate reading on radioactivity; test for naturally occurring and technically enhanced radioactive material, dissolved uranium, and radon, and require compliance with the Illinois Low Level Radioactive Waste Management Act.

### (2) My comment is on Fracking and Earthquakes

- It is well documented that the injection of fracking wastewater into the ground has the potential to trigger man-made earthquakes.
- Currently the traffic light control system set up by the rules allow for up to four fracking-induced earthquakes of at least magnitude 4.9—even near the New Madrid or Wabash fault lines--before a company has to shut down an injection well.
- The IDNR rules have created a dangerous inadequate warning/shutdown system for injection wells tied to seismic events, and have given companies no reason to actually abide by this warning system other than negligible fines.

- The rules do not at all call for the implementation of a seismic monitoring system that can accurately assign responsibility to particular fracking operators in the event fracking operations do induce earthquakes.
- The rules also fail to require insurance from well operators when it comes to property damage and injuries incurred by residents, business, or public institutions as a result of seismic activity tied to fracking.
- The science is clear that injection wells have the potential to cause earthquakes, but the connection can only be drawn with sufficient monitoring infrastructure. This failure, along with no insurance requirement for operators, is akin to allowing motorists to drive without auto insurance.
- Even though the original legislation calls for IDNR to consult with the Illinois State Geological Survey and, by extension, the National Academy of Sciences, it does not appear that IDNR did so.
- **Solution**: Observe these 5 empirically derived steps posed by Stanford University geophysicist Mark Zoback:
    - Avoid injection into active faults and faults in brittle rock.
    - Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.
    - Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.
    - Protocols should be established in advance to define how operations will be modified if seismicity is triggered.
    - Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard.

**(3) Part 1: My comment is on automatically revoking permits if the wells aren't built to specification**

- While the original regulatory bill (Sec. 1-70 in bill) requires that the construction and testing of fracking wells meet standards set by the American Petroleum Institute (API), the rules create absolutely no incentive for companies to meet these standards (Sec. 245.1100) - as of now it only states that IDNR "may" suspend or revoke permits and or issue penalties in the event these standards are not met.
- Without following these standards, all fracking wells would be in grave danger of blowouts, fires, and explosions that endanger the lives of workers and nearby residents.
- The largest environmental disaster in American history – the BP Deepwater Horizon explosion in the Gulf of Mexico is a perfect example of what happens when corporations are allowed to skimp on these very important standards.
- **Solution:** Automatically suspend/revoke permits when companies violate these standards by changing the language to say that IDNR "will" suspend/revoke permits and or issue penalties. This way companies will know to think twice about violating these provisions.

**(3) Part 2: My comment is on the weak fines for Administrative and Operating violations**

- Corporations exist for one purpose: profit. Big banks, fossil fuel companies, all sorts of companies throughout history have broken laws, poisoned our environment, and endangered human lives for the sake of profit.
- The only way to ensure corporations follow the law and protect us and our environment is to make it more expensive to break the law than it is to follow the law.
- The Hydraulic Fracturing Regulatory Act placed strict fines and penalties for violating the rules.
- But the rules drafted by the IDNR contain minimal fines on corporations for very serious violations of human and environmental safety. Fines start at a token $50 per violation and only go up to $2500 violation (Sec. 245.200). Many of these fines are smaller than minor traffic violations.
- Furthermore, Sec. 245.1120 discounts violations from companies if they are more than 2 years old.
- The top 5 producers of oil and gas made over 118 billion in profits last year. A $50 or $2500 fine will not slow these corporations down.
- Fines should reflect the cost of the damage created if violations occur--The cost of polluting the groundwater, the cost of cancer and other illnesses caused by contaminated water and air, the cost of structural damage caused by fracking-induced earthquakes.
- **Solution:** Require the fines and penalties outlined in the original legislation

**(4) My comment is on Local Control**

- Section 245.210 requires that fracking permits include documents certifying consent for fracking operations to occur from the municipal authorities affiliated with the particular city village, or incorporated town where the well site is supposed to be located and that no permit be issued otherwise.

- But the vast majority of fracking in Illinois is going to occur outside of municipalities; it will occur in areas where the local government unit is the county.
- The intent of the legislation was to recognize that local units of government should have decision-making power regarding whether to allow fracking in their jurisdictions.
- This section demonstrates blatant disregard for the realities of the geography of fracking in Illinois regarding cities compared to counties. Little if any fracking is anticipated within the cities of Decatur, Carbondale, Marion, or other metro areas affected by the majority of fracking land leases. If permission is important for metropolitan communities, why are the proposed rules silent regarding neighborhoods in counties and the families living there?
- There is no substantive difference between a municipal or county government in Illinois in its powers other than the issue of Illinois Constitutional Home Rule. However, the lack of county Home Rule has never preempted a county power to issue permits on mineral or oil extraction. Numerous county governments have long histories and traditions in the permitting process regarding mineral and drilling industries.
- Counties and municipalities of government tax, employ law enforcement, provide social services and infrastructure. The rules provide no explanation why citizens residing in counties of Illinois should have less input regarding fracking permits. The regulatory differentiation between the rights of residents in municipalities vs. counties creates a group of second class citizens. These second class citizens have fewer rights in their ability to participate and ultimately determine the type and quality of energy extraction allowed in their neighborhoods.
- There is no reasonable expectation that the personnel at IDNR have any better or more clear understanding of the will of citizens in counties regarding fracking permits than the residents themselves. As the proposed IDNR rules envision municipalities empowered to decide fracking sites, what possible argument does IDNR have that it is better equipped or knowledgeable on the needs of residents living in Illinois counties?
- **Solution**: As the current fracking law is largely silent on the issue of county control, IDNR rules should err on the side of history and citizen decision-making and give counties and other local governmental decision-makers a say in whether fracking will be allowed in their communities and, if allowed, exactly how it will occur.

**(5) My comment is on Wastewater Storage**

- Fracking waste is filled with all sorts of heavy metals and is highly toxic and carcinogenic and even radioactive. Any sensible regulation should prevent any and all human, animal, and environmental contact with it.
- The Illinois law limits open pits to emergency situations and states they can only exist for 7 days from when the waste water is put in them.
- But the rules drafted by the IDNR (Subpart H, Section 245.830, 245.850) contain a huge loophole that allows fracking companies to store this highly toxic waste water until 7 days after the completion of fracking. (Section 245.850). This means the wastewater could be in the pits for months.
- Wastewater can easily leak from these pits into the groundwater, contaminate drinking water, and generate toxic fumes.
- **Solution:** require that drillers calculate the appropriate sized tanks needed for sufficient storage of flowback and produced water and clarify that wastewater must be removed from the pit within 7 days of the first use of the pit rather than 7 days after fracking operations are complete.

**(6) My comment is on Monitoring Water for pollution**

- Section 245.600(b)(1) of the proposed rules provides for the testing and monitoring of water sources within 1,500 feet of the well site. The problem with this is a horizontal leg of the well bore can extend for up to two miles from the well site.
- Limiting testing to an arbitrary 1500 feet is a reckless disregard of the known risk of the underground migration of toxic fluids, especially when hydraulic fracturing involves the use of explosive charges and especially in areas known for the risk of higher-magnitude earthquakes.
- In a report issued on September 5, 2012, the U.S. Government Accountability Office acknowledged this risk:
  *"Oil and gas development, whether conventional or shale oil and gas, pose inherent environmental and public health risks, but the extent of these risks associated with shale oil and gas development is unknown, in part, because the studies GAO reviewed do not generally take into account the potential long-term, cumulative effects."*
  --Information on Shale Resources, Development, and Environmental and Public Health Risks, U.S. Government Accountability Office, GAO-12-732 (2012), "What GAO Found".

- The agency mentioned specifically the risk of underground migration of toxic gases and chemicals: *"[A] number of studies and publications GAO reviewed indicate that shale oil and gas development poses risks to water quality from contamination of surface water and groundwater as a result of erosion from ground disturbances, spills and releases of chemicals and other fluids, or* ***underground migration of gases and chemicals****."* (Emphasis added.)
- To make matters worse, the proposed rules mandate testing for only a limited number of chemicals that they refer to as "indicator chemicals." The law mandates that fracking companies have the burden of proof to demonstrate that water pollution within testing areas are not caused by fracking. By limiting testing to "indicator chemicals, IDNR has limited the scope of the law which states that *"hydraulic fracturing operations will be conducted in a manner that will protect the public health and safety and prevent pollution or diminution of any water source."*
- **Solution**: IDNR needs to at the very least insure that the list of chemical indicators in Section 1-85 of the law all be referenced for testing as required by Section 1-80.

**(7) My comment is Non-water fracking and how critical it is that non-water fracking not be exempted from the rules.**

- The law defines "high volume" fracking based on the number of gallons of base fluid" (at least 80,000 gallons per stage and 300,000 gallons total).
- Problem: Gallons are units of volume used to measure liquids. But what if a liquid isn't used in fracking? Not all fracking base material can be measured by gallons. If non-water base fluids are accounted for as liquid gallons, the gallonage total will fall below the threshold set by the rules. Suddenly a fracking operation will no longer be considered "high volume", even though the operation is comparable in scale – and therefore risk – to a high volume frack in terms of chemical use, pressures, or other measures.
- Why is this important? If fracking operations use less than 300,000 gallons of fluid, they are considered "medium volume" fracking and they are exempt from all of the regulations in the law.
- Either IDNR has intentionally created a loophole to exempt the majority of fracking operations from regulations or it is simply inept and lazy—either of which could have disastrous outcomes for Illinoisans.
- Had IDNR done its due diligence, it would have realized that non-water, gas-based fracks are fundamentally different from water-based fracks and that a simple conversion of gas and water volumes is completely arbitrary.
- **Solution:** If IDNR is actually interested in regulating the vast majority of fracking operations slated to occur in Illinois then it must come up with scientifically sound method of determining thresholds for gas-based fracks. This determination must be independently based on an evaluation of risk and field data from gas-based fracks.

**(8) My comment is on the need for Health Professionals' to have Access to Chemicals**

- There are tremendous health and safety risks that come with pumping tons of highly toxic and radioactive water deep into our bedrock. But the IDNR Rules allow the actual chemicals to be kept secret, so not even doctors and health care workers know what toxins have been involved when they see a sick patient.
- Section 245.730 of the IDNR rules impede the ability of affected patients that come in contact with highly toxic fracking pollutants to acquire immediate treatment.
- Even though the law requires IDNR to provide health professionals about the chemicals used in fracking when that information is necessary to treat a patient, the rules provide a circular definition of an "affected patient" which requires doctors to test for exposure to secret chemicals in order to get fracking companies to disclose exactly what these secret chemicals are. There are over 353 chemicals used in fracking; expecting physicians to run 353 tests is medically and financially unfeasible and places the burden on the medical establishment instead of on the fracking company where it belongs.
- To make matters worse, the rules give medical professionals only one of two options in the event of a medical emergency - call the IDNR during "normal business hours" or call a "trade secret holder" (Sec. 245.730b1).
- IDNR gives no indication of how one can go about identifying who exactly this "trade secret holder" is and how one can actually go about contacting them in the event of an emergency outside of IDNR's business hours.
- Finally, the rules do not require IDNR and the trade secret holder to provide information to health professionals; they say the "may" rather than "shall" provide the information. This means they have complete discretion whether or not they want to share information about the chemicals involved in fracking, regardless of medical necessity. Why do IDNR and fracking companies have the ability to make life and death decisions for other people?

**(9) My comment is on Volatile Organic Compound (VOC) Emissions**

- Even though Section 1-53 of the regulatory bill requires that fracking operations be conducted in a "manner that will protect the public health and safety and prevent pollution," there are currently almost known provisions on how to reduce the highly toxic Volatile Organic Compound or VOC emissions that are generated by the fracking process.
- VOC's have scientifically been shown to cause asthma, cancer, and severe illnesses. In Colorado, oil and gas emissions are the main source of VOC's and, unsurprisingly, there have been many reported cases of illnesses from fracking pollution in Colorado since the boom began.
- The rules currently contain no best practice standards for mitigating these risks that could cause irreversible neurological and or respiratory damage to children, adults, and other living things.
- As of now, the Rules allow companies to be wholly exempt from runaway natural gas and hydrocarbon fluids from production (Sec 245.900e) or flowback(Sec. 245.845c) if the regulation of these isn't "cost effective" or if it is "economically unreasonable".
- Ozone-forming air pollution measured in Colorado is up to twice the amount that government regulators have calculated should exist.
- IDNR completely avoids defining "cost effectiveness" or "economically unreasonableness" – essentially allowing companies to define these terms for themselves. And we can assume that companies will make sure that they define it to their own benefit.
- A cost/benefit analysis that only calculates private costs of companies while ignoring the social costs on the people and the environment will result in privatizing profits for big corporations while socializing losses for taxpayers, adding an unjust burden to local and state governments.
- **Solution**: The Department should quantify the cost of various kinds of emissions utilizing independent scientific studies on this issue. Included in the quantification should be the health and environmental costs of emissions relative to the costs of capturing/reducing emissions.

**(10) My comment is on the Risk of Large Scale Environmental Disasters**

- Section 1-53 of the regulatory bill requires that fracking operations be conducted in a "manner that will protect the public health and safety and prevent pollution", the rules do not at all address the risk of large-scale and widespread environmental disasters that can occur as a result of fracking in the Wabash Valley and New Madrid Earthquake Zones or in the Illinois 100-year floodplain.
- The New Madrid Earthquake zone has been known to historically cause "major" earthquakes of over 7 on the Richter magnitude scale. The Illinois Emergency Management Agency itself identifies these areas with its most severe earthquake zone ratings of "Destructive" and "Ruinous." An earthquake of these magnitudes, compounded with fracking and injection wells spread throughout the affected zone is quite literally, a recipe for disaster.
- Furthermore earthquakes of these magnitudes can easily damage fracking wells, open air pits, pipelines, injection wells - causing toxic and radioactive fracking fluids to pour out into the ground and contaminate the soil and groundwater sources of hundreds of thousands of Illinoisans.
- Similarly, allowing any sort of fracking operations to occur within the Illinois 100 year floodplain zone is also asking for disaster. The environmental devastation caused by the recent floods in Colorado is a case in point. Inundated oil pads, flooded wells, overturned tanks, and ruptured lines were just a few of the horrific images of toxic chemicals spewing all over Colorado. Open-air pits—which the Rules allow—are particularly vulnerable to floods and would only compound the disaster.
- **Solution:**
  - Follow the guidelines set forth in the Illinois Oil Field Brine Disposal Assessment. (Illinois Environmental Protection Agency: Water Quality Managing Program.)
  - Use the Illinois 100-year flood plain map and avoid fracking in flood plains.

**(11) My comment is on an unfair Public Hearing Process**

- First of all, Section 245.230e creates a loophole whereby the 60-day review period for permit applications begins to run even before the application is deemed complete by the Department. This is simply inviting companies to submit incomplete permits as a way of avoiding public oversight and comment. IDNR needs to ensure that the 60 day review period only begins to run after IDNR deems applications as being complete.

- Next, Section 245.270 undercuts the robust public participation that was required by the law:
  - The rules (Sec. 245.720a6) require that public petitions concerning permits be served upon the presence of the Department, hearing officer, and the applicant. This is creating an unnecessarily high barrier for the public to petition the department when the Statute only specifies that the applicant must petition the Department.
  - The rules (Sec. 245.270b2) also give IDNR the discretion to hold hearings outside of the affected county rather than within. One would hope that it is obvious why it is important that hearings concerning local residents be held near those residents. Residents may simply not have the resources or child care options to travel out of town. It also limits the ability to call local witnesses that have critical information but may be unable or unwilling to travel far away from home. It should be IDNR's duty to make the hearing process as accessible as possible for the public.
  - The rules (Sec. 245.720g6) do not require the IDNR to testify under oath and be available for cross-examination. How is the public to be assured that their concerns will be addressed if IDNR only has to sit and listen to them without responding?
  - The rules (245.270a3e) force petitioners to present their concerns in the context of the rules. The IDNR should be concerned about the content of the complaint, not the technicalities. The average citizen will not have the legal background to determine if their fracking-polluted well water violates the rule or laws. That is IDNR's job. The hearing requestor should only need to know the legal basis for the request "if applicable" rather than "if known".
  - Section 245.270f allows IDNR to issue permits to operators even if they fail to show for public hearings, defeating the whole purpose of hearings in the first place. Failure to appear to hearings should either merit a rescheduling or a complete denial of the permit application.
  - Sec. 245.270i gives the hearing officer the ability to make a decision on all issues raised at public hearings without reporting back to the department first. It seems unlikely that IDNR ensure that the hearing officer has both the expertise and the necessary materials to make these decisions on the spot.
  - Sec. 245.270i places the legal burden on hearing officers to prove that operators are not otherwise entitled to a permit – the burden should be on frackers to prove that their applications are worthy of consideration given the issues raised.
  - Section 245.720n allows fracking applicants to attempt to correct any issues identified at public hearings without public notice of these corrections and no ability for the public to then provide revised and or updated comments. IDNR should allow the public adequate time to request follow-up hearings and submit comments to address the new information
  - Lastly, for some reason the rule gives IDNR "no more than 60 days to make a decision" – what happens if the issue is so serious that IDNR needs more than 60 days to make a fair decision?

**(12) My comment is on not allowing old fracking operations to be exempted from the rules.**

- As it stands, the draft rules (Sec. 245.100) only apply to fracking operations occurring since June 17, 2013, when the original regulatory act in Section 1-20 explicitly says that it ought to apply to all operations that are planned, *have occurred,* or are occurring in this State"
- If the whole intention of the regulatory act is to make fracking operations safer for Illinois people and the environment we so no reason why IDNR is intentionally limiting the scope of the rules to only apply to new fracking operations if older wells carry the same health and safety risks.
- Unless IDNR is drafting these rules to protect businesses and corporations over the safety and well-being of Illinois citizens, then it should:
  - Require all fracking companies to report any prior fracking activities that fall under the definition of "high volume hydraulic fracturing", regardless of when the activity occurred.
  - Ensure that past operations comply with the regulations outlined by IDNR to the furthest extent possible. For example, while it would not make sense for an operator to go back and re-perform drilling activities that did not conform to the Act, it should require compliance of ongoing obligations mandated by the rules – such as air emissions control requirements associated with production, post-frack testing and reporting, etc.

I agree with all of the above comments.
Linda D [illegible] 12/17/13

U22274

Soy Wilcoerly - chemicals

marileaw@Frontier.com

Marilea White

Hello. My name is MW & I'm a member of IF Bloomington. My comment is on protecting public health and the Environment.

10 yrs. ago I had a serious lung disease that resulted in me being barely able to function or to take care of myself. After 2 horrible years on Prednisone & many medical tests & ~~many medical tests~~, I am much better ~~now~~ but due to damage to my lungs, I still have periodic shortness of breath & must use oxygen when I sleep.

I do everything in my power to avoid exposure to smoke & chemicals. I avoid all aerosols, many perfumes, after shave lotions, soap powders, cigarettes, room deodorizers, chemicals farmers put on their fields & neighbors put on their lawns, etc.

I can't imagine living, or even being, near a fracking operation. The chemicals used in fracking, the methane that escapes from the wells, the chemicals that would be stored in open pits, the dust from silica sand — all these things, and many more, would have serious consequences for my health & well-being.

I love to camp, and have camped several times in the Shawnee National Forest, but if there is fracking nearby, I won't be able to go there again.

022275

In short, the proposed regulations will not

protect the E... health...

Hydraulic Fracturing – Proposed Administrative Rules
Public Hearing – Decatur, Illinois

December 17, 2013

On behalf of the Illinois Professional Land Surveyors Association and all professional land surveyors registered in the State of Illinois, I respectfully request that three (3) sections within the proposed rules be revised to reflect only Illinois professional land surveyors are licensed to produce well locations as required by these proposed rules. The following sections are:

- Section 245.210 Permit Application Requirements, Item a-2
- Section 245.250 Public and Government Notice by the Permit Applicant, Item a-5-D
- Section 245.1200 Medium Volume Horizontal Hydraulic Fracturing Completion Reports, Item c-1

The well location information required in the proposed rules are the responsibility of the Illinois Professional Land Surveyor per the Illinois Professional Land Surveyor Act of 1989 (225 ILCS 330), Section 1 (Declaration of Public Policy) and Section 5 (Practice of Land Surveying Defined) as attached for reference.

We respectfully ask that the Illinois Department of Natural Resources revise its proposed rules in order to be in compliance with these current Illinois State Statutes.

Timothy Burch, P.L.S.
Government Affairs - Chair
Illinois Professional Land Surveyors Association

e) Within 21 days after receipt of a registration form, if the Department determines that the registration form is deficient relative to the requirements of subsection (b), or the person submitting the registration form is not properly registered as a permittee under the Illinois Oil and Gas Act, then the registration shall not be accepted and the Department will notify the registrant with a statement of the deficiencies. The registrant shall not be considered registered for purposes of applying for high volume horizontal hydraulic fracturing permits pursuant to this Section until the deficiencies have been cured, the registration form resubmitted and a Department determination pursuant to subsection (d) has been made.

f) *A registrant must* keep its registration current at all times while it holds a permit issued under this Part by notifying *the Department of any change in the information identified in subsection* (b) within 60 days after the change. (Section 1-35(a)(3) of the Act)

g) All registrants shall resubmit the registration form pursuant to subsections (b) and (c) beginning September 1, 2016 and by September 1 of every even numbered year thereafter.

**Section 245.210 Permit Application Requirements**

a) *Every applicant for a permit under this* Part *must submit the following information to the Department on an application form provided by the Department* (Section 1-35(b) of the Act):

1) Applicant Information
*The name,* email address, and *address of the applicant*, the name and address of *any parent, subsidiary, or affiliate* of the applicant, and the applicant's high volume horizontal hydraulic fracturing registration number (Section 1-35(b)(1) of the Act);

2) Well Location
*The proposed well name*, well location, *and legal description* per the Public Land Survey System *of the* well, *well site, and its unit area* (Section 1-35(b)(1) of the Act). The well location shall be surveyed by an Illinois licensed land surveyor or Illinois registered professional engineer and the description of the surveyed well location shall also include the legal description, the GPS latitude and longitude location, and ground elevation of the well. The GPS location shall be recorded as degrees and decimal degrees recorded to 6 decimal places in the North American

Datum 1983 projection and shall be accurate to within 3 feet. The reported GPS location is required to be an actual GPS field measurement and not a calculated or conversion measurement;

3) Well Site Setback Plan
*A statement whether the proposed location of the well site is in compliance with the* setback *requirements of Section* 245.400 *and a plat* map, *which shows the proposed surface location of the well site, providing the distance in feet from the surface location of the well site to the features described in Section* 245.400(a) (Section 1-35(b)(3) of the Act) and a statement explaining how the size of the well site is sufficient to conduct all aspects of high volume horizontal hydraulic fracturing operations within its boundaries;

4) Directional Drilling Plan
*A detailed description* of the directional drilling plan *for the proposed well to be used for the high volume horizontal hydraulic fracturing operations, including, but not limited to, the following information* (Section 1-35(b)(4) of the Act):

A) *the approximate total* true vertical and measured *depth to which the well is to be drilled or deepened* (Section 1-35(b)(4)(A) of the Act);

B) *the proposed angle and direction* (heading) *of the well* (Section 1-35(b)(4)(B) of the Act);

C) *the actual depth or the approximate depth at which the well to be drilled deviates from vertical* (Section 1-35(b)(4)(C) of the Act);

D) the planned depth at which the well enters the formation that will be stimulated as part of the high volume horizontal hydraulic fracturing operations;

E) *the angle and direction of any nonvertical portion of the well until the well reaches its total target depth or its actual final depth* (Section 1-35(b)(4)(D) of the Act) *;*

*proposed well site will be located* (Section 1-50(d) of the Act). The notice shall include:

1) the date, time and place of the public hearing;

2) the name and mailing address of the Hearing Officer scheduled to preside over the public hearing;

3) the purpose of the public hearing and the name of the applicant;

4) the legal description, per the Public Land Survey System, of the proposed well site and unit area;

5) the review number for the permit application; and

6) *a statement that any person having an interest that is or may be adversely affected, any government agency that is or may be affected, or the county board of a county to be affected under a proposed permit may file* (Section 1-40(c)(3)(G) of the Act) a request for public hearing on the permit application pursuant to Section 245.270.

**Section 245.250 Public and Governmental Notice by the Permit Applicant**

a) *The applicant shall provide the following public* and governmental *notice* (Section 1-40(c) of the Act):

1) *Applicants shall mail specific public notice by U.S. Postal Service certified mail, return receipt requested, within 3 calendar days after submittal of the high volume horizontal hydraulic fracturing permit application to the Department to*:

A) *all persons identified as* landowners *of* any *real property* surface interest in land *within 1,500 feet of the proposed well site as disclosed by the records in the office of the recorder of the county or counties*;

B) *all persons identified as* persons with an oil and gas lease *within 1,500 feet of the proposed well site as disclosed by the records in the office of the recorder of the county or counties*;

C) all permittees under the Act or the Illinois Oil and Gas Act in land *within 1,500 feet of the proposed well site as disclosed by the records in the office of the recorder of the county or counties*;

D) the governing body of *each municipality in which the well is proposed to be located; and*

E) the county board of *each county in which the well is proposed to be located.* (Section 1-40(c)(1) of the Act)

2) *Except as otherwise provided in this subsection (a)(2), applicants shall provide general public notice by publication, once each week for 2 consecutive weeks, beginning no later than 3 calendar days after submittal of the high volume horizontal hydraulic fracturing permit application to the Department, in a newspaper of general circulation published in* or, if necessary, as near possible to *each county where the well proposed for high volume* horizontal *hydraulic fracturing operations is proposed to be located. If a well is proposed for high volume* horizontal *hydraulic fracturing operations in a county where there is no daily newspaper of general circulation, applicant shall provide general public notice, by publication, once each week for 2 consecutive weeks, in a weekly newspaper of general circulation in that county beginning as soon as the publication schedule of the weekly newspaper permits, but in no case later than 10 days after submittal of the high volume* horizontal *hydraulic fracturing permit application to the Department.* (Section 1-40(c)(2) of the Act)

3) *Within 15 calendar days after submitting the permit application to the Department, the applicant must provide a copy of the* permit application's *well site safety plan to the county or counties* and all local fire departments with jurisdictions covering the well site *in which* high volume horizontal *hydraulic fracturing operations will occur.* (Section 1-35(b)(12) of the Act)

4) *Within 15 calendar days after submitting the permit application to the Department, the applicant must provide a copy of the* permit application's *traffic management plan to the county or counties in which the well site is located* and any impacted highway authorities identified in the traffic management plan pursuant to Section 245.210(a)(15) (Section 1-35(b)(15) of the Act).

5) *The specific and general public notices required under* subsections (a)(1) and (a)(2) shall be on forms provided by the Department and *shall contain the following information* (Section 1-40(c)(3) of the Act):

A) *the name and address of the applicant* (Section 1-40(c)(3)(A) of the Act);

B) *the date the application for a high volume horizontal hydraulic fracturing permit was* received by the Department (Section 1-40(c)(3)(B) of the Act);

C) *the dates for the public comment period and a statement that anyone may file written comments*, objections and recommendations *about any portion of the applicant's submitted high volume horizontal hydraulic fracturing permit application with the Department during the public comment period* (Section 1-40(c)(3)(C) of the Act);

D) *the proposed well name*, review number assigned by the Department, well location, *and legal description* per the Public Land Survey System *of the* well, *well site, and its unit area* (Section 1-40(c)(3)(D) of the Act). The well location shall be surveyed by an Illinois licensed land surveyor or Illinois registered professional engineer and the description of the surveyed well location shall also include the legal description, the GPS latitude and longitude location, and ground elevation of the well. The GPS location shall be recorded as degrees and decimal degrees recorded to 6 decimal places in the North American Datum 1983 projection and shall be accurate to within 3 feet. The reported GPS location is required to be an actual GPS field measurement and not a calculated or conversion measurement;

E) *a statement that the information filed by the applicant in its application for a high volume horizontal hydraulic fracturing permit is available from the Department through its website* (Section 1-40(c)(3)(E) of the Act);

F) *the Department's website and the address and telephone number for the Department's* Office of Oil and Gas Resource Management (Section 1-40(c)(3)(F) of the Act);

b) Any violation of this Part may also include violations of the permittee's Oil and Gas permit related to the same well, the Illinois Oil and Gas Act, and regulations adopted under that Act.

c) All violations related to the same well may be brought as one case at the discretion of the Department.

d) Failure to meet the burden of proof required for revocation or suspension of a permit under the Act, this Part, the Illinois Oil and Gas Act, or the regulations promulgated under that Act, does not mean that the Department necessarily failed to prove other violations under the Act, this Part, the Illinois Oil and Gas Act, or the regulations promulgated under that Act.

e) Knowing violations of this Part may be a criminal offense as defined in Section 1-100 of the Act, which will be, in addition to any administrative action taken by the Department, referred to the State's Attorney in the county where the violation occurred or the Attorney General's Office.

f) Any person who violates this Part may also be liable for a civil penalty as defined in Section 1-101 of the Act, which will be in addition to any administrative action taken by the Department.

SUBPART L: MEDIUM VOLUME HORIZONTAL HYDRAULIC FRACTURING OPERATIONS COMPLETION REPORTS

**Section 245.1200 Medium Volume Horizontal Hydraulic Fracturing Completion Reports/**

a) *For* any horizontal *hydraulic fracturing operations* where *all* combined *stages of a stimulation treatment of a horizontal well are by the pressurized application of more than 80,000 gallons but less than 300,001 gallons of hydraulic fracturing fluid and proppant to initiate or propagate fractures in a geologic formation to enhance extraction or production of oil or gas*, reporting under subsection (c) is required (Section 1-98(a) of the Act).

b) Permittees with a high volume horizontal hydraulic fracturing permit are not required to report under subsection (c).

c) *Within 60 calendar days after the conclusion of* horizontal *hydraulic fracturing operations* identified in subsection (a), *the permittee shall file a* medium volume horizontal *hydraulic fracturing operations completion report with the*

*Department. The* medium volume horizontal *hydraulic fracturing operations completion report shall contain the following information* (Section 1-98(b) of the Act):

1) *the name and location of the well* (Section 1-98(b)(1) of the Act). The well location shall be surveyed by an Illinois licensed land surveyor or Illinois registered professional engineer and the description of the surveyed well location shall also include the legal description, the GPS latitude and longitude location, and ground elevation of the well. The GPS location shall be recorded as degrees and decimal degrees recorded to 6 decimal places in the North American Datum 1983 projection and shall be accurate to within 3 feet. The reported GPS location is required to be an actual GPS field measurement and not a calculated or conversion measurement;

2) the permittee number and well reference number issued pursuant to the Illinois Oil and Gas Act;

3) *the total and per-stage gallons of hydraulic fracturing fluid used at the well* (Section 1-98(b)(2) of the Act), the quantity recovered during the flowback period, and what the permittee did to dispose of, reuse or recycle the flowback;

4) *depth of the wellbore (including both total vertical depth and total measured depth)* (Section 1-98(b)(3) of the Act);

5) *length of horizontal wellbore* (Section 1-98(b)(4) of the Act);

6) *the maximum surface treating pressure used* (Section 1-98(b)(5) of the Act);

7) *the formation targeted* (Section 1-98(b)(6) of the Act);

8) *the number of hydraulic fracturing stages* (Section 1-98(b)(7) of the Act)*; and*

9) *total perforated interval and individual perforation intervals* (Section 1-98(b)(8) of the Act).

6:30pm-8:30pm (Doors open at 5:30pm)
Decatur Civic Center, Auditorium
#1 Gary K. Anderson Plaza
Decatur, IL 62523
View Map

**Thursday, December 19, 2013**
6:00pm-8:00pm (Doors open at 5:00pm)
Southern Illinois University at Carbondale (SIUC)
Student Center, Ballroom B
1255 Lincoln Drive
Carbondale, IL 62901
View Map

**Procedures for the Public Hearings:**

- The purpose of the public hearings is to facilitate the submission of views, and comments, regarding s aspects of the proposed administrative rules implementing the Hydraulic Fracturing Regulatory Act. The Pro Administrative Rules are available on this website for your review.
- The hearing will be conducted by a Hearing Officer. Staff from IDNR will be present to listen to comment staff probably will not be able to respond to each comment due to time limitations.
- The Department will have a sign-up sheet at each location for people who would like to make a public cor The Hearing Officer will use a lottery system to determine the order of the speakers.
- In order to listen to as many comments as possible, the Hearing Officer will limit each person to **four mi** The Department recommends that commenters reference the section of the proposed rules that relates t comment so that the Department can better understand the recommendation.
- Each person who intends to provide comments should bring a **written copy** of his or her remarks so th Department has a record of the testimony. If anyone is unable to speak due to time constraints, the Depa will accept written comments at the end of the hearing.
- If you cannot attend either public hearing, the Department will continue to accept comments through **F January 3, 2014**, via mail to the Department's Headquarters in Springfield, or through an online submitta Written comments carry the same weight as oral testimony at a hearing, and IDNR staff will conside equally during the rulemaking process.
- If you have questions regarding the rulemaking process, please visit the website of the Joint Committ Administrative Rules of the General Assembly.



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## PROFESSIONS AND OCCUPATIONS

## (225 ILCS 330/) Illinois Professional Land Surveyor Act of 1989.

(225 ILCS 330/1) (from Ch. 111, par. 3251)
(Section scheduled to be repealed on January 1, 2020)

Sec. 1. Declaration of public policy. The practice of land surveying in the State of Illinois is hereby declared to affect the public health, safety, and welfare and to be subject to regulation and control in the public interest. It is further declared that the determination and physical protraction of land boundaries, together with the attendant preparation of legal descriptions and plats, which bear witness for posterity to chronicle the acts and wishes of landowners throughout this State is a matter of public interest and concern. Therefore, it is in the public interest that the practice of land surveying, as defined in this Act, merit and receive the confidence of the public, and that only qualified persons be authorized to practice land surveying in the State of Illinois. This Act shall be liberally construed to best carry out this purpose.
(Source: P.A. 93-467, eff. 1-1-04.)

(225 ILCS 330/2) (from Ch. 111, par. 3252)
(Section scheduled to be repealed on January 1, 2020)

Sec. 2. Short title. This Act shall be known and may be cited as the Illinois Professional Land Surveyor Act of 1989.
(Source: P.A. 86-987.)

(225 ILCS 330/3) (from Ch. 111, par. 3253)
(Section scheduled to be repealed on January 1, 2020)

Sec. 3. Exceptions. This Act does not prohibit any person licensed in this State under any other Act from engaging in the practice for which that person is licensed.
(Source: P.A. 93-467, eff. 1-1-04.)

(225 ILCS 330/4) (from Ch. 111, par. 3254)
(Section scheduled to be repealed on January 1, 2020)

Sec. 4. Definitions. As used in this Act:

(a) "Department" means the Department of Financial and Professional Regulation.

(b) "Secretary" means the Secretary of the Department of Financial and Professional Regulation.

(c) "Board" means the Land Surveyors Licensing Board.

(d) "Direct supervision and control" means the personal review by a Licensed Professional Land Surveyor of each survey, including, but not limited to, procurement, research, field work, calculations, preparation of legal descriptions and plats. The personal review shall be of such a nature as to assure the client that the Professional Land Surveyor or the firm for which the Professional Land

Surveyor is employed is the provider of the surveying services.

(e) "Responsible charge" means an individual responsible for the various components of the land survey operations subject to the overall supervision and control of the Professional Land Surveyor.

(f) "Design professional" means a land surveyor, architect, structural engineer, or professional engineer licensed in conformance with this Act, the Illinois Architecture Practice Act of 1989, the Structural Engineering Practice Act of 1989, or the Professional Engineering Practice Act of 1989.

(g) "Professional Land Surveyor" means any person licensed under the laws of the State of Illinois to practice land surveying, as defined by this Act or its rules.

(h) "Land Surveyor-in-Training" means any person licensed under the laws of the State of Illinois who has qualified for, taken, and passed an examination in the fundamental land surveyor-in-training subjects as provided by this Act or its rules.

(i) "Land surveying experience" means those activities enumerated in Section 5 of this Act, which, when exercised in combination, to the satisfaction of the Board, is proof of an applicant's broad range of training in and exposure to the prevailing practice of land surveying.

(j) "Address of record" means the designated address recorded by the Department in the applicant's or licensee's application file or license file maintained by the Department's licensure maintenance unit. It is the duty of the applicant or licensee to inform the Department of any change of address, and such changes must be made either through the Department's website or by contacting the Department's licensure maintenance unit.

(Source: P.A. 96-626, eff. 8-24-09.)

**(225 ILCS 330/5) (from Ch. 111, par. 3255)**

(Section scheduled to be repealed on January 1, 2020)

**Sec. 5. Practice of land surveying defined.** Any person who practices in Illinois as a professional land surveyor who renders, offers to render, or holds himself or herself out as able to render, or perform any service, the adequate performance of which involves the special knowledge of the art and application of the principles of the accurate and precise measurement of length, angle, elevation or volume, mathematics, the related physical and applied sciences, and the relevant requirements of law, all of which are acquired by education, training, experience, and examination. Any one or combination of the following practices constitutes the practice of land surveying:

(a) Establishing or reestablishing, locating, defining, and making or monumenting land boundaries or title or real property lines and the platting of lands and subdivisions;

(b) Establishing the area or volume of any portion of the earth's surface, subsurface, or airspace with respect to boundary lines, determining the configuration or contours of any portion of the earth's surface, subsurface, or airspace or the location of fixed objects thereon, except as performed by photogrammetric methods or except when the level of accuracy required is less than the level of accuracy required by the National Society of Professional Surveyors Model Standards and Practice;

(c) Preparing descriptions for the determination of title or real property rights to any portion or volume of the earth's surface, subsurface, or airspace involving the lengths and direction of boundary lines, areas, parts of platted parcels or the contours of the earth's surface, subsurface, or airspace;

(d) Labeling, designating, naming, or otherwise

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identifying legal lines or land title lines of the United States Rectangular System or any subdivision thereof on any plat, map, exhibit, photograph, photographic composite, or mosaic or photogrammetric map of any portion of the earth's surface for the purpose of recording the same in the Office of Recorder in any county;

(e) Any act or combination of acts that would be viewed as offering professional land surveying services including:

(1) setting monuments which have the appearance of or for the express purpose of marking land boundaries, either directly or as an accessory;

(2) providing any sketch, map, plat, report, monument record, or other document which indicates land boundaries and monuments, or accessory monuments thereto, except that if the sketch, map, plat, report, monument record, or other document is a copy of an original prepared by a Professional Land Surveyor, and if proper reference to that fact be made on that document;

(3) performing topographic surveys, with the exception of a licensed professional engineer knowledgeable in topographical surveys that performs a topographical survey specific to his or her design project. A licensed professional engineer may not, however, offer topographic surveying services that are independent of his or her specific design project; or

(4) locating, relocating, establishing, re-establishing, retracing, laying out, or staking of the location, alignment, or elevation of any proposed improvements whose location is dependent upon property lines;

(f) Determining the horizontal or vertical position or state plane coordinates for any monument or reference point that marks a title or real property line, boundary, or corner, or to set, reset, or replace any monument or reference point on any title or real property;

(g) Creating, preparing, or modifying electronic or computerized data or maps, including land information systems and geographic information systems, relative to the performance of activities in items (a), (b), (d), (e), (f), and (h) of this Section, except where electronic means or computerized data is otherwise utilized to integrate, display, represent, or assess the created, prepared, or modified data;

(h) Establishing or adjusting any control network or any geodetic control network or cadastral data as it pertains to items (a) through (g) of this Section together with the assignment of measured values to any United States Rectangular System corners, title or real property corner monuments or geodetic monuments;

(i) Preparing and attesting to the accuracy of a map or plat showing the land boundaries or lines and marks and monuments of the boundaries or of a map or plat showing the boundaries of surface, subsurface, or air rights;

(j) Executing and issuing certificates, endorsements, reports, or plats that portray the horizontal or vertical 022287 relationship between existing physical objects or structures and one or more corners, datums, or boundaries of any portion of the earth's surface, subsurface, or airspace;

(k) Acting in direct supervision and control of land surveying activities or acting as a manager in any place of business that solicits, performs, or practices land surveying;

(l) Offering or soliciting to perform any of the services set forth in this Section.

In the performance of any of the foregoing functions, a licensee shall adhere to the standards of professional conduct enumerated in 68 Ill. Adm. Code 1270.57. Nothing contained in this Section imposes upon a person licensed under this Act the responsibility for the performance of any of the foregoing functions unless such person specifically contracts to perform such functions.

(Source: P.A. 96-626, eff. 8-24-09; 96-1000, eff. 7-2-10; 97-333, eff. 8-12-11; 97-813, eff. 7-13-12.)

(225 ILCS 330/6) (from Ch. 111, par. 3256)

(Section scheduled to be repealed on January 1, 2020)

Sec. 6. Powers and duties of the Department.

(a) The Department shall exercise the powers and duties prescribed by The Illinois Administrative Procedure Act for the administration of licensing Acts. The Department shall also exercise, subject to the provisions of this Act, the following powers and duties:

(1) Conduct or authorize examinations to ascertain the fitness and qualifications of applicants for licensure and issue licenses to those who are found to be fit and qualified.

(2) Prescribe rules for a method of examination.

(3) Conduct hearings on proceedings to revoke, suspend, or refuse to issue, renew, or restore a license, or other disciplinary actions.

(4) Promulgate rules and regulations required for the administration of this Act.

(5) License corporations, partnerships, and all other business entities for the practice of professional surveying and issue a license to those who qualify.

(6) Prescribe, adopt, and amend rules as to what shall constitute a surveying or related science curriculum, determine if a specific surveying curriculum is in compliance with the rules, and terminate the approval of a specific surveying curriculum for non-compliance with such rules.

(7) Maintain membership in the National Council of Engineering Examiners or a similar organization and participate in activities of the Council or organization by designating individuals for the various classifications of membership and appoint delegates for attendance at zone and national meetings of the Council or organization.

(8) Obtain written recommendations from the Board regarding qualification of individuals for licensing, definition of curriculum content and approval of surveying

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John Baird, from Decatur, member of Illinois People's Action and member of Fair Economy Illinois + Central Christian Church

I have two concerns I would like to address:

1) Hydraulic Fracturing and Earthquakes

It is well documented that the injection of fracking water into the ground has the potential to trigger manmade earthquakes. Currently the control system set up by your rules allows for up to four fracking-induced earthquakes as high as the magnitude of 4.9 before a company has to shut down an injection well.

Why did you choose the earthquake magnitude of 4.9 for your rule? It's curious to note that the US Geological Survey classifies any earthquake with a magnitude of 5 or higher as risky, and your rule says that a magnitude of 4.9 is okay. They say 5 is risky, and you say 4.9 is okay. Can we agree that if 5 is risky, that 4.9 is also risky? This slightly lower number allows the companies to go on creating earthquakes and to claim that they aren't dangerous.

And you allow ~~your proposed~~ fracking companies to induce **four such earthquakes** of that magnitude before someone steps in and says "maybe we should back off, this is getting a little dangerous".

You need to come up with rules that clearly give priority to protecting the public, not the interests of the oil and gas industry. In the interest of public safety you cannot be issuing permits to fracking companies that allow procedures that could cause major earthquakes.

The rules also need to call for the implementation of a **seismic monitoring system** that can accurately assign responsibility to particular fracking operators in the event that fracking operations DO induce earthquakes.

Also, the rules need to require **insurance** from well operators when it comes to property damage and injuries incurred by residents, businesses, or public institutions as a result of **seismic activity tied to fracking**. Failure to require insurance for fracking operators is like allowing motorists to drive without auto insurance.

2) Fines for breaking the rules

I understand that the fines you are proposing for breaking the rules ... are as low as $50. But the potential for damage is large. People in other states have already suffered serious losses from negligence and rule breaking. It seems to me that the fines, instead of being $50, should be more on the order of $50,000 for the first offense, and revocation of license for the second offense. Without tough consequences for violators, frackers have no incentive to follow IDNR rules.

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<u>This legislation has been touted as the best</u> and safest that any state has yet passed for protecting citizens and the environment from the dangers of fracking, but this (quote-unquote) "best" legislation is still dangerously inadequate. If those other states [redacted] passed legislation that was, say, 10% adequate, and Illinois bumped that safety up to **15% adequate**, <u>that's still 85% inadequate</u>!

This legislation was promoted as a big step in the right direction, and maybe it is, but a step in the right direction, over a two-step ditch ... will fail ... to protect us. We need tighter rules to protect the people of Illinois and our environment.

Thank you.

(not spoken, but included in doc submitted to IDNR)

- **Solutions for minimizing the danger of fracking-induced earthquakes**: Observe these 5 empirically derived steps posed by Stanford University geophysicist Mark Zoback:
  - Avoid injection into active faults and faults in brittle rock.
  - Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.
  - Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.
  - Protocols should be established in advance to define how operations will be modified if seismicity is triggered.
  - Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard.

**Comments to the IDNR on Hydraulic Fracking and it's impact on our drinking water Resources December 17, 2013**

My name is George Virgil. I'm a graduate of the University of Illinois with a major in Chemistry. Because our surface and ground water are so vital to our health, as well as our economic growth, here in Macon county, the fracking technology, as it exists today, would have a serious negative impact. I would like to comment on 5 reasons that it is vital that no fracking be allowed here that would or could harm or reduce our surface or ground water.

First, there are reports of carcinogenic chemicals used or extracted in the process, like benzene and toluene. Unfortunately, the chemicals used are **not** required to be reported. No permit should be issued to anyone who doesn't list the chemicals, the quantity and the toxic or hazardous nature of them. The EPA lists one that is often used and is of concern--- Polyacrylamide. It used in a ratio of 1 gallon per 1,000 gallons of water or 1000 parts per million. A typical well would use about 2,700 gallons. It's purpose is to minimize friction between the fluid and the pipe. Polyacrylamide is a polymer of acrylamide. While the polymer is not particularly toxic or carcinogenic, it contains residual amounts of acrylamide and the polymer can be de-polymerized into acrylamide, which is carcinogenic. EPA regulations indicate that this chemical should be **zero** in drinking water.

Second, the shear volume of water typically used (about 2.7 million gallons) is a negative draw on an already diminishing supply of both surface and ground water. Until there is a process to totally clean up the water once contaminated by the fracking process (known as flowback) it will remain a negative impact. Our Lake Decatur is currently 2 feet below normal winter levels at 610.4 feet.

Third, there will be spills and accidents involving the dozen or so chemicals used in the fracking process, which may include some toxic or carcinogenic chemicals. In my 50 year career working in industrial plants that use many of these same chemicals, spills or major leaks have occurred, do to human error, poor engineering design, or just plain accidents. While some, like sand, will do little harm, others like acrylamide or hydrochloric acid can harm individuals and our drinking water.

Fourth, simply drilling through the ground water aquifer can have a negative impact on it's integrity.

Finally, the fifth concern is that there needs to be a plan to deal with earthquake disasters that would potentially destroy the integrity of the well, the stored chemicals and the flowback water.

What I find most disturbing is that this whole hearing process seems to be flying under the radar. Only 2 hearings prior to this one were scheduled for public input. Both were scheduled just before and after Thanksgiving holiday at two remote locations from Macon county, thus minimizing public comment. Fortunately, we now 3 more opportunities to comment. Ground and surface water for Macon and surrounding counties are vital natural resources that contribute heavily to our economic well being as well as to our health and recreation.

In 2011 the USEPA started a comprehensive study on the impacts of hydraulic fracking. It would be wise for the IDNR, to wait for the completion of that study.

In closing, I realize the driver for hydraulic fracking is economic. Illinois must take extreme care not to exploit our natural resource of **water** in its haste to create jobs and income from this new technology. We urge the IDNR to consider the **existing and future jobs** that depend on our **water resources**.

## (4) Local Control

1. Section 245.210 requires that fracking permits include documents certifying consent for fracking operations to occur from the municipal authorities affiliated with the particular city village, or incorporated town where the well site is supposed to be located and that no permit be issued otherwise.

2. The intent of the legislation was to recognize that local units of government should have decision-making power regarding whether to allow fracking in their jurisdictions.

3 This section demonstrates a strong disregard for the geography of fracking in Illinois . Little if any fracking is anticipated within cities such as Decatur, Carbondale, Marion, or other metro areas. It will be done in rural areas where the county provides the local governmental authority. The question to be asked is this: if permission is important for metropolitan communities, why are the proposed rules silent regarding areas in the counties and the families living there?

4. There is no substantive difference between a municipal or county government in Illinois in its basic powers. Counties and municipalities of government both levy taxes,provide for law enforcement, provide social services and other infrastructures. The rules provide no explanation why citizens residing in counties of Illinois have fewer rights in their ability to participate in and

ultimately determine the type and the quality any energy extraction in their neighborhood.

5. Numerous county governments have long histories and traditions in the permitting process regarding mineral and drilling industries, and there is no reasonable expectation that the personnel at IDNR have any better r understanding of the will of citizens in the counties regarding fracking permits than the residents themselves. As the proposed IDNR rules envision municipalities empowered to decide about fr acking sites, what possible argument does it have not to give this decision making to citizens living in the counties?

**Solution**: As the current fracking law is largely silent on the issue of county control, IDNR rules should err on the side of history and citizen decision-making and give counties and other local governmental decision-makers a say in whether fracking will be allowed in their communities and, if allowed, exactly how it will occur.

Rachi Eads
IPA

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# Citizen's Comments at Public Hearing on Fracking Rules

Tuesday, December 17, 2013

I want to thank the IDNR rules committee for this opportunity to present my views on the proposed Illinois fracking rules. My name is Mel Weinstein. I have been a resident of Illinois for 33 years. I worked for 10 years as a chemistry instructor in a local community college and over 20 years as an analytical chemist in a major agrichemical company in Decatur. Given my professional background, I know something about industrial chemicals, particularly the health hazards and safe handling of them.

I specifically want to address those sections of the fracking rules that concern the chemicals used by the fracking industry. Section 245.720 (Department Publication of Chemical Disclosures & Claims of Trade Secret) states, in my own translation, that companies can submit chemical disclosure information under a claim of trade secret and redact, or mark out, parts of the master list of chemicals used in the fracking process. In the IDNR'S own words, "The Department shall use the redacted copies when posting the master list of chemicals on its websites." This is a direct violation of the public's right to know what hazardous chemicals are being utilized at a fracking site that may pose human health concerns or environmental damage.

Why does this matter? Why care about it? In April of 2011, the US House of Representatives Committee on Energy and Commerce Minority Staff published a report entitled "Chemicals Used in Hydraulic Fracking." That committee investigated 14 oil and gas service companies involved in fracking operations between 2005 and 2009. Here is what they found. "(the companies) used more than 2500 hydraulic fracturing products containing 750 chemicals and other components ... some (of the chemicals) were extremely toxic, such as benzene and lead ... The oil and gas companies used hydraulic fracturing products containing 29 chemicals that are (1) known or possible human carcinogens, (2) regulated under the Safe Drinking Water Act for their risks to human health, or (3) listed as hazardous air pollutants under the Clean Air Act. These 29 chemicals were components of more than 650 different products used in hydraulic fracturing." These chemicals included benzene, toluene, xylene, and ethylbenzene, all chemicals with nasty track records for human health. "The hydraulic fracturing companies injected 11.4 million gallons of products containing at least one (of these) chemicals over the five year period." The companies used 279 products that contained a chemical or component that the manufacturers deemed proprietary or a trade secret. Although some oil and gas service companies provided information about these chemicals upon request, most of them did not because the information was not made available by the chemical manufacturers.

In the interest of full disclosure, the IDNR rules should require that all chemicals used by fracking companies be publicly listed with their identifying Chemical Abstract Services (CAS) number along with Material Safety Data Sheets (MSDS) revealing the health and environmental hazards of the chemicals. The citizens of Illinois deserve to know what chemicals they may be exposed to in the event of a spill, contamination of surface or ground water, or direct exposure to workers in the industry. If fracking companies are using dangerous chemicals, they should not be allowed to hide behind a trade secret curtain.

Section 245-730 (Trade Secret Disclosure to Health Professional), in my own translation, states that information about a trade secret chemical can be released to a health professional to determine the type of treatment to give an an affected patient. Let me see if I understand this section. A citizen or a fracking employee gets exposed to a chemical used by a fracking company. That person gets ill, then goes to see a doctor. The doctor then has to determine if the patient was sick due to an exposure to a hazardous chemical in the environment or the workplace or to some other cause. Suspecting chemical toxicity, the doctor next checks with the IDNR to find out what chemicals the person was exposed to. The doctor then has to determine which chemical or chemicals adversely affected the patient. Finally, while the patiently is awaiting relief and treatment, the doctor has to ask whether there were any undisclosed chemicals at the fracking site. According to Section 245.730, the health professional shall:

1) state a need for the information and articulate why the information is needed,
2) identify whether the affected patient requires emergency or nonemergency healthcare services (this is before the health professional knows what their patient has been exposed to!),and
3) identify the name and profession of the health professional and the name and location of the facility where the affected patient is being treated.

Then, after getting the medical information about the secret chemicals, the health professional has to jump through a number of other hoops to safeguard the manufacturer's trade secret. How ridiculous is this rule where a health professional must use their psychic ability to guess that a trade secret chemical is making their patient sick.

In view of my statements here, I request that the IDNR be honest with the citizens of Illinois. Rather than protect the vested interests of the oil and gas companies and manufacturers of fracking products, the Department should place the personal health and environmental safety of Illinois citizens at the top of its list, not somewhere towards the bottom. If fracking companies want to do business in this state, the IDNR should require full and public disclosure of the chemicals that are used!!!!! Anything short of that requirement is a disservice to the people of Illinois.

Mel Weinstein
Decatur, IL

## IDNR HEARING TESTIMONY IN DECATUR DECEMBER 17, 2013

My name is Paul Rosenberger. I have lived in Decatur, Illinois since 1955. I am a graduate Agricultural Engineer and a retired design engineer from Caterpillar. I was raised on a 200-acre farm in northwest Iowa that was first owned by my grandfather in 1890. My brother and I sold the farm 100 years later, but if we still owned that farm, we definitely would not want a fracking operation on it because of the potential for destruction of some of the highly productive three-foot-deep black soil there that is very similar to Central Illinois' high quality soil.

I'm also a representative of First Presbyterian Church in Decatur as a member of Illinois People's Action – IPA and from Fair Economy, Illinois. As a lifetime Presbyterian, I have learned that our church leaders try to make decisions in a 'Decent and Orderly Fashion.' In that way I will try to comment on what seems to me to be an unfair or ambiguous public hearing process.

First, the verbiage in Section 245.230e of the proposed Illinois Department of Natural Resource, IDNR, rules creates a loophole whereby the 60-day review period for permit applications starts the clock ticking even before the application is deemed complete and accurate by the IDNR. I believe this invites fracking companies to deliberately submit incomplete permit applications as a way of avoiding public oversight and comment. IDNR needs to ensure that the 60-day review period begins only AFTER IDNR deems the permit applications are complete.

Second, Section 245.270 in the rules undercuts the robust public participation that was required by the statute passed by the legislature as follows:

1) The rule (Sec. 245.720a6) requires that public petitions concerning permits be served upon the presence of the department, the hearing officer, and the applicant. This could create an unnecessarily high barrier for the public to petition the department when the IDNR rule only specifies that the applicant must petition the department.

2) The rule (Sec. 245.270b2) also gives IDNR the discretion to hold hearings outside of the affected county. It seems obvious to me why it is important that the hearing concerning local residents be held near those residents. Residents may not have the resources nor child care options to travel in or out of town to another county. The rule also limits the ability to call local witnesses that have critical information but whom also may be unable or unwilling to travel far away from home. It should be IDNR's duty to make the hearing process as accessible as possible for the public. Obviously, I could speak about other accessibility issues, too.

3) The rule (Sec. 245.720g6) does not require the IDNR participants to testify under oath and be available for cross-examination. How is the public to be assured that their concerns will be addressed if IDNR only has to listen to them without responding?

4) The rule (245.270a3e) forces petitioners to present their concerns in the context of the rules. The IDNR should be concerned about the content of the complaint, not the technicalities. The average citizen will not have the legal background to determine if his or

her fracking-polluted well water violates the rule or laws. That should be IDNR's job. The hearing requestor should only need to know the legal basis for the request "if applicable" rather than "if known."

5) The rule (Section 245.270f) allows IDNR to issue permits to fracking operators even if they fail to show for public hearings, thus defeating the whole purpose of hearings. Failure to appear at hearings should either result in rescheduling a hearing or in a complete denial of the permit application.

6) The rule (Sec. 245.270i) gives the hearing officer the ability to make a decision on all issues raised at public hearings without first reporting back to the department. It seems unlikely that IDNR can ensure that the hearing officer has both the expertise and the necessary materials to make these decisions on the spot.

7) The rule (Sec. 245.270i) also places the legal burden on hearing officers to prove that fracking operators are not otherwise entitled to a permit. The burden should be placed on the frackers to prove that their applications are worthy of consideration in defense of the issues raised.

8) The rule (Section 245.720n) allows fracking permit applicants to attempt to correct any issues identified at public hearings without public notice of these corrections and therefore, no ability for the public to then provide revised and/or updated comments. IDNR should allow the public adequate time to request follow-up hearings and submit comments to address the new information.

In conclusion, for some reason the proposed rules give IDNR "no more than 60 days to make a decision." What happens if an issue is so serious that IDNR may need more than 60 days to make a fair and technically correct decision? It appears to me that the proposed rules contain inconsistencies and are very prone to arguments.

By: Paul Rosenberger

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## Fracking statement

1 message

**Rachel Shively** <shively.rachel@gmail.com> Tue, Dec 17, 2013 at 3:02 PM
To: "shively.rachel@gmail.com" <shively.rachel@gmail.com>

My name is Rachel Shively. I live in Bloomington, IL, ~~and work at Illinois State University in Normal, IL~~. I'm also a member of Illinois People's Action, although I speak for myself as a resident of IL.

First, I will say that I strongly support a total ban on fracking. It is dangerous to the natural environment and to the health of IL residents. The oil and gas companies will come into our state, extract the gas resources, and then leave us, the people who live here, with a devastated environment. I have read reports from reliable sources about other states where fracking has already taken place and those states have seen their communities' drinking water, air quality, and land contaminated by fracking. The short term profits that the multibillion dollar oil and gas industry will obtain from fracking are not worth the damage that will be done to the residents of IL as a result of fracking.

However, I know that tonight we are here to discuss the fracking regulations being proposed by the IL Department of Natural Resources. My comment addresses the issue of Volatile Organic Compound (VOC) emissions. This is a personal issue to me and to other residents of IL who suffer, as I do, from asthma. A number of air contaminants are released through the various drilling procedures, including construction and operation of the well site, transport of the materials and equipment, and disposal of the waste. Some of the pollutants released by drilling include: methane, benzene, toluene, xylene and ethyl benzene, particulate matter and dust, ground level ozone, or smog, nitrogen oxides, carbon monoxide, and formaldehyde. Exposure to these pollutants is known to cause short-term illness, cancer, organ damage, nervous system disorders and birth defects or even death. For people suffering from asthma like myself, whose respiratory systems are very sensitive to contaminants in the air, these chemicals have the potential to greatly aggravate our condition, damage our health, and drastically reduce our quality of life.

Even though Section 1-53 of the regulatory bill requires that fracking operations be conducted in a "manner that will protect the public health and safety and prevent pollution," there are currently almost no provisions on how to reduce the highly toxic VOC emissions that are generated by the fracking process. In Colorado, oil and gas emissions are the main source of VOCs and, unsurprisingly, there have been many reported cases of illnesses from fracking pollution in Colorado since the boom began. The rules currently contain no best practice standards for mitigating these risks that could cause irreversible neurological and or respiratory damage to the residents of IL. As of now, the Rules allow companies to be wholly exempt from runaway natural gas and hydrocarbons from production (Sec 245.900e) or flowback (Sec. 245.845c) if the regulation of these isn't "cost effective" or if it is "economically unreasonable". IDNR completely avoids defining "cost effectiveness" or "economically unreasonableness" – essentially allowing companies to define these terms for themselves. And we can assume that companies will make sure that they define it for their own monetary benefit.

A cost/benefit analysis that only calculates private costs of companies while ignoring the social costs will cause damage to people and the natural environment, which the IDNR has the responsibility to protect. The solution is that the IDNR should quantify the cost of various kinds of emissions using independent scientific studies on this issue. Included in the quantification should be the health and environmental costs of emissions relative to the costs of capturing/reducing emissions. If companies are allowed to frack in IL, they should be held responsible by the IDNR through strict standards for reducing VOC emissions in order to protect the health of IL residents and the natural environment.

Hearing on Hydraulic Fracturing Rules
Decatur, Illinois 12/17/13

Citizen: Margaret Keylin
304 N Woodlawn
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section: Rule 245.850

My comment is on preserving the quality of water used for public consumption and agriculture. Because fresh water is an absolute necessity for the survival of all flora and fauna on the planet, there must be no gambling with its safety and protection. Water is not only a "limited" vital natural resource, it is also interconnected. From rivulets to oceans, from glaciers to aquifers, all waters percolate and intermingle. Hydraulic fracturing processes impact fresh water above ground, below ground and in the air. The rules governing fracking must protect fresh water sources at all costs.

Any practice that produces radioactive water cannot be tolerated. There are no safe levels. Once fresh water is contaminated, it is lost forever as a life sustaining resource. It cannot be decontaminated. It cannot be replaced.

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To allow businesses that produce radioactive liquids as a part of their process to operate in Illinois is insane. There are no safe levels of radioactive contamination. We need to be working to eliminate contamination from our fresh water resources not settle for "minimum contamination" levels.

However, since Illinois has opted for fracking, our rules should call for: ① follow up requirements or standards if testing shows radioactivity in the flowback ② testing of "produced water" at all intervals where radioactivity would show up ③ testing for added radioactive materials ④ testing of work areas for levels of radioactivity that would call for OSHA standards of occupational safety.

Our water is quite literally our life. IDNR is mandated to protect the health and safety of the citizens of Illinois. Do your job. Serve the people.

My name is Ron Wojtanowski and I'm a member of Illinois Peoples Action / Fair Economy Illinois. I'm also a member of the Sierra Club and I'm a rural resident.

First I would like to request that the comment period be extended and more hearings be scheduled for after the holidays.

When Governor Quinn signed Illinois' fracking Bill into law last Spring he said it was the strictist in the nation. Sadly because of the shoddy job done by the IDNR in the writing of these rules this is not true. These rules read more like an industry wish list then the strictist fracking rules in the nation.

On page 3, Paragraph 6 of the Proposed Hydraulic Fracturing Regulatory act it states – "Published studies or reports and sources of underlying data used to compose this rulemaking: NONE."

From the moment the IDNR decided to ignore the best scientific information available, these rules were doomed to be mediocre. This created a fundamental flaw that weakens every rule ~~one of these them~~.

~~rules~~ And because these rules are so weak they guarantee that we will experience the same serious problems with fracking that are currently occurring in other states. This was our chance to avoid these serious problems and these rules have failed.

The proposed rules are riddled with examples of how IDNR has put the health and welfare of the people of Illinois at risk. We at IPA are calling the 12 worst rules the Dirty Dozen.

For instance, radioactive waste water from the fracking process is completely under-regulated. The penalties for breaking any of the rules are laughable. They start at $50. That's less then a speeding ticket. This serves as no deterant for these multi-billion dollar companies to play-by-the-rules.

Hydraulic fracturing was illegal for 20 years under the Safe Drinking Water Act. It is only because of the Halliburton waiver that it is now legal. However fracking is still dangerous and needs to be regulated strictly. These rules fail to do that.

If the governor and the legislature were sincere about having the strictest ~~set~~ rules in the nation then IDNR violated their trust by draughting the weakest rules possible.

~~Again and again these rules are either incomplete, inconsistent, or otherwise deficient. This is grounds for rejecting them until they can be rewritten by competent people who will utilize the latest scientific information available.~~

Again and again these rules pose a significant hazard to public health, aquatic life, wildlife, and the environment. This is IDNR'S own criteria for rejecting them. They must be rewritten by competent people who will utilize the latest scientific information available.

We can not ignore the serious problems with fracking that are occurring in other states. We must learn from past history. The people of Illinois deserve to have the strictest fracking rules in the nation, not the weakest.

Ron Wojtanowski

**Testimony to JCAR Fracking Hearing December 17, 2013**

Thanks to JCAR for this opportunity to express my concerns about the scope of the draft fracking rules.

The Hydraulic Fracturing Regulatory Act was controversial legislation. The consensus support the act ultimately achieved was based substantially on the promise that Illinois' fracking regulations would be the strongest in the country. Whatever the merits of the act, it has not been shown that the rules governing fracking in this state will fulfill that promise.

For example, the draft rules (per Sec. 245.100) apply only to fracking operations occurring since June 17, 2013, while the original regulatory act clearly mandates that the provisions in the act apply to past, current, and future wells.

Specifically, Section 1-20 of the Hydraulic Fracturing Regulatory Act passed earlier this year states that the Act "applies to all wells where high volume horizontal hydraulic fracturing operations are planned, *have occurred*, or are occurring in this State".

Why then, is IDNR intentionally limiting the scope of the rules to only apply to new fracking operations if older wells carry the same health and safety risks?

The whole intention of the regulatory act is to make fracking operations safer for the people of Illinois and our environment. The existence and presumed necessity of the rules is clear evidence that unregulated fracking poses a significant risk to our health and safety. It therefore makes no sense for IDNR to intentionally limit the scope of the rules to apply only to new fracking operations, while bypassing regulations on old wells. One might even argue that older wells--given both their age and the lack of regulations at the time of their construction-- would merit greater attention from regulatory agencies.

Unless IDNR is drafting these rules to protect businesses and corporations over the safety and well-being of Illinois citizens, then it should:

1. Require all fracking companies to report any prior fracking activities that fall under the definition of "high volume hydraulic fracturing", regardless of when the activity occurred, and
2. Ensure that past operations comply with the regulations outlined by IDNR to the furthest extent possible. For example, while it would not make sense for an operator to go back and re-perform drilling activities that did not conform to the Act, it should require compliance of ongoing obligations mandated by the rules – such as air emissions control requirements associated with production, post-frack testing and reporting, etc.

Again, the people of Illinois were promised that their health and safety would be protected by the strongest fracking regulatory regime in the nation. We deserve nothing less. JCAR must do everything in its power to ensure that this promise is kept.

Larry Jones
Mackinaw IL

TO: IDNR

FROM: Roy Wehrle TO: IDNR

Subject: Decatur Testimony on Fracking

Date: December 17, 2013

## I. Probability of One of a Series of Events Occuring

Fracking can cause a variety of undesired outcomes. While the probability of any one outcome happening in a drilling field is generally low, the chances that at least one of the outcomes may happen is much higher. Since any of the bad outcomes could seriously damage health, life quality and hurt the environment, it is important that this assessment of the probability of damage be recognized and highlighted.

The probability analysis of any one of a series of possible outcomes, assuming the outcomes are independent of one another, is as follows:

I. Assume three possible, independent outcomes, for example: a) spills of polluted produced water sterilizing a number of acres, b) serious radioactivity produced in the drilling of the well, and c) leakage of methane, salt and toxic chemicals from the fracking which destroys the value of an aquifer.

II. Assume the probability of each of these events happening from a well field is: 1/a, 1/b and 1/c.

III. then find the probability that none of these events will occur which is "1 minus the probability above that something will happen. Then each probability that that event will not happen is multiplied times each of the other probabilities, or (a-1) * (b-1) * (c-1)/a*b*c.

III. then find the probability of something rather than nothing happening which is "1 minus the probability of nothing happening" or 1 – the answer or probability obtained in III..

VI. Illustration: Let a = 2, b = 3 and c=4. Then we have ½*1/3*1/4 which turns into the following when we look for the probability of nothing happening in each case or (1-1/2) * (1-1/3) * (1-1/4) all divided by 2*3*4 which = 6/24 = ¼ which when subtracted from 1 to get probability of something happening is ¾ or 75%, much higher of course than any of the individual happening probabilities.

**Talking Notes -- Decatur Hearings December 17th * Roy Wehrle**

**Introduction:** Professor of Economics at UIS Emeritus, speaking as a member of Illinois People's Action and Fair Economy Illinois: formerly on the Council of Economic Advisors to President Kennedy and appointed by President Johnson to manage economic affairs in Vietnam during the war there.

**Thanks you – two points this evening: Probability of Damage and VOCs**

**I. Probability of Harm.** What is not well understood by the public is that though the probability is low for any one bad thing happening in fracking, the probability is much higher that *something* bad will happen. In other words, the probability in one fracking field may be quite low for each of these occurrences: radioactive contamination, leakage of methane or benzene into the aquifer, and an earthquake. But what is most important is not the likelihood of each event but of ***any serious event taking place***. And the latter probability is always a good deal higher than the former. Assume there are eight possible bad consequences that could occur in a fracking field, and each has a probability of 1/10 or 10% of happening. It turns out that the probability that ***one of these bad things will happen*** is 83%. None of us would like to live in a neighborhood with those odds of bad things occurring. Quite a difference, 10% and 83%. I will hand in a memo setting forth the mathematics of estimating such a one-in-a-series-occurring events.,

**II. Volatile Chemical Compounds** First, three quick points on chemistry. First, volatile means that the substance boils at a low temperature so that volatile liquids boil and hence evaporate at low temperatures, even below zero. Volatility is how we smell most things. Maybe that is how the talking trees in C. S. Lewis' masterpiece Narnia talked to each other.

Second, volatility is a stealth process. Liquids and gases escape invisibly during the drilling and also the subsequent fracking process and also when volatile liquids are stored on the drilling pad and moved from the pad.

Though invisible to our eyes, an infrared camera shows plumes of these gases moving into the air at drilling sites.

Third, ground-level ozone smog is created by volatile chemicals combining with the nitrous oxides from exhausts, all baked in sunlight. When these volatile chemicals, often called smog precursors, combine with Nitrous Oxide they produce ground-level smog. Many volatile chemicals and compounds are smog precursors.

As many as 100 different chemicals are used in the combined drilling/fracking process by the various drillers, many are volatile and many of these chemicals damage human health directly while others become the smog that damages human health by slowly eating away at the tissue of the lungs, as described by Dr. Theo Colburn. He tells us that, unlike other bodily tissues, damaged lung tissue cannot be repaired by the body.

So how serious are these volatile chemicals and compounds, these VOCs, to human life and happiness? VERY. Consider first smog and other air pollutants which now engulf major Chinese Cities and killed prematurely 1.2 million Chinese in 2010. Now smog is found in our countryside where fracking takes place. There are many other damaging health effects from VOCs including: irritation to eyes, ears and nose, headaches, damage to kidneys and liver and to nervous and immune systems, cancer of various forms, impairment of mental processes including memory loss, and loss of coordination, dizziness. Heart rending accounts by individuals who have breathed in these toxic chemicals are as real as real can get, and well documented in Pennsylvania, Colorado, Texas and North Dakota. The following web site gives testimony from 1,100 people whose lives were besmirched by VOCs and other fracking caused pollution. http://pennsylvaniaallianceforcleanwaterandair.files.wordpress.com/2012/05/list-of-the-harmed51.pdf VOCs are toxic invaders of schoolrooms, houses and businesses, unwelcome and unseen, until eyes smart and burn.

The proposed IDNR rules do not protect our citizens from these toxic trespassers.

it is essential that each well site be carefully monitored for escaping VOCs and that all transportation of materials containing VOCs be monitored. As the draft rules now read, firms do not have to mitigate escaping VOCs if it is not *cost effective* or proves *economically unreasonable*. One asks in wonderment: "Why does this regulation only consider the producers' costs and not the costs in damage to the people and wildlife? The costs to the public must be recognized and estimated using the various studies that are available. The costs of asthma, neurological damage, endocrine damage to the immune and reproductive system and many more health effects must be counted in as public costs. These costs are every bit as real and morally more important than the remediation costs to the producers.

Protection and remedial steps should be added to the final rules: a) monitoring escaping volatile gases and setting limits on these, b) requiring remediation where harmful gases are escaping requiring VOC abatement technologies be used where feasible, (http://www.epconlp.com/air-pollution-control-systems/voc-abatement.php?gclid=CJrlsczUt7sCFdE-MgodfFYA2Q ), c) forbid storage of volatile liquids in open pits, d) require manifests for all haulers taking away produced water and other liquids containing VOCs and toxic chemicals showing quantity, origin and destination of the transit, e) require that the well be capped and terminated when the VOC regulations are breached or the VOC emissions exceed a set ceiling.

Finally, you all know the saying: "If it seems too good to be true, it isn't". I would add a sister saying which goes "If many things could go wrong, one will". Thank you kindly for your attention. .

**Comment Prepared by Sandra Lindberg**
**for IDNR Hearing on Proposed Fracking Rules,**
**Decatur IL, December 17, 2013**

Good evening. My name is Sandra Lindberg. I am a member of Illinois People's Action and Fair Economy Illinois.

This comment focuses on monitoring water for pollution and involves several rules.

The IDNR's current design for water monitoring will not safeguard the waters of Illinois. Report citations I provide in this document come from U.S. and international sources and government departments. Most of the studies describe risks to surface and ground water supplies inherent in fracking. Most acknowledge that pollutants migrating from frack wells into water supplies require extensive study—especially with regard to unconventional fracking operations and gas or foam fracking techniques.

Many of these reports offer recommendations for the proper monitoring of state waters, details I will share with you now ~~as well as points directly applicable to IDNR regulations.~~

1. 245.600 and 245.610 narrow the scope of their oversight to so-called "high volume hydraulic fracturing wells." The words "high volume" need to be deleted. Illinois New Albany shale fields likely will require gas or foam fracks. Current IDNR regulations seem to exempt such lower-water fracks from the water monitoring process. Some of the studies I cite report an increased chance for chemical migration from gas or foam fracks. Water monitoring of frack wells should occur for all of them, regardless of how much water they use.

2. Extensive discrepancies exist between the water monitoring practices required in 600 and 610. The more stringent requirements of 610 should be required for baseline and interval water testing, though even 610 needs to be strengthened. Without this concordance, comparing data sets from the two rules will pose significant problems and may seem to exempt frackers from some pollution accountability. As my biologist partner Dr. Samuel Galewsky tells me, experiments that are being compared must test for exactly the same set of variables and must be conducted in exactly the same way if comparisons are to be useful and persuasive. For fracking wells, IDNR rules should require baseline and recurrent water tests for all chemicals listed in 35 Illinois Administrative Code 6290.310(a)(3)(A)(i).

3. The range of testing for each well is grossly inadequate. Studies I cite indicate that unsafe water contamination is to be found in wells half a mile from a fracking well, and significant contamination has been found in private wells as far as one

mile away. To limit testing to 1500 feet from a frack site forces the IDNR to ignore existing peer reviewed data on well contamination.

4. Neither 600 nor 610 discuss surface water contamination, or the monitoring of surface waters. Baseline studies of these bodies of water need to be conducted and they need to be tested regularly throughout the well's operation.

5. Neither regulation discusses how geological data provided in the permittee's application will be used to determine which wells pose the largest threats to groundwater or surface water contamination. Such locations should be identified and regulations drafted that involve greater oversight for them.

6. The number of water tests currently required by the IDNR is inadequate. Current industry reports recognize that each well may now be fracked from 60 to 100 times and a well may operate for decades. We already know that cement casings' failure rates increase as the number of fracks goes up and as the well ages. If anything, the IDNR needs to determine how it will increase the requirement for water testing after 10 fracks or after 3 years, rather than stopping all testing after 30 months.

7. The water testing and water pollution rules need to state the IDNR's awareness that scientific data on the effects of fracking chemicals is lacking, that their combined effects are unknown, and that its ability to be certain of how chemicals will migrate below or above ground from a fracking site requires much more study. Most importantly, the IDNR needs to review yearly instances in Illinois of reported and established cases of fracking's water contamination issues, and revise its rules as necessary—even to the point of placing a moratorium on fracking when IDNR realizes fracking's ability to pollute Illinois' waters is far greater than current regulations imagine.

8. I would applaud if the IDNR recognized publicly what its counterpart agency in North Carolina wrote--that it lacks the financial resources needed to monitor the state's proposed fracking industry. How will the current IDNR budget and staff accomplish this regulation process?

Sandra Lindberg

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17 December 2013

Robert G. Mool
Office of Legal Counsel, Department of Natural Resources
One Natural Resources Way
Springfield, IL 62702-1271

Dear Mr. Mool:

I write this letter with respect to the draft rules for the definition of high volume horizontal hydraulic fracturing (HVHF) operations in the Illinois Hydraulic Fracturing Act [PA98-002, §1-5] and in its supporting Rule (§245.100(a)]. The phrase of relevance is the "pressurized application of more than 80,000 gallons per stage or more than 300,000 gallons total of hydraulic fracturing *fluid*." It is clear from the overall framing of the law that the General Assembly is referring to gallons of water as "fracturing *fluid*" and expected the IDNR to work out the details on other base fluids. Instead, IDNR copies the definition for HVHF verbatim. No other base fluids or formulas for converting non-water fluids to water gallon equivalents are provided in the Rule.

***Legal issues:***

Rule §245.100(a) is *incomplete, inconsistent* and *deficient,* and this inadequacy *"constitutes a serious threat to the public interest, safety, or welfare" of Illinois citizens"* because it is likely to exempt a very sizeable fraction of shale gas wells from severance taxes and regulatory oversight. I am referring to fracks that will use something other than a 100% water as its base fluid. Fracks that rely on 100% nitrogen, some other non-water base fluid, or a mix of water and non-water fluids or foams may possibly involve more hazard than a 100% slickwater frack.

***Elaboration on legal issues:*** There are three problems with this Rule:

1.) With the exception of the depocenter in southeast corner of the state, which lies at ~3,500 feet, most of the New Albany shale field in Illinois is only 500 to 2,500 feet beneath the surface (DOE 2009). As Table 1 and Figure 1 show, *Illinois New Albany shale is closer to the surface than any other shale field in the United States.*

**Table 1. Measurement Data in Feet for United States Shale Gas Basins**

| Basin (State) | Barnett (TX) | Fayetteville (AK) | Haynesville (TX, LA) | Marcellus (NY, PA, WV) | Woodford (TX) | Antrim (MI) | **New Albany (IL, IN, KY)** |
|---|---|---|---|---|---|---|---|
| Depth, Ft. | 6,500 - 8,500 | 1,000 - 7,000 | 10,500 - 13,500 | 4,000 - 8,500 | 6,000 - 11,000 | 600- 2,200 | **500 - 2,000** |
| Net Pay, Ft. | 100-600 | 20-200 | 200-300 | 50-200 | 120-220 | 70-120 | **50-100** |
| Rock Col. Ft.: Surface $H_2O$ to Top of Shale | 5,300- 7,300 | 500 - 6,500 | 10,100 - 13,100 | 2,125 - 7,650 | 5,600 - 10,600 | 300- 1,900 | **100-1,600** |
| Produced $H_2O$ Barrels $H_2O$/Day | N/A | N/A | N/A | N/A | N/A | 5-500 | **5-500** |

*U.S. Department of Energy. 2009,* p. 17.

A related issue follows in the train of our mostly close to the surface shale field. The sine qua non of safe fracking is a thick layer of impermeable cap rock to prevent the migration of methane (and possibly fracking byproducts) into shallow groundwater. The International Energy Agency (2012) and a panel of German experts (Ewen et al. 2012), who were funded and provided with data by ExxonMobil, both state that a distance of at least 1,000 meters (3,280 feet) should separate the top of the shale field from the land surface.[1] Many gas



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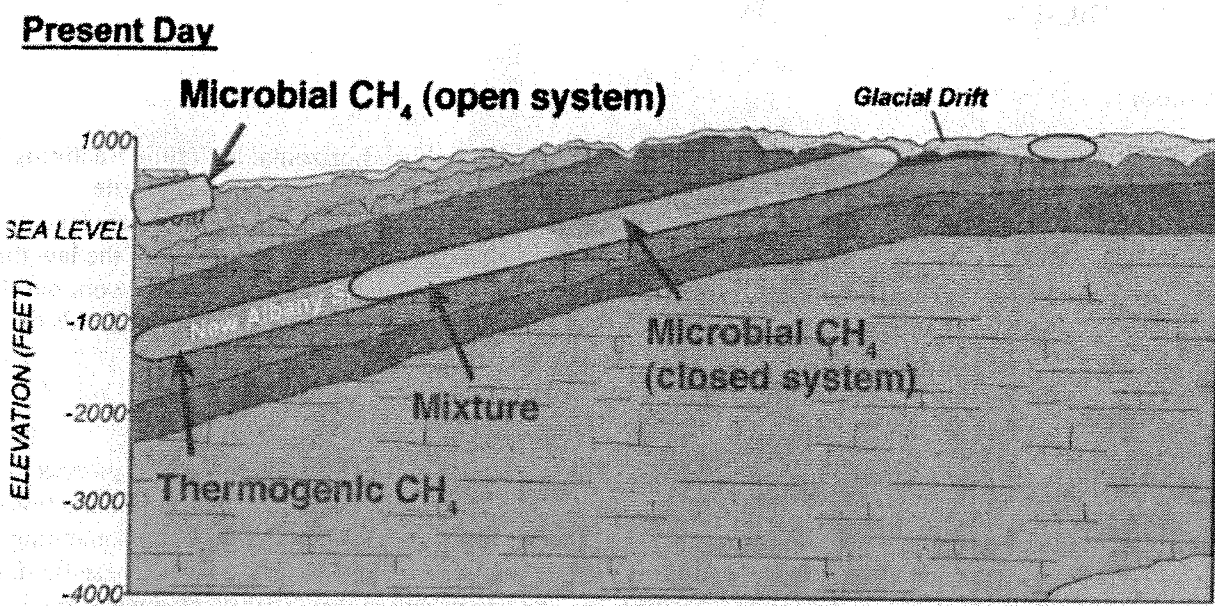
fracks in Illinois will be above 3,000 -- that is, inside a danger zone. Figure 1, generated as part of the Gas Technology Institute (2009) study of the New Albany Shale Formation, shows the closeness to the surface of New Albany Shale gas (see also Perry 2009).

***Figure 1. New Albany Shale Schema***




*Source: Perry (2009)*

2.) Water does not work well in shallow fracks and, as a result 100% nitrogen fracks are typically used in these close to the surface fracks. Apparently, there is not enough pressure in these shallow wells to drive frack water quickly back to the surface. Water therefore has time to interact with clay and cause swelling, and the swelling reduces the recovery efficiency of a well (Walser 2012; Ditoro 2012). Hence, the turn to nitrofracs which have been employed in Indiana, Tennessee (Little 2010), and Kentucky (Brashear 2012)

To become liquid nitrogen is cooled to -320°F. When it is pumped into the well liquid nitrogen quickly converts to a gas; *the expansion ratio during the liquid to gas shift is **1 to 696.5*** (Material Safety Data Sheet 1995). It is the gas, not the liquid, that fractures the rock. To compare 1 gallon of liquid nitrogen to 1 gallon of water is therefore absurd. There are other issues: a greater probability of "out of formation" fracks with the attendant risk of water pollution, especially in these shallow fields, and the high probability that raw methane will be vented into the atmosphere during well completion. I will present these issues in another letter.

**Conclusion: IDNR must provide formulas in revised rules for converting all non-water base fluids into water gallon equivalents.**

3.) Horizontal fracks for oil in Illinois will occur in dolomite strata below the New Albany Shale (see Figure 2). Strata-X (2013) , one of the first companies to announce its plans in Illinois, states that its oil play is similar to the Elm Coulee or Middle Bakken Formation in Montana. According to Bill Walker (2006), a multi-stage, 5,000 foot lateral will require about 210,000 gallons of a gelled water-sand frack. If these facts are correct, then the vast majority of horizontal oil fracks in Illinois (1) will NOT fall under the regulatory provisions of PA98-0022, and (2) will pay no severance taxes.

I realize that the HVHF definition is written into the law and cannot be changed through rulemaking. At the same time I am convinced that the General Assembly was unaware of the full ramifications of the HVHF definition.

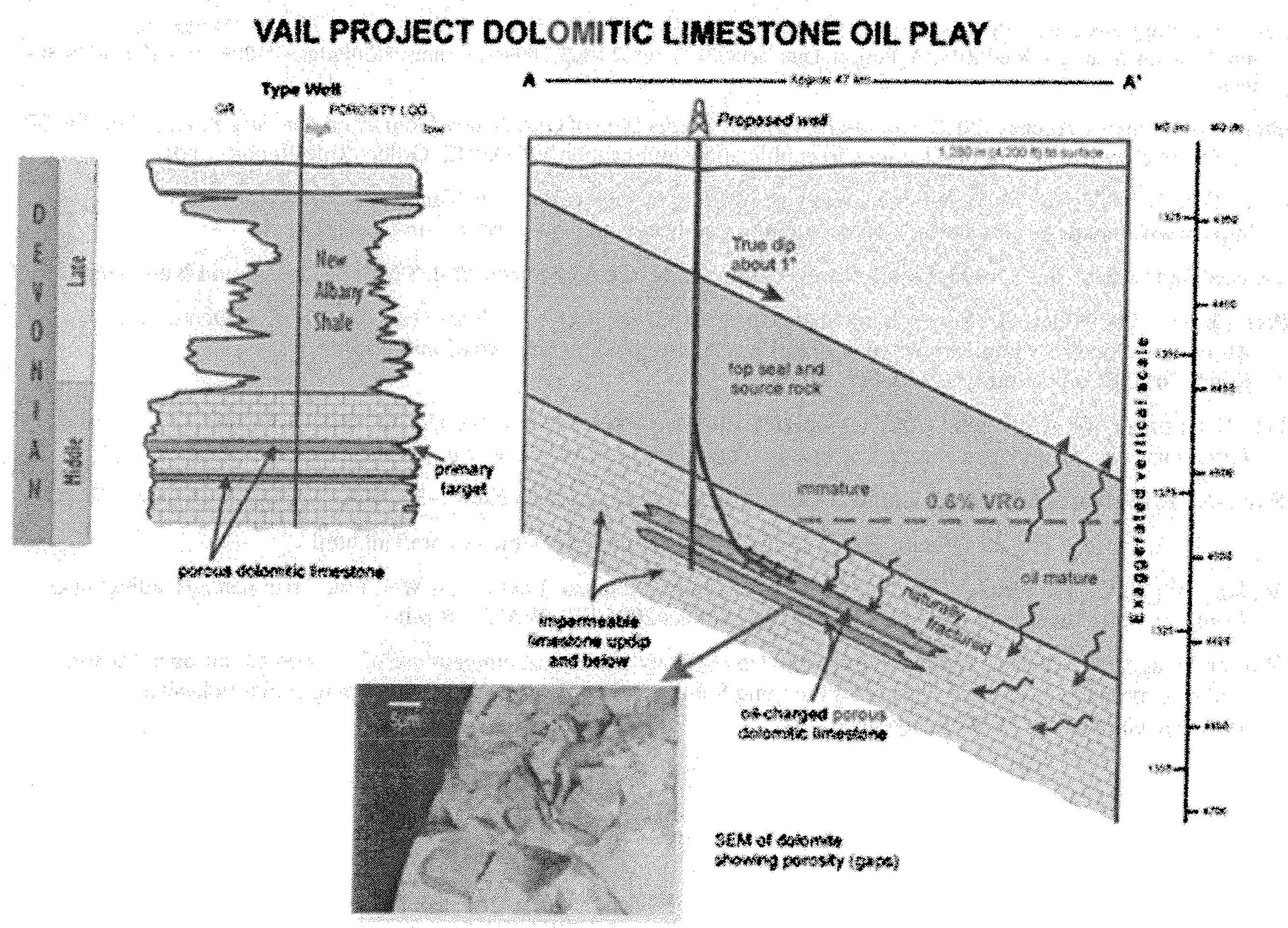
Had they been aware last spring of the consequential financial and regulatory consequences of the present definition, I am fully confident they would have changed the definition then.

**I am therefore requesting that you bring this issue to the attention of JCAR Senators and Representatives so that they can decide whether to pursue a change in the present definition in the law during the spring session of the General Assembly.**

Sincerely yours,

William C. Rau
Spokesperson, Illinois People's Action
& Professor Emeritus,
Illinois State University
313 Vista Drive
Bloomington, IL 61701-2123

***Figure 2. Strata-X Image for a Clay County, IL Horizontal Hydrofrack Well***




*Source: http://www.strata-x.com/images/vailmap1-02.png*

## Notes

[1] This standard is informed by a growing and extensive body of evidence on the height of hydraulically induced fractures. See: Davies, Richard J. et al. 2012 (April). "Hydraulic Fractures: How Far Can They Go?" *Marine and Petroleum Geology* http://www.dur.ac.uk/resources/dei/JMPG_1575.pdf ;

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17 December 2013

Robert G. Mool
Office of Legal Counsel, Department of Natural Resources
One Natural Resources Way
Springfield, IL 62702-1271

Dear Mr. Mool:

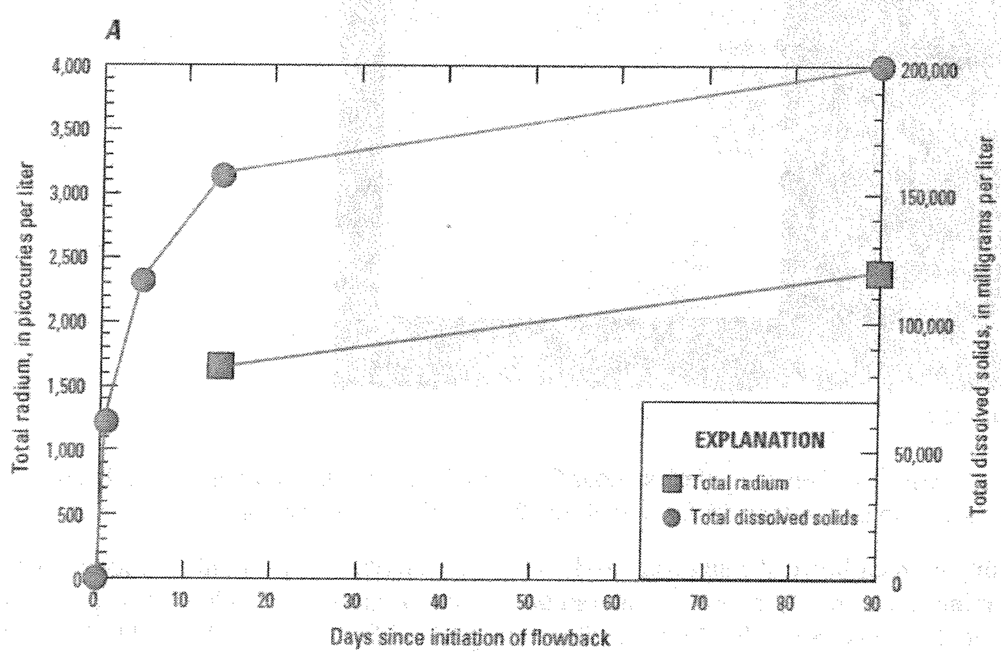
I write this letter with respect to the draft rules regarding "radioactivity testing" in the Illinois Hydraulic Fracturing Act [PA98-002]. Of necessity, this issue must also involve the section in the Act calling for compliance with applicable federal and State laws. Here are the specifics:

***Legal issues:*** Act §1-75(a)7 requires radioactivity testing *"once per well site"* for (1) flowback water and ground *"adjacent to"* (2) storage tanks and (3) reserve pits. Act §1-120 requires IDNR compliance with all "applicable federal, State, and local laws." One applicable State law is the Illinois Low-Level Radioactive Waste Management Act [PA 83-991 / 420ILCS20]. Another is the Occupational Health and Safety Administration (OSHA) standards for workplace safety in settings with exposure to radioactivity [29 CFR 1910.1096].

Rules §245.850(d)1-E and §245.850(e) are *incomplete* and *deficient,* and these inadequacies *"constitute a serious threat"*--indeed, deadly threat-- *"to the public interest, safety, or welfare" of Illinois citizens."* These rules, therefore, do not conform with the requirements set forth in the Illinois Administrative Procedure Act.

***Elaboration on legal issues:*** Five problems stand out:

1.) IDNR does not define a Fixed Date for testing. Day 1, Minute 1 test results will be orders of magnitude lower than either Day 2 or Day 10 tests results, and Day 10 tests results will be significantly lower than Day 90 results. *The rules do not require companies to list the date and hour of the test.* Failure to define a Fixed Test Date renders test data so many irrelevant apples and oranges and allows companies to report suppressed, meaningless results by reporting Day 1, Minute 1 data.




*Source: Rowan el al. (2011)*



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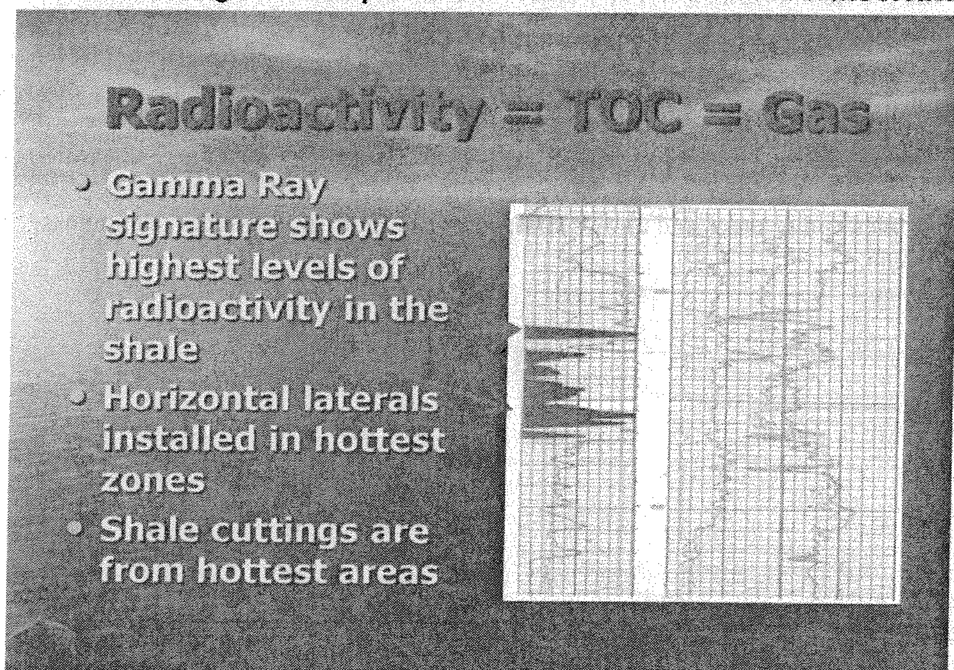
The United States Geological Survey figure above (Rowan et al. 2011) illustrates the nature of the problem. Total dissolved solids increase rapidly for the first two weeks; at about week three the rate of increase levels off and becomes approximately linear. A similar pattern of increase is documented by Spellacy (2013), not only for total dissolved solids, but chloride, sodium, strontium, and arsenic.

Note that radium is not tested at Day 1, Minute 1 in the USGS figure. However, radium co-precipitates with barium which, along with chloride and sodium, is part of total dissolved solids (TDS). It will therefore track TDS fairly closely. Also, note that total radium at Day 90 is over 2,000 picoCuries per liter of produced water. However, using the IDNR Rules, it would be possible to generate a result of less than 100 pCi / l.

Conclusion: companies will be testing the very first flowback water to emerge from a fracked well. *It will be Day 1, Minute 1 test results.* Filing these results will be a waste of paper.

2.) There are two pits on a frack pad, one for so-called "emergency" flowback and another, smaller one for drill cuttings and drilling mud. It is a basic principle in horizontal fracking to steer the drill bit through the horizontal strata with the highest gamma radiation readings (GAPI logs). The reason is that radioactivity correlates highly with total organic content (TOC) in the rock, and TOC correlates highly with oil and gas yields (e.g., Weatherington-Rice 2013; Resnikoff 2012). This means that rock cuttings in the smaller drill mud and cuttings frack pit will often be more radioactive than flowback or produced water. The IDNR is aware of this; yet it does not call for testing of drill bit pits as allowed under the Powers and duties section of the Act (§1-15).




*Source: Weatherington-Rice (2013)*

3.) The term *"adjacent to"* requires a "precise, clear standard" [IAPA, §100/5-20]. None is given. Does "adjacent to" mean 6 inches,16 inches, 6 feet, 16 feet, or 60 feet? The IDNR does not say.

4.) The General Assembly granted IDNR the authority to define "radioactivity." What kind of "radioactivity" does the IDNR have in mind: uranium $^{238}$, radium $^{226}$ and radium $^{228}$, and/or radon$^{222}$? Each of these poses its own risks to our soil, water and kitchens. So, will IDNR mandate testing for all four? Three? Two? One? The rule does not say.

5.) Frack pad pipes and equipment can become incredibly radioactive over time. The very large temperature and pressure drops, as fluids move to the surface from thousands of feet underground, means that a portion of the dissolved radioactive salts precipitate out as scale on pipes and equipment. The levels of radioactivity in pipe scale can exceed 100,000 picoCuries per gram (EPA 2012) and constitute a hazard to workers, or others who are exposed to recycled scrap metal from gas and oil operations. Yet, IDNR does not call on its General Assembly deferred "Power and authority" [Act, §1-15(e)] to test pipe, tanks, sludge, and equipment. Radioactive scale on pipes and equipment has been an issue in the oil and gas industry since the 1980s.

***Radiation Concentration Levels in Produced Water, Pipes and tanks***

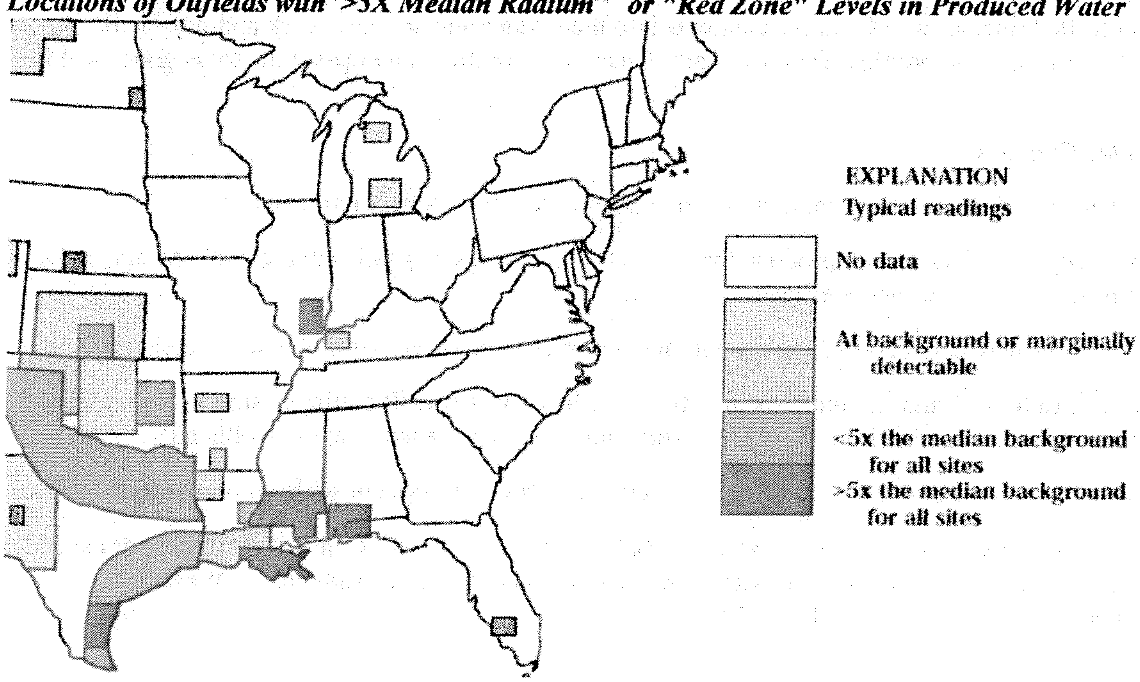
| **Wastes** | **Radiation Level [pCi/g]** | | |
|---|---|---|---|
| | low | average | high |
| Produced Water [pCi/l] | 0.10 | NA | 9,000 |
| Pipe/Tank Scale [pCi/g] | <0.25 | 480 | 400,000 |

*Source: EPA ( 2012)*

6.) The Act calls for a "traffic light" system for seismicity [§1-96]. It is our opinion that such a traffic light system is as important, if not more important, for radioactivity. And IDNR has the "Power and authority" to create one. Yet, is does not do so. At what level is intervention by the Illinois Emergency Management Administration, which bears responsibility for the Lowe Level Radioactivity Management Act [420 ILCS 20], appropriate under an interagency memorandum? IDNR does not say. At what level of worker exposure is OSHA involvement either desirable or mandated by law? IDNR does not say. How is radioactive scrap pipe and equipment to be kept out of the recycle metal market? Once more, IDNR remains silent.

***Consequences:*** According to studies by the Illinois State Geological Survey (Ostrom et al. 1955; Swanson 1961; Stevenson & Dickerson 1969) , Illinois New Albany Shale, the source rock for our oil and gas reserves, has above average levels of uranium. Uranium decays into radium and thence radon. Both uranium and radium are water soluble, and the levels of dissolved radioactive salts in Southern Illinois oilfield brine stand out. U.S. Geological Survey has found oil field brine or produced water in Southern Illinois to have radium$^{226}$ levels that average more than 1,000 picoCuries / liter (USGS 1999). These readings are for traditional, horizontally fracked wells will have higher readings. Even so, the USGS reading is 67 times above the maximum contamination level of the EPA. Radium$^{226}$ has a half life of *1,600 years.* Uranium$^{228}$ has a half life of *4.468 <u>billion</u> years.* If these water soluble salts leach into our aquifers, nearby communities will require--if possible--very expensive water treatment for *the next $^{+}$1,000 years.*

***Locations of Oilfields with >5X Median Radium$^{226}$ or "Red Zone" Levels in Produced Water***



*Source: USGS (1999)*

The radioactive levels for produced water from shale gas operations are likely to average 2 to 4 times higher than oilfield brine -- or 2,000 to 4,000 picoCuries per liter. That's an average, not a maximum value. In addition, radon levels in methane, propane, and ethane may be dangerously high. When it becomes commercial to extract shale gas from the SE corner of the state, major markets, such as Springfield and Chicago, will be respectively 0.9 and 1.4 days removed from shale gas wellheads. Even though radon$^{222}$ has a half life of only 3.8 days, the closeness of major Illinois retail gas markets will mean that large number of people will be breathing in high levels of radon if they use natural gas to cook meals.

| **Miles from Karbers Ridge, Hardin County, IL (New Albany depocenter) to:** | | | | | |
|---|---|---|---|---|---|
| Marion | 43 | Decatur | 166 | Peoria | 292 |
| Carbondale | 59 | Champaign-Urbana | 204 | Chicago | 335 |
| Mount Vernon | 80 | Springfield | 219 | Moline | 382 |
| Effingham | 126 | Danville | 255 | Waukegan | 397 |
| St. Louis | 153 | Bloomington-Normal | 266 | Rockford | 402 |

The average level of indoor exposure to radon in Illinois is *already* 4.4 pCi/L ( American Lung Association 2013). The EPA maximum level--the point at which corrective action should be taken--is 4.0 pCi/L, and the preferred level is ≤3.0 pCi/L. The turn to shale gas, with its high levels of radon, will also turn a major Illinois public health problem in the wrong direction.

Radioactive scale in pipe and equipment presents another problem (e.g., Baier 1989); high levels of radioactivity have been found in school playground equipment and bleachers in school sports stadiums in Mississippi and Texas. Do we want untested oil and gas field scrap metal sold into Illinois markets? Do we want our children exposed on a daily basis to radioactive metal? The present rules creates no barriers to such an outcome.

The problems cited above are why Illinois, with its large number of nuclear power plants, has a Low-Level Radioactive Waste Management Act. It and OSHA are the applicable State and Federal agencies with respect to the issue of radioactive waste and work safety standards in settings with exposure to radioactivity. If we faithfully follow applicable State and federal laws, Illinois can minimize the pernicious problems other states are going to face from the uncontrolled release of radioactive elements into their water and soil and work and non-work settings. We should prevent these problem from the start. Cleanup, after the oil and gas industry is gone, will be dreadfully expensive.

***Recommended Rules Changes:***

1. Define the test date as ≥ Day 21, the point at which increases in test results begin to level off.
2. Test for "radioactivity" in (1) flowback/produced water, (2) drill cuttings, (3) soil "adjacent to" storage tanks and (4) reserve pits, and (5) pipes and well pad equipment.
3. Define "adjacent to" as between 6 and 12 inches with test samples to be taken within the top 6 inches of soil
4. Test for uranium$^{238}$, radium$^{226}$ and radium$^{228}$ in flowback/produced water, drill cuttings, storage and reserve pit areas. Test for radium $^{226}$ and radium $^{228}$ in pipes and equipment, and radon$^{222}$ at the wellhead.
5. Rely on experts and scientific studies, to create a radioactivity traffic light system with cut points for:

   (1) controlled management, transportation, and disposal of any water, solids, or metals that meet or exceed criterion classifying it as low level radioactive waste (Illinois Low-Level Radioactive Waste Management Act [PA 83-991 / 420ILCS20]);

(2) guidance/intervention by OSHA when safety clothing, gloves and goggles are required to reduce workplace exposure (Nicholl 2012; Argone 2011);

(3) quarantines for natural gas with elevated radon levels until those levels drop to a point where the gas is safe (after transport) for retail markets;

(4) rigorous labeling, management, and disposal rules for radioactive pipe and equipment;

(5) the posting of easily read, prominently displayed radioactive warning signs at frack pads;

(6) creating clean zones for eating and storing personal goods at wells sites deemed a potential workplace hazard.

I intend to do everything in my power to ensure that the granddaughter of my granddaughter's granddaughter does not inherit a carcinogenic landscape due to the wreck less abandon of our generation. I hope you, the IDNR and the Government of the State of Illinois will help to achieve that outcome.

Sincerely yours,

William C. Rau
Spokesperson, Illinois Peoples' Action
& Professor Emeritus,
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313 Vista Drive
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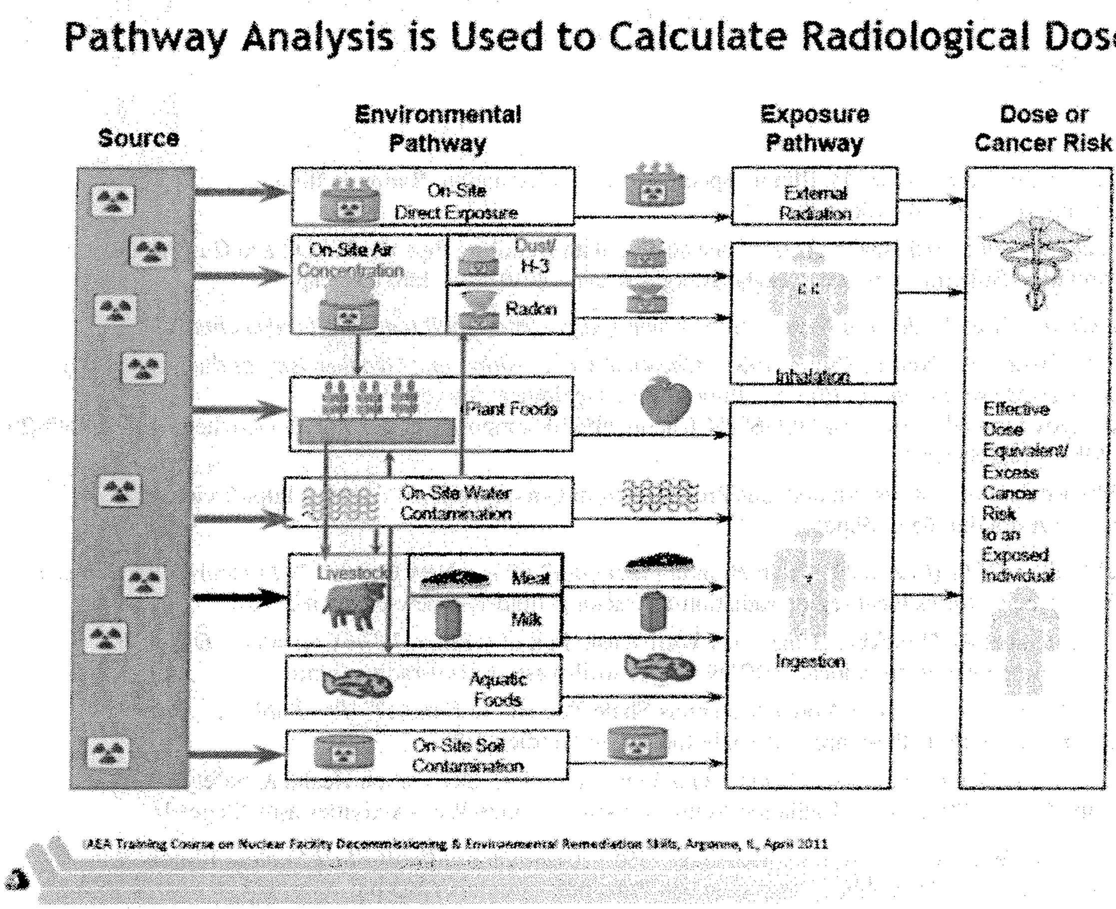
Routes of exposure are captured graphically in this figure provided by the Argonne National Laboratory:




Source: Argonne. 2011. Overview of Radiological Dose and Risk Assessment; http://www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN/ANL%20Course/Day_5/RiskOverview_revised.pdf

Testimony
Bill Poorman
Illinois People's Action
Decatur public hearing, proposed rules, Illinois Hydraulic Fracturing Act
December 17, 2013

Hello, I'm Bill Poorman. I'm with Illinois People's Action and Fair Economy Illinois, a coalition of churches, groups, and individuals working for economic and social justice. I will be speaking to subpart K – section 245-dot-1100 – of the rules that cover enforcement.

When the legislature and Governor Quinn passed the Hydraulic Fracturing Regulatory Act earlier this year, they told us it would serve as a national model for environmental safety – that the rules would be strict and tough in order to protect Illinois' environment and people. Judged on that basis, the proposed rules fall far short.

Starting right at the top, the proposed rules say the IDNR "may" suspend or revoke permits, order remediation, or issue penalties if one of the rules is broken. But the law itself requires that the construction and testing of wells "must" be done in line with the standards set by the American Petroleum Institute. There is no "may". There is no discretion.

And for good reason. Without these standards, fracking wells could be in danger of blowouts, fires or explosions that threaten workers, nearby residents, and the environment. The BP Deepwater Horizon disaster happened because these standards were not followed and not enforced. We cannot take those kind of risks here in Illinois.

These rules need to be toughened by changing the language to read that IDNR "will" or "must" suspend or revoke permits or issue penalties if the rules are broken. We need a policy closer to one strike, and you're out, so that drillers have every incentive to make sure they're doing the job right.

In a similar way, there must be tougher financial penalties for gas and oil companies when they break the rules. Let's be honest here – these companies really only care about the money they can extract from drilling in Illinois. That's their only purpose. And history shows that corporations will take shortcuts to increase those profits – even if people, the environment, and laws stand in the way. If we want enforcement to matter at all, we have to make it more expensive to break the law than it is to follow it. We've got to punch them in the profit margin.

Right now, the proposed rules do not do that. The law itself set strict penalties that could go up to tens of thousands of dollars. But the rules have minimal fines that start at a token $50 – less than many speeding tickets – and only go up to $2500. (Section 245.1120) The top five producers of oil and gas made more than 118 billion in profits last year. These relatively paltry fines will not slow these companies down. Heck, some of these fines could be covered by just laying off a couple of workers. Fines need to reflect the true cost of the damage the drillers do to people and the environment. We must have the fines and penalties outlined in the law itself.

We need strong rules, steep fines, and tough cops on the beat. As written, the proposed rules don't provide for any of those. If the IDNR wants to accomplish the aim of the law – the safety of Illinois and its people – it must makes these rules stricter and more expensive. Or oil and gas companies will see them as nothing more than a cost of doing business. Thank you.

IDNR HEARING TESTIMONY IN DECATUR DECEMBER 17, 2013

My name is Verlyn Rosenberger, a member of Illinois People's Action – IPA through First Presbyterian Church, Decatur, Illinois and of Fair Economy Illinois. As such, I have great concern for social justice, economic justice and environmental justice.

My comment is on the need for health professionals to have access to information about chemicals used in fracking because public health and safety should be the primary concern of government officials of Illinois and its agencies, as well as the officials of municipalities and counties. Nothing about fracking is healthy and safe for humans, animals, nor the environment, but strict fracking rules that must be adhered to can reduce the harmful effects, if enforced properly.

When secret, highly toxic and radioactive chemicals are used in fracking, accidents, leaks, spills, and even unscrupulous acts on the part of some individuals or the fracking industry are bound to occur. When a property owner, family member, neighbor or industry worker is injured by exposure to these unknown chemicals, how can a health care professional treat him or her? The IDNR Rules allow the actual chemicals to be kept secret, even from health care workers. Exposure to these harmful chemicals should have immediate treatment.

Section 245.730 of the IDNR rules keep immediate treatment from happening. The law requires IDNR to provide health care professionals information about the chemicals used in fracking when that information is necessary to treat a patient. But the rules provide a circular definition of the "affected patient" which requires doctors to test for 353-700 chemicals that can be used in fracking to determine which ones were used so a correct diagnosis can be made. Conducting hundreds of tests takes time and thus is medically and financially unfeasible. It places the burden on the medical establishment instead of on the fracking company where it belongs.

Of course, a medical emergency must occur during IDNR's "normal business hours" so the health care professionals can obtain needed information about the chemicals. During off hours, calls have to be made to the trade secret holder for such information, but the IDNR rules gives no clue about who they are and how to contact them. Before you know it, the patient could be dead!

The rules do not require IDNR and the trade secret holder to provide information to health professionals; instead the rules say they "may" rather than "shall" provide the information. This means they have complete discretion whether or not they want to share information about the chemicals involved in fracking, regardless of medical necessity. Why do IDNR and fracking companies have the ability to make life and death decisions for other people?

The residents of Illinois are depending upon the IDNR to protect their health, safety and the safety of their water, soil and air. IDNR needs to return to the intent of the law and mandate that fracking companies disclose all chemicals used their operations, WITH NO EXCEPTIONS.

Verlyn Rosenberger

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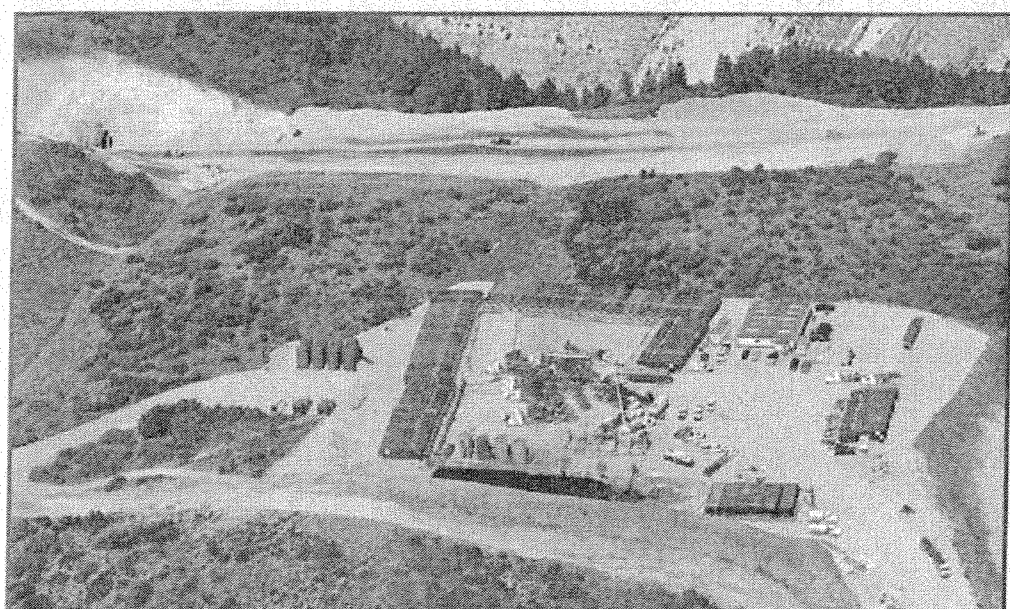
EM: pcrvkr@aol.com

# Fracking Chemicals Found to Disrupt Hormone Function

Kaye Spector | December 16, 2013 5:13 pm | Comments
211 0Share0 2 469

University of Missouri researchers have found that 11 chemicals commonly used in fracking for oil and natural gas are endocrine disruptors, while water near hydraulic fracturing drilling sites had greater hormone-disrupting properties than in areas without drilling.

Endocrine disruptors interfere with the body's endocrine system, which controls numerous body functions with hormones such as the female hormone estrogen and the male hormone androgen. Exposure to endocrine-disrupting chemicals has been linked by other research to cancer, birth defects and infertility.



A fracturing operation on top of Colorado's Roan Plateau. The green tanks hold the fluids for fracking. Photo credit: TEDX The Endocrine Disruption Exchange

"More than 700 chemicals are used in the fracking process, and many of them disturb hormone function," researcher Susan Nagel, Ph.D, associate professor of obstetrics, gynecology and women's health at the University of Missouri School of Medicine said in a media release. "With fracking on the rise, populations may face greater health risks from increased endocrine-disrupting chemical exposure."

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The study, "Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region," will be published in the journal *Endocrinology*.

**Visit EcoWatch's FRACKING page for more related news on this topic.**

WHY?



# Water officials spared jail

## *Pair mixed tainted water into Crestwood supply*

CHICAGO (AP) — A federal judge Thursday pointed the finger of blame directly at an uncharged ex-mayor as she declined to imprison two former water officials for lying about mixing tainted well water into a Chicago suburb's drinking supply.

Judge Joan Gottschall sentenced Theresa Neubauer, 55, and Frank Scaccia, 61, to two years of probation and ordered Neubauer to do 200 hours of community service and placed Scaccia under six months of home confinement.

In deciding not to imprison the former Crestwood officials, the judge said prison time would have hastened the ailing Scaccia's death, and she called Neubauer "a low-level soldier" in a scheme led by then-Mayor Chester Stranczek.

The former mayor, she went on, was a "charlatan" and an "evil genius" who ordered subordinates, including Neubauer and Scaccia, to mix contaminated well water with cleaner but pricier lake water so he could brag to voters about keeping water rates low.

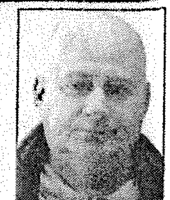
Stranczek's own deteriorating health made it impossible to ever file charges against him, Judge Gottschall and prosecutors told Thursday's hearing.

"So, I'm left to do justice the best I can," Gottschall said, explaining her sentence to a courtroom crowded with relatives of the defendants and residents of Crestwood.

There's no telephone listing for Stranczek in Crestwood. His former attorney says he no longer represents Stranczek. In one of his few public comments on the matter in 2009, Stranczek said, "I've never been accused of doing something wrong."

Officials in the 11,000-resident village mixed the contam-


Neubauer


Scaccia

inated water with water from Lake Michigan from 1982 until the allegations arose in 2008. They kept pumping the polluted water even after environmental officials warned in the mid-1980s that chemicals had oozed into the well, prosecutors said.

Gottschall said the objective was to ensure the mayor would be "perpetually elected" by citing his alleged credentials as a fiscal conservative. By drawing the well water, they saved about $400,000 annually, prosecutors have said.

Before the judge announced the sentence, Neubauer apologized to the residents of Crestwood in a brief statement. But she added that she never had an inkling that the well water might be contaminated.

## Cougar found in Northern Illinois

MORRISON (AP) — State wildlife biologists are investigating after a cougar was found roaming near a Northern Illinois farm.

The Illinois Department of Natural Resources said Thursday that they euthanized the animal found Wednesday near Morrison in rural Whiteside County. The cougar was between 5 and 6 feet long and weighed about 100 pounds. Wildlife biologists plan an autopsy.

Farmers called conservation police after seeing the cougar exit a cornfield. Police found the animal in tunnel under a corn crib.

Experts say there were three confirmed cougars in Illinois between 2002 and 2008. Trail cameras in recent years have shown a

& watch

FALL 2013

# SPECIAL REPORT

This Special Report details many disturbing incidents of farm animals sickened and suddenly dying after exposure to fracking contaminants as well as how it is possible for tainted livestock and crops to move through the food system and onto your plate without detection. Food & Water Watch is mobilizing nationwide to ban fracking and protect America's food and water systems from this unprecedented threat.

## Fracking from Farm to Table

Livestock exposed to fracking chemicals—either accidentally or incidentally—are dying by the scores.

For example, at an organic dairy farm just two miles from nine fracking sites in Pennsylvania the water tastes so bad the cows won't drink it. But they're the lucky ones, suffering only boils and skin rashes. The cattle at a neighboring farm down the road also suffered from fertility problems and early miscarriages.

In another part of the state, 140 cattle were exposed to fracking wastewater when an impoundment pond was breached. Half the animals died. And among the remaining herd, only 11 calves were born, of which just three survived.

On the other side of the country in North Dakota, five cows dropped dead after fracking began on 32 wells three miles away from one cattle ranch.

And ever since a fracking unit blow-out just half a mile away, a creek on the ranch has been clogged with scummy growth and regularly burps up methane. The creek never freezes, despite 40-below winter temperatures.

When a fracking crew continued to drill at a well that had sprung a leak, the rancher's cattle began limping, legs swollen and weak with infections. Cows quit producing milk for their calves and lost 60 to 80 pounds in a week—even their tails fell off!

When wind-blown fly ash from fracking settled over another North Dakota farm, a cow that either inhaled or ingested the caustic dust died and the stock pond was contaminated with arsenic at double the accepted level for drinking water.

A Wyoming farmer who raises alfalfa hay and runs a cow-calf operation has more than 200 fracking wells within a four-mile radius, some only 200 feet from his home. Dozens of his calves suddenly dropped dead and his well water smells like hydrocarbons.

Tests showed methane, plastics, polymers, phthalates and glycols in the groundwater, including some of the same toxic chemicals used to frack the wells.

In Louisiana, 17 cows died after only *one hour's* exposure to spilled fracking fluid.

*(over, please)*

**1616 P Street NW, Suite 300 Washington, DC 20036**
**Phone: 202.683.2500 Fax: 202.683.2501 www.foodandwaterwatch.org E-mail: info@fwwatch.org**

Hair testing of sick cattle that grazed around fracking wells in New Mexico found petroleum residues in 54 of 56 animals.

And nothing is preventing contaminated animals from making their way into the food system. While animals that have died before slaughter are not supposed to be sold in the marketplace, livestock is being raised in areas that have tested positive for air, water and soil contamination.

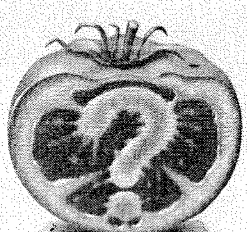
## And it's not just beef—all farm animals and produce is potentially at risk.

Toxic chemicals could appear in meat and dairy products made from these animals and you would never know it. Ranchers are not required to prove their livestock are free from fracking contaminants before they're sold, and USDA inspectors are not looking for them.

With animals either sickened or tainted by fracking chemicals currently able to enter the food chain undetected, Food & Water Watch is urgently mobilizing Americans nationwide to compel the USDA to inspect all meat and poultry to ensure our meat is free of fracking contaminants.

It is not only our meat that is at risk. Fracking has started in California and is slated for massive expansion in the Central Valley and Salinas Valley, where much of the nation's fruits and vegetables are grown.

These areas are already struggling with water supply and quality problems and fracking threatens to make them much worse at the expense of family farmers, while putting your food at risk for contamination.

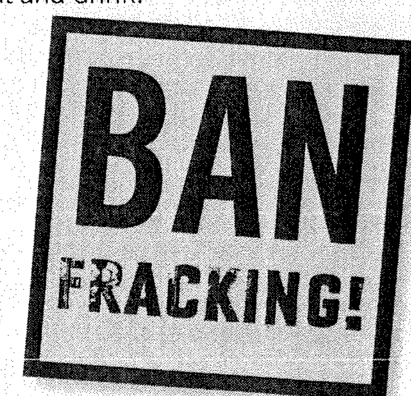


That's why we need you to sign our petition to the FDA demanding that our produce and dairy products be inspected to ensure they are free of fracking contaminants.

Food & Water Watch is mobilizing rapidly to prevent Big Oil & Gas from fracking our food system into total toxicity. Every contribution you make in support of our advocacy is a direct investment in making sure the groceries you buy are safe to eat and drink.

In spite of the huge climb we face and the sheer inequality of resources at our disposal compared to the fracking industry, what the Food & Water Watch team has achieved over the past two years has been nothing less than incredible. The anti-fracking movement—powered by Food & Water Watch's leadership, hard work and grassroots organizing—has grown into a potent political force.

Even the oil and gas industry now sees our strategy as politically viable and threatening. An insider whitepaper said that *"outright bans constitute the most significant political risk to the industry ..."* and *"mobilization of grassroots opposition has been fundamental to the global anti-fracking movement"* and as *"local groups combine to form national or international coalitions, there is likely to be more scope for top-down messaging, common advocacy platforms."*




Food & Water Watch is at the front leading the way. With your investment in our shared mission, we're rallying the grassroots, organizing and mobilizing a growing citizens movement to protect the country's food system and water resources.

And now, given the gravity of the threat fracking poses to the safety of what we feed our families, our continued action is imperative. Our petition campaign to the USDA and FDA to have all food products inspected for fracking contaminants is an essential safeguard until we succeed in winning a nationwide ban on this extremely dangerous drilling method.

Thank you for all your help!
W.H.



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# Fracking Chemicals Found to Disrupt Hormone Function

Kaye Spector | December 16, 2013 5:13 pm | Comments
211 0Share0 2 469

University of Missouri researchers have found that 11 chemicals commonly used in fracking for oil and natural gas are endocrine disruptors, while water near hydraulic fracturing drilling sites had greater hormone-disrupting properties than in areas without drilling.

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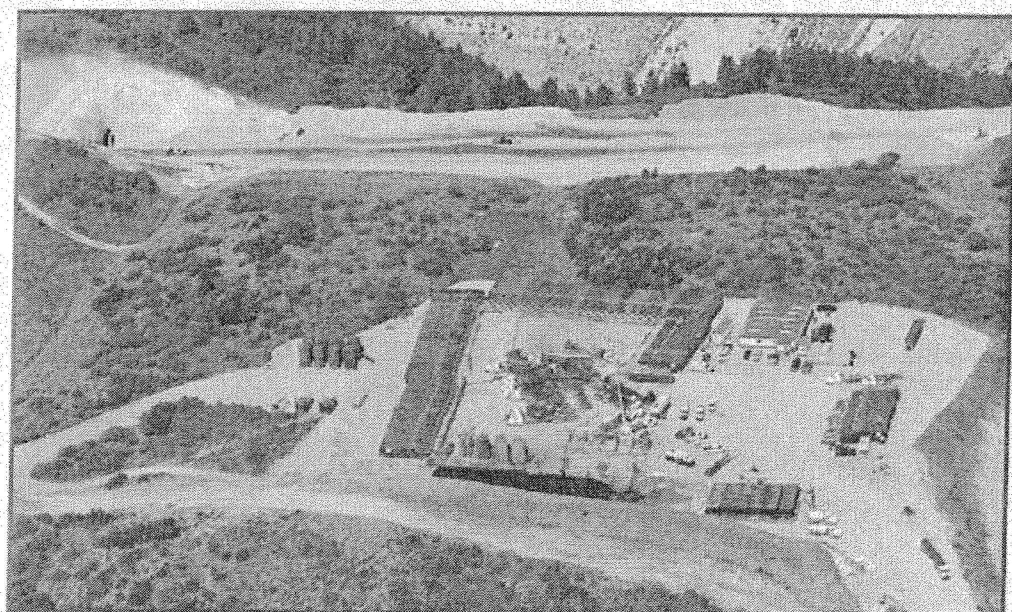

A fracturing operation on top of Colorado's Roan Plateau. The green tanks hold the fluids for fracking. Photo credit: TEDX The Endocrine Disruption Exchange

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**Visit EcoWatch's FRACKING page for more related news on this topic.**

# The Costs of Fracking

## The Price Tag of Dirty Drilling's Environmental Damage

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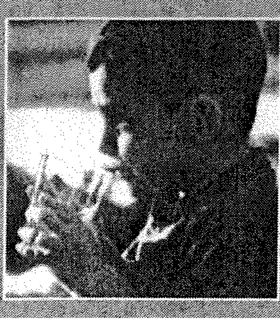

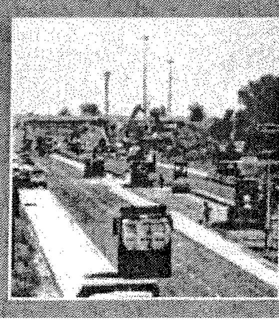

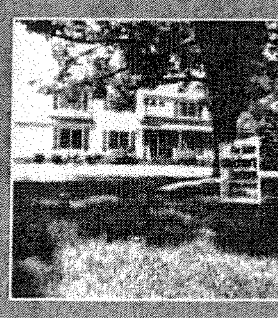

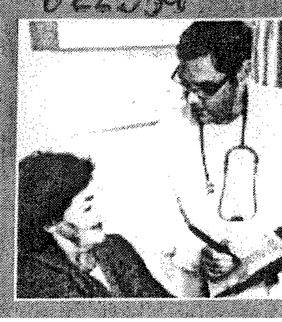

# The Costs of Fracking
## The Price Tag of Dirty Drilling's Environmental Damage

Environment Illinois
Research & Education Center

Tony Dutzik and Elizabeth Ridlington,
Frontier Group

John Rumpler,
Environment America
Research & Policy Center

Fall 2012

# Acknowledgments

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The authors bear responsibility for any factual errors. The recommendations are those of Environment Illinois Research & Education Center. The views expressed in this report are those of the authors and do not necessarily reflect the views of our funders or those who provided review.



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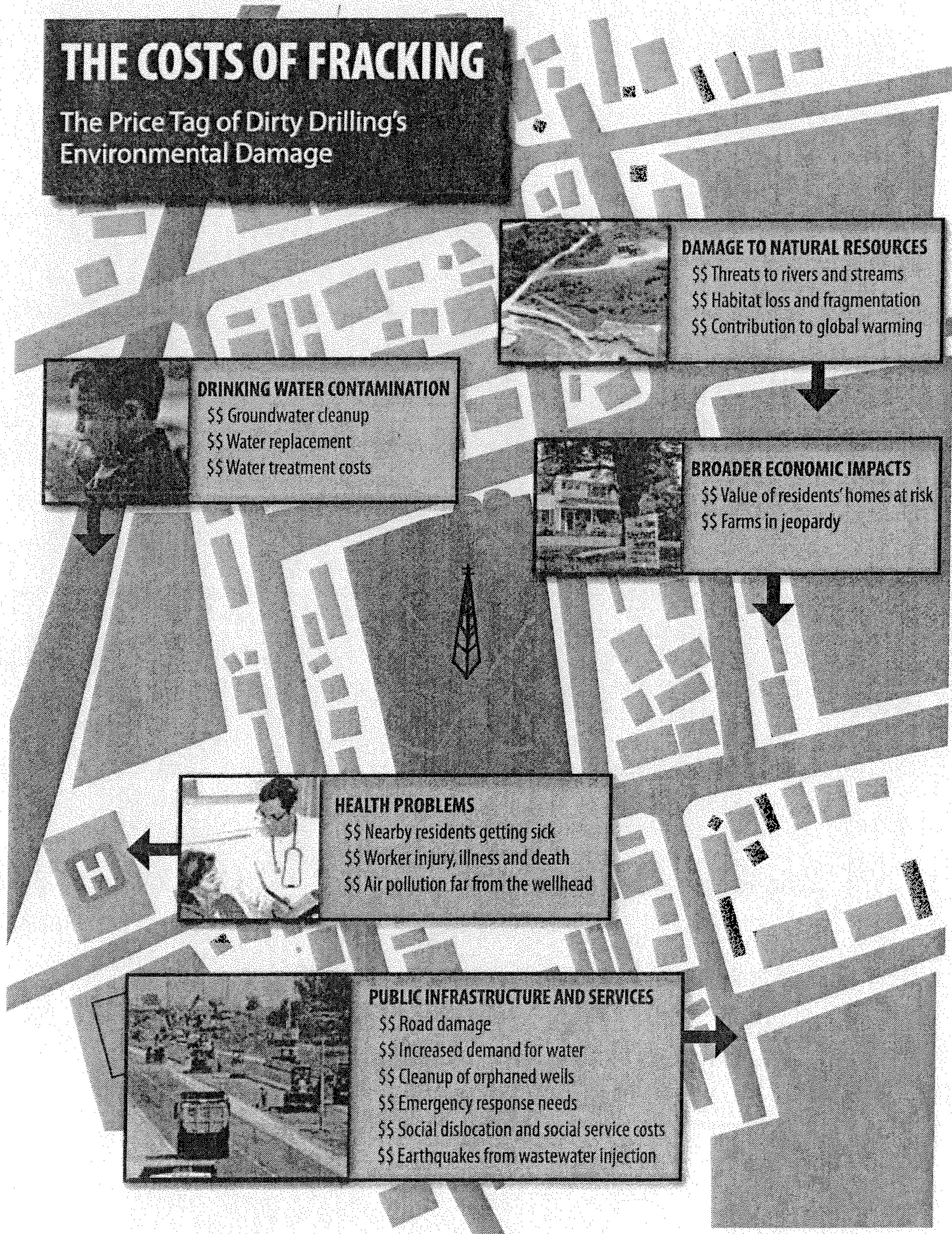


Infographic design: Jenna Leschuk

# Executive Summary

Over the past decade, the oil and gas industry has fused two technologies—hydraulic fracturing and horizontal drilling—to unlock new supplies of fossil fuels in underground rock formations across the United States. "Fracking" has spread rapidly, leaving a trail of contaminated water, polluted air, and marred landscapes in its wake. In fact, a growing body of data indicates that fracking is an environmental and public health disaster in the making.

However, the true toll of fracking does not end there. Fracking's negative impacts on our environment and health come with heavy "dollars and cents" costs as well. In this report, we document those costs—ranging from cleaning up contaminated water to repairing ruined roads and beyond. Many of these costs are likely to be borne by the public, rather than the oil and gas industry. As with the damage done by previous extractive booms, the public may experience these costs for decades to come.

The case against fracking is compelling based on its damage to the environment and our health alone. To the extent that fracking does take place, the least the public can expect is for the oil and gas industry to be held accountable for the damage it causes. Such accountability must include up-front financial assurances sufficient to ensure that the harms caused by fracking are fully redressed.

**Fracking damages the environment, threatens public health, and affects communities in ways that can impose a multitude of costs:**

**Drinking water contamination** – Fracking brings with it the potential for spills, blowouts and well failures that contaminate groundwater supplies.

- Cleanup of drinking water contamination is so expensive that it is rarely even attempted. In Dimock, Pennsylvania, Cabot Oil & Gas reported having spent $109,000 on systems to remove methane from well water for 14 local households, while in Colorado, cleanup of an underground gas seep has been ongoing for eight years at a likely cost of hundreds of thousands of dollars, if not more.

022345

- The provision of temporary replacement water supplies is also expensive. Cabot Oil & Gas reported having spent at least $193,000 on replacement water for homes with contaminated water in Dimock, Pennsylvania.

- Fracking can also pollute drinking water sources for major municipal systems, increasing water treatment costs. If fracking were to degrade the New York City watershed with sediment or other pollution, construction of a filtration plant would cost approximately $6 billion.

**Health problems** – Toxic substances in fracking fluid and wastewater—as well as air pollution from trucks, equipment and the wells themselves—have been linked to a variety of negative health effects.

- The National Institute of Occupational Safety and Health recently warned that workers may be at elevated risk of contracting the lung disease silicosis from inhalation of silica dust at fracking sites. Silicosis is one of a family of dust-induced occupational ailments that imposed $50 million medical care costs in the United States in 2007.

- Residents living near fracking sites have long suffered from a range of health problems, including headaches, eye irritation, respiratory problems and nausea—potentially imposing economic costs ranging from health care costs to workplace absenteeism and reduced productivity.

- Fracking and associated activities also produce pollution that contributes to the formation of ozone smog and particulate soot. Air pollution from gas drilling in Arkansas' Fayetteville Shale region imposed estimated public health costs of more than $10 million in 2008.

**Natural resources impacts** – Fracking converts rural and natural areas into industrial zones, replacing forest and farm land with well pads, roads, pipelines and other infrastructure, and damaging precious natural resources.

- The clearance of forest land in Pennsylvania for fracking could lead to increased delivery of nutrient pollution to the Chesapeake Bay, which already suffers from a vast nutrient-generated dead zone. The cost of reducing the same amount of pollution as could be generated by fracking would be approximately $1.5 million to $4 million per year.

- Gas operations in Wyoming have fragmented key habitat for mule deer and pronghorn, which are important draws for the state's $340 million hunting and wildlife watching industries. The mule deer population in one area undergoing extensive gas extraction dropped by 56 percent between 2001 and 2010.

- Fracking also produces methane pollution that contributes to global warming. Emissions of methane during well completion from each uncontrolled fracking well impose approximately $130,000 in social costs related to global warming.

**Impacts on public infrastructure and services** – Fracking strains infrastructure and public services and imposes cleanup costs that can fall on taxpayers.

- The truck traffic needed to deliver water to a single fracking well causes as much damage to local roads as nearly 3.5 million car trips. The state of Texas has approved $40 million in funding for road repairs in the Barnett Shale region, while

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Pennsylvania estimated in 2010 that $265 million would be needed to repair damaged roads in the Marcellus Shale region.

- The need for vast amounts of water for fracking is helping to drive demand for new water infrastructure in arid regions of the country. Texas' official State Water Plan calls for the expenditure of $400 million on projects to support the mining sector over the next 50 years, with fracking projected to account for 42 percent of mining water use by 2020.
- The oil and gas industry has left thousands of orphaned wells from previous fossil fuel booms. Taxpayers may wind up on the hook for the considerable expense of plugging and reclaiming orphaned wells—Cabot Oil & Gas claims to have spent $730,000 per well to cap three shale gas wells in Pennsylvania.
- Fracking brings with it increased demands for public services. A 2011 survey of eight Pennsylvania counties found that 911 calls had increased in seven of them, with the number of calls increasing in one county by 49 percent over three years.

**Broader economic impacts** – Fracking can undercut the long-term economic prospects of areas where it takes place. A 2008 study found that Western counties that have relied on fossil fuel extraction are doing worse economically compared with peer communities and are less well-prepared for growth in the future.

- Fracking can affect the value of nearby homes. A 2010 study in Texas concluded that houses valued at more than $250,000 and within 1,000 feet of a well site saw their values decrease by 3 to 14 percent.
- Fracking has several negative impacts on farms, including the loss of livestock due to exposure to spills of fracking wastewater, increased difficulty in obtaining water supplies for farming, and potential conflicts with organic agriculture. In Pennsylvania, the five counties with the heaviest Marcellus Shale drilling activity saw an 18.5 percent reduction in milk production between 2007 and 2010.

**As with previous fossil fuel booms that left long-term impacts on the environment, there is every reason to believe that the public will be stuck with the bill for many of the impacts of fracking.**

## Defining "Fracking"

In this report, when we refer to the impacts of "fracking," we include impacts resulting from all of the activities needed to bring a well into production using hydraulic fracturing, to operate that well, and to deliver the gas or oil produced from that well to market. The oil and gas industry often uses a more restrictive definition of "fracking" that includes only the actual moment in the extraction process when rock is fractured—a definition that obscures the broad changes to environmental, health and community conditions that result from the use of fracking in oil and gas extraction.

- Existing legal rules are inadequate to protect the public from the costs imposed by fracking. Current bonding requirements fail to assure that sufficient funds will be available for the proper closure and reclamation of well sites, and do nothing at all to ensure that money is available to fix other environmental problems or compensate victims. Further, weak bonding requirements fail to provide an adequate incentive for drillers to take steps to prevent pollution before it occurs.

- Current law also does little to protect against impacts that emerge over a long period of time, have diffuse impacts over a wide area, or affect health in ways that are difficult to prove with the high standard of certainty required in legal proceedings.

**The environmental, health and community impacts of fracking are severe and unacceptable. Yet the dirty drilling practice continues at thousands of sites across the nation.** Wherever fracking does occur, local, state and federal governments should at least:

- **Comprehensively restrict and regulate** fracking to reduce its environmental, health and community impacts as much as possible.

- Ensure **up-front financial accountability** by requiring oil and gas companies to post dramatically higher bonds that reflect the true costs of fracking.

022348

12-17-13

To IDNR,

Comments on new Proposed Rules:

- Let's not fix what isn't broken

- There's no impiracle or anecdotal evidence to require more rules. (Just perceived fear) vs. (science and fact)

- Boils down to the fundamental right of:
  - property
  - free contract between parties.

Let's let science prevail
and Feedom Ring

Thank you,
Sherry Procarione

022349

# Illinois Public Health Association

*223 South Third Street, Springfield, IL 62701-1144*
® *Phone: 217-522-5687 FAX: 217-522-5689 E-mail: ipha@ipha.com Web Site: www.ipha.com*

**Comments on the Illinois Department of Natural Resources proposed rule to implement the Hydraulic Fracturing and Regulatory Act (225 ILCS 732).**

Local health departments in Illinois are responsible for protecting the cleanliness of ground water and potable water supplies and regulating the construction of wells for potable water. In order to ensure that local health departments can perform these functions in coordination with hydraulic fracturing operations, the Illinois Public Health Association recommends that the Department of Natural Resources amend its proposed rule. Local health departments are the first agency of local government contacted by the general public regarding possible pollution of drinking water.

The Association's comments follow three themes:

1) Local health departments should be notified of and have access to registrations, permit applications, testing reports, compositions of fluids and violations of the Act or the rule. All of the documents received by the Department or issued by the Department pertaining to the operation of any well for horizontal hydraulic fracturing should be posted on the Department's web site that can be easily searched by county

2) A permit fee should also be paid to each certified local health departments with jurisdiction for an area that will be affected by a hydraulic fracturing procedure;

3) Water should be tested every 30 days to detect pollution before it rises to the level of posing a threat to public health.

**Notification**

The local health department(s) with jurisdiction for the areas affected by a well-constructed horizontal hydraulic fracturing should have access to all of the documents pertaining to the construction, operation and closure of each well. This can be accomplished by expeditious posting all of these documents on the Department's web site in a database that can be searched by county. The list of documents includes:

- Registration for a permit (Section 245.200)

- All public comments and responses (245.260)
- The permit decision (245.300), the permit, including any permit conditions (245.320), or permit denial (245.310)
- Permit modifications (245.330)
- Permit transfers (245.340)
- Permit releases (245.350)
- The results of testing to Establish Internal Mechanical Integrity (245.540)
- The results from Testing of Blowout Prevention Equipment (245.550)
- The location and depths of any hydrocarbon-bearing zones or fresh water zones that are open to the wellbore above the casing shoe (245.560(c))
- The results from testing the internal mechanical integrity of the production casing (245.570(j))
- The results from formation integrity testing (245.580(d))
- The results of baseline and follow-up water quality testing (245.600)
- Water Pollution Investigations (245.610)
- An unredacted copy of the chemicals used by the permittee for horizontal hydraulic fracturing (245.720), to be held in confidence (not disclosed to the public prior to or during an investigation) and used only in the investigation and control of disease outbreaks that may be related to the horizontal hydraulic fracturing operation
- The results from testing the hydraulic fracturing string (245.805)
- The results of Surface Equipment Pressure Testing (245.810)
- Approval to Commence High Volume Horizontal Hydraulic Fracturing Operations (245.815)
- The results of secondary containment inspections (245.820)
- The results of Mechanical Integrity Monitoring (245.835), including suspension and resumption of operations
- Completion of Horizontal Hydraulic Fracturing operations and progress in site remediation (245.850 and 245.1200)
- Spills (245.855)
- Annual Flaring Reports (245.930)
- Produced water reports (245.940(f))
- Confirmation that abandoned wells have been plugged (245.1010(d)) and leakage from abandoned wells, unpermitted wells or previously plugged wells (245.1010(e))
- Notices of Violation (245.1110), records of the Director's Decisions (245.1120),

  In addition, the local health department should directly receive in writing (printed form):
- Notification that a permit application has been filed (Section 245.240) (Add the administrator of each local health department with jurisdiction over land affected by the operation to the list of required notifications in this section. This notification should be provided within five days of the Department's receipt of a permit application.)

- A copy of the Scaled Plat Maps, Diagrams or Cross-sections (245.210(a)(7)), Chemical Disclosure Report (245.210(a)(8)), Water Source Management Plan (245.210(a)(10)), the Well Site Safety Plan (Section 245.250(a)(1)(3)) and the Water Quality Monitoring Work Plan (245.600) should be provided by the applicant to the administrator of the local health department within 15 days of filing the permit application with the Department.
- The local health department should have access to all operational records maintained by the permitee for operation of each well.

Finally, the local health department administrator should be directly and immediately informed of any reported pollution or diminution of a water source (245.610), a spill (245.855), leakage from an abandoned, unpermitted or previously plugged well (245.1010(e)), or spill of produced water (245.940).

**Permit fees**

Local health departments will perform additional work to coordinate the protection of wells for drinking water with hydraulic fracturing activities and will have additional work to perform in the event of a spill or pollution of a potable water source. Therefore, in addition to fees paid to the Department by the applicant, the local health departments should also receive a non-refundable $5,000 fee from the applicant for filing a permit (245.210(d)) or a significant modification (245.330(d)), and a non-refundable $1,000 fee for insignificant modifications (245.330(3)) or transfers (245.340(c)).

**Routine Water Testing**

The proposed rule appropriately requires baseline (245.600(b)) and follow-up testing after the conclusion of hydraulic fracturing operations (245.600(c)), but it does not provide for routine testing of water sources within 1,500 feet of the well site. In order to promptly and proactively detect any threat to the public's health during hydraulic fracturing operations, the permitee should be required to test water sources within 1,500 feet of the well site every 30 days during hydraulic fracturing operations.

Amy Allen
2400 Parkview Drive
Springfield, IL, 62704

I have lived in Illinois all my life, and am concerned about protecting its precious land, water, and air, from Starved Rock State Park to Shawnee National Forest, and all the acres of farmland in between. For this reason, I am very concerned about the draft rules released by IDNR to enforce the recent regulation of hydraulic fracturing. The draft rules released by IDNR on fracking have some serious shortcomings and fail to enforce the protections in the law, especially in regards to water pollution, applicability, and public notice.

The rules do not impose an appropriate deadline on how long flowback material can be stored above ground in emergencies. The law states that this material can be stored above ground for only 7 days after injection. The rules say only that the material can be stored above ground for 7 days after the end of production, without defining when production "ends." The rules should be amended to impose the "7 days after injection" deadline given in the law.

The law states that the burden of proof in cases of contamination is on the producer, and provides a list of over 100 known water-polluting chemicals. In the rules, this list is replaced with a smaller set of "indicator chemicals," excluding some known to be found in fracking fluids. The rules should refer to the same set of chemicals as the law itself.

The law states that it applies retro-actively to existing fracked wells, which the rules do not. Also, the rules define "high volume hydraulic fracturing" in terms of gallons of fluid used, without providing an equivalency to foams which are sometimes used in fracking. The rules need to clearly define applicability to forms of fracking that use foams and gases in base fluids, and clearly state their retro-active applicability.

The penalties imposed by the rules amount to a slap on the wrist. Penalties must be set high enough that they are a deterrent to non-compliance, and not merely a cost of doing business. Also, the law states that trade-secret protected information must be disclosed to health workers when necessary, in both emergency and non-emergency situations. The rules give IDNR discretion over when to share this information, and give health workers the options only of "contacting the trade-secret holders" or "contacting IDNR during business hours." This is not adequate to provide important information in an emergency, which could occur at any time, day or night.

The law requires "significant modifications" to a permit to undergo public review processes—notices, comment, and public hearings. The rules narrow the type of modifications that require public processes—allowing permit holders to skirt public notification. The rules should be amended so that they reflect the law itself.

DNR should correct these shortcomings in the final version of the rule. I also strongly urge DNR to extend the comment period beyond the minimum 45 days and hold more public hearings to allow more people to take part in the process. Given the holidays, 622353

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022354

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Sec. 1-120 of the statute requires operators to comply with local laws, yet your proposed regulation does nothing to implement that requirement, except to require consent from municipalities involved. Illinois has many other local jurisdictions with ordinances and regulations. Counties, such as McLean, may have zoning ordinances requiring operators to obtain a special use permit before drilling. Townships may have weight limits for vehicles on their roads. If you do not require applicants to make sure their plans are in compliance with local laws before they receive permits, you are setting them and local communities up for disaster, endless conflict, terrible community relationships, and expensive litigation. That may be good for lawyers but bad for everyone else.

You should have a rule requiring applicants to meet with all local jurisdictions involved, not just those where the vertical drilling is proposed, but also all of those above proposed horizontal drilling and all of those whose roads would be used by the operators to move heavy machinery. Applicants should be required to produce certifications from all relevant local jurisdictions that they have fully disclosed their plans and appear to be in compliance with local law.

Jack Porter
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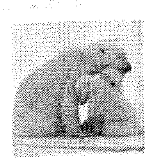

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Illinois Department of Natural Resources
Comments on Proposed Rules – Public Hearing, December 17, 2013

Illinois Register, Volume 37, Issue 46, November 15, 2013, p. 18097

My main concern with the proposed rules concerns the amount of fines that can be levied for harm to persons or the environment as a result of hydraulic fracturing. The proposed rules define the maximum fine for operating violations in Section 245.1120 (c)(2) as: "Five or more previous violations of the same rule: **$2,500**".

Let's compare this provision of the proposed rules to how companies have been fined for fracking violations elsewhere.

- A southern California oil company was fined $60,000 after being caught on camera illegally dumping a toxic discharge produced by hydraulic fracturing. The company, Vintage Productions of Kern County, agreed to pay the fee after they were caught on film by an area farmer dumping a black liquid discharge into an unlined, open pit on the well site in Shafter, CA. November 2013 (rt.com)

- An ExxonMobil subsidiary was fined $100,000 and was ordered to spend $20 million to improve its hydraulic fracturing wastewater management system in the wake of a 2010 leak that contaminated a tributary of the Susquehanna River. July, 2013 (ecowatch.com)

- A company whose oil well north of Windsor, Colorado, sprayed out 84,000 gallons of hydraulic fracturing flowback water volunteered to pay a larger fine. The Colorado Oil and Gas Conservation Commission (COGCC) could have fined PDC Energy around $9,000, but company officials said it was the "appropriate thing to do" to go beyond that, so they will pay a $35,000 fine instead. June, 2013 (isssource.com)

- Natural gas production company Chesapeake Appalachia LLC has been fined a total of $565,000 in civil penalties and reimbursement costs by the state of Pennsylvania for an April 2011 fracking well control incident, for erosion and sediment control violations and for wetland encroachment violations. February 2012 (ens-newswire.com)

- The Pennsylvania Department of Environmental Protection fined Talisman Energy USA Inc. of Horseheads $15,506 for a spill of used natural gas drilling fluids last November at its Klein gas well pad in Armenia Township, Bradford County, that polluted a small, unnamed waterway. November 2009 (pressconnects.com)

And in other countries, the previously cited fines seem small.

- The New Brunswick, Canada, government is proposing 116 different changes to the regulatory framework that oversees the oil and gas industry and in particular the controversial process of hydraulic fracturing. The provincial government is going to hike those penalties as high as $1 million. May, 2012 (cbc.ca)

- Companies engaged in any potential fracking for shale gas in Ireland will face fines of up to €3million if they break safety rules, the energy regulator has announced. Anyone involved in breaching the regulations could also face a jail sentence of up to three years. (thejournal.ie)

Companies engaged in hydraulic fracturing have made and stand to make millions of dollars to continue the process anywhere they determine a profit is imminent. I note that PDC Energy operating in Colorado *volunteered* to pay a higher fine than would have been levied. These companies, in many cases, consider fines a cost of doing business. They simply pay their fines and continue to violate rules and regulations like those proposed here. It seems to me that fines for endangering our citizens and our environment should be much higher, even for so-called administrative violations, but definitely for operating violations.

Thank you for considering an increase of the fines for operating violations in these proposed rules.

Linda R. Green

Linda R. Green
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Morrisonville, IL 62546

Email: lgreen@consolidated.net

Here are a list of my concerns with fracking in general and with the drafted regulations of the IDNR.

Where will all the water come from?

Transporting all this toxic water will put a strain on our infrastructure. Who will pay for the repairs to our roads and bridges?

Who will pay for monitoring wells sites and holding tanks for leakage?

What if there is a spill of this toxic water, can it really be cleaned up safely?

What good are the strict regulations if only a slap on the wrist is given for violations? In Pennsylvania there have been thousands of violations to the state's regulations since 2008. Any judgment they pay is literally a drop in the bucket to them, much cheaper than following safety standards.

Why in your draft do you have discretion over when to share the information about all the chemicals that are used?

Why does your draft limit the industry's burden of proof concerning water pollution?

Why does your draft allow wastewater to sit in open pits for longer than a week?

What happens if there is more flow back water than the pits can handle?

Wastewater will flow back up for years, which has to be disposed of. Who will be responsible for this?

In 2013 New York put a moratorium on fracking. In 2012 North Carolina extended it's ban. Vermont banned it. NewJesey has a one year ban on fracking. What do they know that we don't know ?

We don't want Southern Illinois to be another Superfund site.

Can anyone really know what the long term environmental and health consequences will be?

Do we really want to risk our health and pollute the land in exchange for a few jobs ? Oh, and not to mention the Politian's that will get reelected because they brought prosperity to the area.

Thank you for giving me this opportunity to voice my opinions.

Pat Hite

1605 W Grand Ave

Carterville, IL 62918

Patti Walker Represent Karbers Ridge IL
VOC section 1-53 Allows exemption sec 245.960e & sec 245.845.c
I wanted to share important recent news

① 245.270a3e
forced to present concerns in context of the rules
NOT enough knowledge to make regulations so soon

U. of Missouri just published a
Combined 2 seperate Studies

(A.) author identified 12 chemical additive commonly used in fracking
11 are endocrine disrupters and have been found to cause significant increase in cancers & liver desease etc.

(B.) authors ~~test~~ 2 Colorado Counties as well as the Colorado River
1. fracked & 2. unfracked
1. heavily contaminated with 11 chem additives
2. no contamination ~~of~~
Colorado River was ~~moderately contaminated~~

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Study only covers additives
Larger problem is chemicals brought up from shale during the fracking process
VOC, heavy metals, methane, and radium

2. Scary studies: DNA not the only thing passed from parent to child
but a paradigm shift is occuring in biology and is quite credible with unrefuted experiment
1 particular mechanism is that some type of chem. call methylates can attach to eggs + sperm
Has been proven in experiments that they attach for multiple generations down to at least great grandchild level
endocrine ~~interrupters~~ disrupters block certain gene expression ~~in~~ ways harmful passing health damage from one generation to ~~the~~ next

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Korfgers Ridge Patti Walker Page A

Endocrine Disruptors – Toxic Effects Inherited Without DNA Mutations – Through Methyllates Attached to Germ Cells

Michael Skinner's biggest discovery began, as often happens in science stories like this one, with a brilliant failure. Back in 2005, when he was still a traditional developmental biologist and the accolades and attacks were still in the future, a distraught research fellow went to his office to apologize for taking an experiment one step too far. In his laboratories at Washington State University, she and Skinner had exposed pregnant rats to an endocrine disruptor—a chemical known to interfere with fetal development—in the hope of disturbing (and thereby gaining more insight into) the process by which an unborn fetus becomes either male or female. But the chemical they used, an agricultural fungicide called vinclozolin, had not affected sexual differentiation after all. The scientists did find lower sperm counts and decreased fertility when the male offspring reached adulthood, but that was no surprise. The study seemed like a bust.

By accident, though, Skinner's colleague had bred the *grandchildren* of those exposed rats, creating a fourth generation, or the great-grandchildren of the original subjects. "It's OK," Skinner told her. "You might as well analyze them." If nothing else, he thought, the exercise might take her mind off her mistake. So she went ahead and studied the rats' testes under a microscope.

What they found would not only change the direction of Skinner's research but also challenge a bedrock principle of modern biology. And Skinner would become the forerunner of a new way of thinking about the possible long-term health consequences of exposure to environmental chemicals.

His discoveries touch on the basic question of how biological instructions are transmitted from one generation to the next. For half a century it has been common knowledge that the genetic material DNA controls this process; the "letters" in the DNA strand spell out messages that are passed from parent to offspring and so on. The messages come in the form of genes, the molecular equivalent of sentences, but they are not permanent. A change in a letter, a result of a random mutation, for example, can alter a gene's message. The altered message can then be transmitted instead.

The strange thing about Skinner's lab rats was that three generations after the pregnant mothers were exposed to the fungicide, the animals had abnormally low sperm counts—*but not because of a change in their inherited DNA sequence*. Puzzled, Skinner and his team repeated the experiments—once, twice, 15 times—and found the same sperm defects. So they bred more rats, and tested more chemicals, including substances that lead to diseases in the prostate, kidney, ovaries and immune system. Again and again, these diseases also showed up in the fourth- and fifth-generation offspring of mothers exposed to a chemical.

"In essence," Skinner explains, "what your great-grandmother was exposed to could cause disease in you and your grandchildren."

And, startlingly, whatever disease pathway a chemical was opening in the rats' fur-covered bodies, it did not begin or end at a mutation in the genetic code. Skinner and his team found instead that as the toxins flooded in, they altered the pattern of simple molecules called methyl groups that latch onto DNA in the fetus' germ-line cells, which would eventually become its eggs or sperm. Like burrs

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stuck to a knit sweater, these methyl molecules interfered with the functioning of the DNA and rode it down through future generations, opening each new one to the same diseases. These burrs, known to be involved in development, persisted for generations. The phenomenon was so unexpected that it has given rise to a new field, with Skinner an acknowledged leader, named transgenerational epigenetics, or the study of inherited changes that can't be explained by traditional genetics.

A study by Skinner and colleagues published last year in the journal *PLOS One* has upped the ante considerably. The burrs were not just haphazardly attached, Skinner found. Instead, they fastened themselves in particular arrangements. When he bathed the insides of his pregnant rats in bug spray, jet fuel and BPA, the plastics component recently banned from baby bottles, each exposure left a distinct pattern of methyl group attachments that persisted in the great-grandchildren of exposed rats.

Not only is your great-grandmother's environment affecting your health, Skinner concluded, but the chemicals she was exposed to may have left a fingerprint that scientists can actually trace.

The findings point to potentially new medical diagnostics. In the future, you may even go to your doctor's office to have your methylation patterns screened. Exposure of lab rats to the chemical DDT can lead to obesity in subsequent generations—a link Skinner's team reported in October. Hypothetically, a doctor might someday look at your methylation patterns early in life to determine your risk for obesity later. What's more, toxicologists may need to reconsider how they study chemical exposures, especially those occurring during pregnancy. The work raises implications for monitoring the environment, for determining the safety of certain chemicals, perhaps even for establishing liability in legal cases involving health risks of chemical exposure.

These possibilities have not been lost on regulators, industries, scientists and others who have a stake in such matters. "There are two forces working against me," Skinner says. "On one side, you have moneyed interests refusing to accept data that might force stronger regulations of their most profitable chemicals. On the other side, you have genetic determinists clinging to an old paradigm."

***

Michael Skinner wears a gray Stetson with a tan strap, and leans back easily in his chair in his office on the Pullman campus. His fly-fishing rod stands in the corner, and a colossal northern pike is mounted on the wall. An avid fly fisherman, Skinner, age 57, was born and raised on the Umatilla Indian Reservation in eastern Oregon. The Skinners are not of Indian descent, but his parents owned a family farm there—"a good cultural experience," he says. His father worked in insurance, and he and his four brothers grew up just as five generations of Skinners had before them—hunting and fishing and cowboying, learning a way of life that would sustain them into adulthood.

He loved the outdoors, and his fascination with how nature worked prompted a school guidance counselor's suggestion that a career in science might be just the thing. He was about 12, and true to form he stuck with it. In high school and then at Reed College he wrestled competitively, and today his supporters and critics alike may detect a bit of his old grappling self in how he approaches a problem—head-on. "It probably taught me how to confront, rather than avoid challenges," he says now. The sport also led him to his future wife, Roberta McMaster, or Bobbie, who served as his high-school wrestling team's scorekeeper. "I was fascinated that someone so young knew exactly

Path Walter Page C

what he wanted to do with his life," Bobbie recalls. He proposed marriage before heading for college, and the two have been together ever since and have two grown children.

He attended Washington State University for his PhD in biochemistry, and during that time he and Bobbie often lived on game that he'd hunted. It was not unheard of to find a freshly killed deer hanging in the carport of their student housing. "They were lean years," Bobbie says. "But they were good ones."

After positions at Vanderbilt and the University of California, San Francisco, Skinner returned to Washington State University. "I wanted a big research college in a rural town," he says. He spent the next decade studying how genes turn on and off in ovaries and testes, and how those organs' cells interact. He wasn't aiming to take on the central idea in biology for much of the 20th century: genetic determinism, the belief that DNA is the sole blueprint for traits from hair and eye color to athletic ability, personality type and disease risk.

In some sense this interpretation of genetic determinism was always oversimplified. Scientists have long understood that environments shape us in mysterious ways, that nature and nurture are not opposing forces so much as collaborators in the great art of human-making. The environment, for example, can ramp up and pull back on gene activity through methyl groups, as well as a host of other molecules that modify and mark up a person's full complement of DNA, called the genome. But only changes in the DNA sequence itself were normally passed to offspring.

So certain was everyone of this basic principle that President Bill Clinton praised the effort to complete the first full reading of the human genome, saying in June 2000 that this achievement would "revolutionize the diagnosis, prevention and treatment of most, if not all human diseases." When stacked against such enthusiasm, Skinner's findings have felt like heresy. And for a while, at least, he was criticized accordingly.

***

Critics of the Skinner-led research pointed out that the doses of vinclozolin in his rat studies were way too high to be relevant to human exposure, and injecting the rats as opposed to administering the toxins through their food exaggerated the effects. "What he's doing doesn't have any real obvious implications for the risk assessments on the chemical," EPA toxicologist L. Earl Gray was quoted telling *Pacific Standard* magazine back in 2009. Until the results are replicated, "I'm not sure they even demonstrate basic science principles."

Skinner responds to assaults on his data by saying that risk assessment, of the type that toxicologists do, has not been his goal. Rather, he's interested in uncovering new biological mechanisms that control growth, development and inheritance. "My approach is basically to hit it with a hammer and see what kind of response we get," he says. He remains calm, even when called on to defend that approach. "Conflicts with individuals solve very little," he says. "The best way to handle these things is to let the science speak for itself."

That science has received a lot of attention (the vinclozolin study has been cited in the scientific literature more than 800 times). Recently, the journal *Nature Reviews Genetics* asked five leading researchers to share their views on the importance of epigenetic inheritance. A "mixture of

Faith Walk
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excitement and caution," is how the editors described the responses, with one researcher arguing that the phenomenon was "the best candidate" for explaining at least some transgenerational effects, and another noting that it might, if fully documented, have "profound implications for how we consider inheritance, for mechanisms underlying diseases and for phenotypes that are regulated by gene-environment interactions."

Though most of Skinner's critics have been reassured by new data from his lab and others, he says he still feels embattled. "I really try to be a scientist first and foremost," he says. "I'm not a toxicologist, or even an environmentalist. I didn't come to this as an advocate for or against any particular chemical or policy. I found something in the data, and I pursued it along a logical path, the way any basic researcher would."

Patti Walker
Korbers R.dg
# page 1

# Fearful Memories Passed Down to Mouse Descendants

Genetic imprint from traumatic experiences carries through at least two generations

By Ewen Callaway and Nature magazine
First published on Dec 1, 2013

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From *Nature* magazine

Pin it

Certain fears can be inherited through the generations, a provocative study of mice reports. The authors suggest that a similar phenomenon could influence anxiety and addiction in humans. But some researchers are sceptical of the findings because a biological mechanism that explains the phenomenon has not been identified.

According to convention, the genetic sequences contained in DNA are the only way to transmit biological information across generations. Random DNA mutations, when beneficial, enable organisms to adapt to changing conditions, but this process typically occurs slowly over many generations.

Yet some studies have hinted that environmental factors can influence biology more rapidly through 'epigenetic' modifications, which alter the expression of genes, but not their actual nucleotide sequence. For instance, children who were conceived during a harsh wartime famine in the Netherlands in the 1940s are at increased risk of diabetes, heart disease and other conditions — possibly because of epigenetic alterations to genes involved in these diseases. Yet although epigenetic modifications are known to be important for processes such as development and the inactivation of one copy of the X-chromsome in females, their role in the inheritance of behaviour is still controversial.

Kerry Ressler, a neurobiologist and psychiatrist at Emory University in Atlanta, Georgia, and a co-author of the latest study, became interested in epigenetic inheritance after working with poor people living in inner cities, where cycles of drug addiction, neuropsychiatric illness and other problems often seem to recur in parents and their children. "There are a lot of anecdotes to suggest that there's intergenerational transfer of risk, and that it's hard to break that cycle," he says.

**Heritable traits**

Studying the biological basis for those effects in humans would be difficult. So Ressler and his colleague Brian Dias opted to study epigenetic inheritance in laboratory mice trained to fear the smell of acetophenone, a chemical the scent of which has been compared to those of cherries and almonds. He and Dias wafted the scent around a small chamber, while giving small electric shocks to male mice. The animals eventually learned to associate the scent with pain, shuddering in the presence of acetophenone even without a shock.

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page #2

This reaction was passed on to their pups, Dias and Ressler report today in *Nature Neuroscience*1. Despite never having encountered acetophenone in their lives, the offspring exhibited increased sensitivity when introduced to its smell, shuddering more markedly in its presence compared with the descendants of mice that had been conditioned to be startled by a different smell or that had gone through no such conditioning. A third generation of mice — the 'grandchildren' — also inherited this reaction, as did mice conceived through *in vitro* fertilization with sperm from males sensitized to acetophenone. Similar experiments showed that the response can also be transmitted down from the mother.

These responses were paired with changes to the brain structures that process odours. The mice sensitized to acetophenone, as well as their descendants, had more neurons that produce a receptor protein known to detect the odour compared with control mice and their progeny. Structures that receive signals from the acetophenone-detecting neurons and send smell signals to other parts of the brain (such as those involved in processing fear) were also bigger.

The researchers propose that DNA methylation — a reversible chemical modification to DNA that typically blocks transcription of a gene without altering its sequence — explains the inherited effect. In the fearful mice, the acetophenone-sensing gene of sperm cells had fewer methylation marks, which could have led to greater expression of the odorant-receptor gene during development.

But how the association of smell with pain influences sperm remains a mystery. Ressler notes that sperm cells themselves express odorant receptor proteins, and that some odorants find their way into the bloodstream, offering a potential mechanism, as do small, blood-borne fragments of RNA known as microRNAs, that control gene expression.

**Contentious findings**

Predictably, the study has divided researchers. "The overwhelming response has been 'Wow! But how the hell is it happening?'" says Dias. David Sweatt, a neurobiologist at the University of Alabama at Birmingham who was not involved in the work, calls it "the most rigorous and convincing set of studies published to date demonstrating acquired transgenerational epigenetic effects in a laboratory model".

However, Timothy Bestor, a molecular biologist at Columbia University in New York who studies epigenetic modifications, is incredulous. DNA methylation is unlikely to influence the production of the protein that detects acetophenone, he says. Most genes known to be controlled by methylation have these modifications in a region called the promoter, which precedes the gene in the DNA sequence. But the acetophenone-detecting gene does not contain nucleotides in this region that can be methylated, Bestor says. "The claims they make are so extreme they kind of violate the principle that extraordinary claims require extraordinary proof," he adds.

Tracy Bale, a neuroscientist at the University of Pennsylvania in Philadelphia, says that researchers need to "determine the piece that links Dad's experience with specific signals capable of producing changes in epigenetic marks in the germ cell, and how these are maintained".

"It's pretty unnerving to think that our germ cells could be so plastic and dynamic in response to changes in the environment," she says.

Humans inherit epigenetic alterations that influence behaviour, too, Ressler suspects. A parent's anxiety, he speculates, could influence later generations through epigenetic modifications to receptors for stress hormones. But Ressler and Dias are not sure how to prove the case, and they plan to focus on lab animals for the time being.

The researchers now want to determine for how many generations the sensitivity to acetophenone lasts, and whether that response can be eliminated. Scepticism that the inheritance mechanism is real will likely persist, Ressler says, "until someone can really explain it in a molecular way", says Ressler. "Unfortunately, it's probably going to be complicated and it's probably going to take a while."

*This article is reprinted with permission from* Nature *magazine. It was first published on December 1, 2013.*

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Korbers Ridge Patti Walker #4

DOCTORS recommend that women who are pregnant, or plan to be, eat plenty of green, leafy vegetables. These are a source of vitamin B9—or folate, as it is also known—a substance that helps embryos develop by encouraging the formation of the neural tube, the precursor to the brain and the spinal cord. Folate has never been recommend to putative fathers, though, for the obvious reason that, sperm apart, a father contributes nothing to the physical substance of an embryo.

If the results of research on mice, by Sarah Kimmins and her colleagues at McGill University, in Montreal, are found to apply to people too, that may need to change. For, as they report in *Nature Communications*, they have discovered something odd: that folate deficiency in fathers can, in rodents at least, be as debilitating for embryos as deficiency in mothers. An absence of folate when sperm are forming causes alterations in them that affect the mice which grow from the eggs those sperm fertilise. In particular, Dr Kimmins saw serious deformities of head, spine and limbs.

This damage seems to be caused by epigenetic modification, the subject of a rapidly emerging field of research. Such modification involves a process called methylation, which alters the behaviour of genes in a way that can be passed from one generation to another. Folate's job is to regulate methylation. How epigenetic modification might cause the defects Dr Kimmins saw, she does not yet know. But when she and her team looked at changes in the methylation patterns of genes in the sperm of folate-deficient rats they found things there that might cause other phenomena, which are not apparent at birth. These include cancer, diabetes, and even autism and schizophrenia.

Marked for death

Dr Kimmins and her team raised male mice that had had a low exposure to folate for the whole of their lives, from conception onwards. In other words, not only they, but also their mothers were fed this diet. Once born, these males were otherwise treated normally, and when mature were introduced to females and allowed to mate. The researchers then followed what happened.

Their first observation was that the folate-deficient males were less fertile than otherwise-comparable control animals. Only 52% of the females they were mated with became pregnant, compared with 85% of those mated with controls. And even among those females that did become pregnant, twice as many pregnancies ended with the fetuses being reabsorbed by the mothers if the father was folate deficient.

Then, when the pups were born, those fathered by the deficient males were much more likely to be deformed. Some 27% of such litters included pups with visible abnormalities, compared with 3% of litters fathered by controls. These abnormalities included hydrocephalus ("water on the brain"), deformed spines and limbs with missing toes.

When they compared the DNA of sperm from folate-deficient males with that from the sperm of males which had had a normal diet, the researchers found 57 places whose methylation patterns differed. These included the sites of 18 genes known in humans to be involved in cancer, six that are involved in various forms of diabetes and seven that have been implicated in autism or schizophrenia.

Patty Walker #5

Whether these abnormal methylation patterns are actually carried into the body cells of animals sired by such sperm, the researchers have not yet found out. Nor is it clear what the effects would be if they were, or whether such effects would be found in people as well as mice.

The researchers note, however, that the causes of more than 40% of birth defects in children in the rich world remain unknown. They also note that the number of people with diabetes in America alone has risen from 6m in 1985 to more than 20m now. Many cancer rates are rising too, and research is throwing up examples of tumours caused by epigenetic modifications of unknown origin. All this suggests it is worth investigating the idea that epigenetically modified sperm may be a previously unrecognised source of disease.

The other point worth noting is that, although some epigenetic modification takes place when sperm cells form (shortly before they are ejaculated), much of it happens early in embryonic development, when the progenitors of those cells come into being. At this point it is the diet of the mother carrying the embryo which matters. How much good it will really do men to change what they eat to improve their sperm is thus moot. It may be that the damage is actually caused before they have any say in the matter.

**PUBLIC HEARING SCHEDULE**

**Tuesday, November 26, 2013**
6:30pm-8:30pm (Doors open at 5:30pm)
University of Illinois at Chicago (UIC)
726 S. Halsted Street, Student Center East, Room 302
Chicago, IL 60607

**Tuesday, December 3, 2013**
6:30pm-8:30pm (Doors open at 5:30pm)
Rend Lake College Theater
468 North Ken Gray Parkway
Ina, IL 62846

**Thursday, December 5, 2013**
6:30pm-8:30pm (Doors open at 5:30pm)
Holiday Inn Effingham, Hotel Ballroom
1301 Avenue of MidAmerica
Effingham, IL 62401

**Tuesday, December 17, 2013**
6:30pm-8:30pm (Doors open at 5:30pm)
Decatur Civic Center, Auditorium
#1 Gary K. Anderson Plaza
Decatur, IL 62523

**Thursday, December 19, 2013**
6:00pm-8:00pm (Doors open at 5:00pm)
Southern Illinois University at Carbondale (SIUC)
Student Center, Ballroom B
1255 Lincoln Drive
Carbondale, IL 62901

Indirect

1loss of Crops, wildlife, ect.

loss of lick Creek, organic, this region will no longer look the way it is

Water- (~~Frack openings~~)
just google the images of destruction + tore down forest.

1. Ingreants
- List type
- List what it is.

When this area is destroyed what will happen to the Campus economy?

2. Open pits
- allow for animals + such
- To ~~eat~~ drink.
- water seeps into the ground to the

3. Dangers ~~of the~~ Shawnee

Lastly, I want to say you can make changes, you can make it hard if Fracking is comming, ~~its comming~~ make it tough as shit and safe. ~~Be~~

What it means to me.

Recycling - You cant treat $H_2O$ that is destroy. It is impossible, we have trouble cleaning of Oil Spills, how the hell are we going to make $H_2O$ safe.

Likeh Creek.

(1) Chemical disclosure.

no regulations to list ingredients, big oil wants them protected because of "trade secret", how ever this is a loose interpretation of trade secret, as it is not protected by current US or international law. They claim this protects "other" big oil to not use their techniques, but how many ways are their to frack: like FDA you should requir the list of ingredients. They should not be disclosed.
- local doctors to treat patients

022370

Respectfully Submitted by:
Sherry Sullivan, Ph.D.
Goreville, IL



Dec. 19, 2013

Earthquakes Section 240.796 Seismicity

The New Madrid seismic zone which is situated in this area of the United States has the potential to produce large earthquakes in the future. The New Madrid zone has had four of the largest North American earthquakes in recorded history, with magnitudes estimated to be as large as 8.0.

Earthquakes occur in the NMZ on a daily basis. In fact over 9,000 earthquakes have been recorded in the NMZ in the last 30 years!

Then, we have the Wabash Valley Seismic zone fault system that extends into Gallatin and White County, Illinois. Researchers state that at least light earthquakes with estimated magnitudes of 6.5 to 7.5 have occured in this seismic zone.

Question:

(1) How do the proposed administrative rules deal with the immense damage and danger to public health and safety that could occur as a result of earthquakes in the proposed fracking regions of Illinois?

Radioactivity - Section 245-850

Another related item that I have concerns about is the lack of attention in Section 245-850 of the proposed rules for testing of fracking fluids one time - during the early flowback stage - and only for "naturally occurring radioactive materials."

Question:

(1) How can the limited radioactivity testing requirement in this section adequately protect Illinois residents from the spread of dangerous *radioactive* materials into our environment, for example in

the case of an earthquake in the fracking area?

The statute and the proposed rules call for testing of flowback (and not produced water) for "naturally occuring radioactive materials." The term "naturally occuring" is not defined in the law or the proposed rules.

Question:

(1) How will IDNR interpret "naturally occuring?" Will testing only be required for specific radioactive materials that are expected to be found naturally in the subsurface at the well site?

(2) Depleted uranium would not be "naturally occuring" at the well site, so will it be detected by the proposed testing? I think the answer is no.

Depleted uranium is a highly dangerous radioactive material with a half-life of 4.5 billion years. We know that some Operators in the fracking industry have incorporated Depleted Uranium into their perforating gun assembly (for use in a Wellbore) in horizontal fracking (U.S. Patent No. 2011000069).

Questions:

① Would this radioactive material (Depleted Uranium) that would be "added" radioactive material, not "Naturally occuring" be detected by your one-time testing? So, is this one-time test of a well sufficient to guarantee public health and Safety? Again, the answer is no.

② Why will well sites only be tested one time during the flowback stage? Does this really account for any radioactive Contamination that may occur later in the fracking process as a result of natural disasters such as earthquakes or floods (to which this region is prone), or as a result of industrial accidents that may occur?

Well sites should require on-going testing and testing that includes all possible sources of radioactive contamination — both "naturally occuring" and those caused by the fracking process itself

Questions:

① Why not perform baseline tests for radioactive levels prior to and during the entire fracking process?

② Why not write the administrative rules so that if levels of radioactivy rise, a well site would be shut down immediately and permanently?

19 Dec 2013 Comment presented to IDNR by:

M J Smerken, Ph.D.
1936 Pine
Murphysboro, IL 62966

Subpart A: General Provisions
Section: "None"
Section 1-53: High volume horizontal hydraulic fracturing permit; determination; judicial review

Section 1-53 requires that fracking operations be conducted in a "manner that will protect the public health and safety and prevent pollution or diminution of any water source." And yet, the rules do not address the risk of large-scale and widespread environmental disasters that can occur as a result of fracking in the Wabash Valley and New Madrid Earthquake Zones or in the Illinois 100-year floodplain.

The New Madrid Earthquake zone has been known to historically cause "major" earthquakes of over 7 on the Richter magnitude scale. The Illinois Emergency Management Agency itself identifies these areas with its most severe earthquake zone ratings of "Destructive" and "Ruinous." An earthquake of these magnitudes, compounded with fracking and injection wells spread throughout the affected zone is quite literally, a recipe for disaster.

Furthermore earthquakes of these magnitudes can easily damage fracking wells, open air pits, pipelines, injection wells - causing toxic and radioactive fracking fluids to pour out into the ground and contaminate the soil and groundwater sources of hundreds of thousands of Illinoisans. Even Ohio Governor, John Kasich, a fracking advocate, has issued an executive order requiring operators to conduct seismic studies before the state will issue well permits.

Similarly, allowing any sort of fracking operations to occur within the Illinois 100 year floodplain zone is also asking for disaster. The environmental devastation caused by the recent floods in Colorado is a case in point. Inundated oil pads, flooded wells, overturned tanks, and ruptured lines were just a few of problems experienced in Colorado as a result of wide-scale flooding. A damaged oil tank dumped 5,250 gallons of oil into the South Platte River south of Milliken, Colorado on 9/18/13 during the flood. The South Platte River, extends to Nebraska and then filters into the Ogallala Aquifer which serves much of the middle of the country.

Open-air pits—which the Rules allow—are particularly vulnerable in a flood. When open-air pits fill with water, there is nothing covering the surface to prevent the fracking wastewater from spilling out of the pit and into the floodwaters, exposing every living thing downstream to the chemicals, brine, radioactivity, etc. that was in the pit.

The solution to these potential devastations is to avoid fracking in active seismic zones and flood plains. A ban on hydraulic fracturing in Illinois is the answer.

Thank you.

Public Hearing on Proposed Rules For Hydrofracturing in IL
Re: Subpart G: Chemical Disclosure; Trade Secrets (245.700-245.730)
Submitted by Frack Free Illinois,
drlora2@yahoo.com, 773-486-7660
www.facebook.com/FrackFreeIllinois

Fracking is a dangerous method of natural gas and oil extraction, which has been in the process of being rolled out by the IIDNR over this summer/fall, after a very insufficient regulatory bill passed the IL General Assembly in the spring, Public Act 098-0022 http://www.ilga.gov/legislation/publicacts/98/PDF/098-0022.pdf

We want to bring your attention to a problem that has been arising across America with fracking, and that is that the industry acts to keep the hundreds of chemicals that they are hosing down under people's land, possibly contaminating their water, releasing into their air, and trucking around their communities, a secret. We suspect that they want to keep them a secret because they want to limit their own liability. The most egregious aspect of this secrecy is that In many states across America the industry has persisted in keeping their exact chemical cocktails, which can differ per frack well, a secret from Physicians and Allied Health Professionals, endangering their patients.

Fracking is very dangerous and the jobs on the frack fields are 7 times more dangerous that any other jobs in America right now. In IL we anticipate blowouts, traffic accidents, chemical exposures of the frack field workers and possibly residents as well. We anticipate air pollution exposing residents to harmful VOCs, and chemical contamination of drinking water. And we suspect that there will be radioactive frack waste that exposes residents and workers to radioactivity.

The health effects of fracking have been poorly studied because the industry seems to work their connections in the Fed and State Governments to keep regulators from looking at these issues; *http://ecowatch.com/2013/fracking-pollution-sickens-residents-in-tx/*
Also many victims of fracking are being silenced by non-disclosure agreements when they win judgments against the oil and natural gas industry. But there have been smaller studies and scientific papers on the various health effects of the hundreds of chemicals used in the fracking process. There are many links in this letter to follow for information that will be useful to health practitioners around the frack fields, and to the IDNR.

At this one link, *http://endocrinedisruption.org/chemicals-in-natural-gas-operations/introduction* you will be able to find all of the articles and info listed below, published by TEDX, the Endocrine Disruption Exchange:
– *"What You Need To Know About Natural Gas Production"by Theo Colbom, Phd. of TEDX*
– *Drilling Chemicals*
– *Pit Chemicals*
– *A Health Effects Summary*
– *"Air Pollution and Natural Gas Operation", by scientists at TEDX, and published in Human and Ecological Risk Assessment, An International Journal in Nov, 2012,*
– *"Natural Gas Operations From a Public Health Perspective" by Theo Colborn, Phd and others: http://ourlongmont.org/wp-content/uploads/2012/10/Theo-*

*Colborn-Peer-Reviewed-Article-on-Public-Health-Perspective-on-Natural-Gas1.pdf*

Studies such as the one done by the Univ. of Colorado, *"Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources." March, 2012,* showed that people are getting sick approx. 1/2 mile from the wells and infrastructure, such as compressor stations, and depending on the wind direction even up to a mile away.
*http://www.ucdenver.edu/about/newsroom/newsreleases/Pages/health-impacts-of-fracking-emissions.aspx*
Below is a link to a major PA health study by the Southwest Pennsylvania Environmental Health Project, SWPA-EHP, *www.environmentalhealthproject.org*, not because they surveyed a lot of people, actually just a very few in 1 county in PA, but because they were able to exclude any other explanations for the health effects found, such as previous medical history, etc. The upshot is: water contamination causes some illnesses eventually, but air pollution around the drill rigs and compressor stations causes many symptoms immediately, especially if the patients live within a thousand feet from a compressor station. Benzene and other VOCs can accumulate in the air in homes close to this natural gas and oil infrastructure. *http://www.huffingtonpost.com/2013/08/25/pennsylvania-fracking-study_n_3813650.html?utm_hp_ref=green*

The link below is for a comprehensive page of health resources from, SWPA-EHP, their latest program is a series of CME Medical Training Workshops entitled *"Health Concerns in the Era of Gas Drilling: A Basic Toolkit for Healthcare Providers."*
*http://www.environmentalhealthproject.org/resources/medical-resources/*

We want to remind the IDNR that they have in the Hydraulic Fracturing Act, Public Act 098-0022, a broad mandate to protect the public health and the environment; **Section 1-83, Order authority.(d) The Department may issue conditions within any order to protect the public health or welfare or the environment.**

This summer we requested that the IDNR put the chemical disclosure of the fracking chemicals in the hands of the IDPH, which was expressly allowed in the Hydraulic Fracturing Act, (see below), but in the draft rules the IDNR has instead configured a situation where the ER Physicians and Nurses, when faced with an emergency situation, after hours or on weekends, will have to track down the fracking companies to get the full list of chemicals that their patient(s) may have be exposed to. This is unacceptable, the frack fields are operating 24/7, this is an undue hardship on Illinois Health Professionals, Emergency Personnel and their patients.

**Public Act 098-0022, Section 1-77 Chemical disclosure; trade secret protection.**
(m) In the event of a release of hydraulic fracturing fluid, a hydraulic fracturing additive, or hydraulic fracturing flowback, and when necessary to protect public health or the environment, the Department may disclose information furnished under a claim of trade secret to the relevant county public health director or emergency manager, the relevant fire department chief, the Director of the Illinois Department of Public Health, the Director of the Illinois Department of Agriculture, and the Director of the Illinois Environmental Protection Agency upon request by that individual.

**From the draft rules, 245.720 Department Publication of Chemical Disclosures and Claims of Trade Secret**

b) When an applicant, permittee, or person performing high volume horizontal hydraulic fracturing operations furnishes chemical disclosure information to the Department under Section 245.210, 245.700, 245.710 or 245.860 under a claim of trade secret, the applicant, permittee, or person performing high volume horizontal hydraulic fracturing operations shall submit redacted and un-redacted copies of the documents identifying the specific information on the master list of chemicals claimed to be protected as trade secret. The Department shall use the
redacted copies when posting the master list of chemicals on its website. (Section 1-77(f) of the Act)

d) Chemical disclosure information furnished under Section 245.210, 245.700,245.710 or 245.860 under a claim of trade secret shall be protected from disclosure as a trade secret if the Department determines that the statement of justification demonstrates that (Section 1-77(h) of the Act):

**From the draft rules, Section 245.730 Trade Secret Disclosure to Health Professional**

Information about high volume horizontal hydraulic fracturing treatment chemicals furnished under a claim of trade secret may be disclosed by the Department to a health professional for the limited purpose of determining what health care services are necessary for the treatment of an affected patient pursuant to the requirements of this Section.

a) A health professional shall complete and submit a request to obtain trade secret chemical information. In the request, the health professional shall:
1) state a need for the information and articulate why the information is needed;
b) In an emergency health care situation, a health professional shall:
1) call the Department during normal business hours and, as soon as circumstances permit without impeding the treatment of the affected patient, submit a completed request for information to the Department online or by fax. The Department shall respond to the health professional as quickly as possible by telephone, fax or other methods determined by the Department to be a secure means of disclosure; or

2) call the trade secret holder at any time (24 hours/7 days a week) and, as soon as circumstances permit without impeding the treatment of the affected patient, submit a completed request for information to the trade secret holder directly by fax or email. The trade secret holder shall respond to the health professional as quickly as possible, but in no case more than 2 hours, by telephone, fax or other methods determined by the trade secret holder to be a secure means of disclosure.

**Regarding the sharing of information by Health Professionals:**

d) The health professional may share information disclosed pursuant to this Section with other persons as may be professionally necessary, including, but not limited to, the affected patient, other health professionals involved in the treatment of the affected patient, the affected patient's family members if the affected patient is unconscious, unable to make medical decisions, or is a minor, the Centers for Disease Control and Prevention, and other government public health agencies.

e) As soon as circumstances permit, the health professional who submitted the request for information shall inform the holder of the trade secret the names of all other health professionals to whom the information was disclosed.

f) As soon as circumstances permit without impeding the treatment of the affected patient, the holder of the trade secret may request a confidentiality agreement consistent with the requirements of this Section from all health professionals to whom the information is disclosed.

g) Any recipient of the information disclosed pursuant to this Section shall not use the information for purposes other than the health needs asserted in the request and shall otherwise maintain the information as confidential. Information so disclosed to a health professional shall in no way be construed as publicly available. (Section 1-77(l) of the Act)

**Below are some excerpts from recent statements by environmental groups and community groups with some of their specific objections to these draft rules released from the IDNR:**

**From the Environmental Law and Policy Center in Chicago**: Emergency Response & Disclosure – The law requires that trade-secret-protected information about chemicals be disclosed to health workers when necessary to treat a patient. IDNR's draft regulations give discretion over when to share this information and direct health workers to contact either "IDNR during normal business hours" or "trade secret holders." This is unacceptable given that emergencies can happen at any time of the day, and emergency personnel can't be expected to figure out which private fracking entity to contact if the Department is not available.

**From Illinois People's Action in Peoria**: IDNR identifies the definition of an "Affected Patient" as "a person receiving health care services from a health professional for an illness or injury diagnosed by the health professional to be caused by exposure to any chemicals used in high volume horizontal hydraulic fracturing operations that are subject to a claim of trade secret by a permittee or contractor."
PROBLEM: This definition is circular: in order to learn what chemical was used, a physician must first test for that chemical so s/he can prove s/he has a right to disclosure of the proprietary chemical. How can a doctor diagnose exposure to a secret chemical used in high volume fracking before s/he knows what the secret chemicals are to test for?

**We request that the IDNR:**
– transfer the responsibility of the full disclosure of all of the chemicals used in every frack well, including the trade secrets, to the Illinois Dept. of Public Health, IDPH. They have 24/7 - on call responsibilities already and they will be able to assist the Emergency Personnel and Health Professionals in a meaningful way. It is not the responsibility of the Illinois health care community to explain to a non-medical agency, such as the IDNR, or to the fracking corporations their needs for timely chemical disclosure, in the course of the medical care of their patients!

– work with the IDPH to allow mandatory reporting of frack field related accidents, disease and death, so that statistics and health related information can be shared with other Illinois Health Professionals. This sharing of health related information, including complete information about any and all chemical exposures, must be facilitated in a timely and meaningful way, pro-actively, for our public health.

– cease asking for "confidentiality agreements ' with Illinois Health Professionals about such an important public health danger as the many and varied health effects that we will surely experience on and around the future frack fields of central and southern Illinois. The needs of our patients and the health professional community for timely and complete medical information about these many public health risks, including case reports pertaining to fracking related illnesses, accidents and deaths are preeminent. This fracking chemical disclosure information must comply with all previous and pertinent health professional standards, without onerous reporting requirements to the IDNR, or "confidentiality agreements".

Thank you for considering our requests and your attention to this very important issue,

Dr. Lora Chamberlain
Organizer for Frack Free Illinois
drlora2@yahoo.com
773-486-7660

You might have missed [4 Attachments]

**Richard Fedder** Today at 11:21 AM

To frack free IL, Illinois Frack, Barb McKasson, and 7 More...

I wanted to share some important recent news that you may have missed:

1. There is a new scientific study our of University of Missouri. Just published. In a nutshell, they combined two separate studies:

A. The authors identified 12 chemical additives commonly used in fracking. They studied the health impact of these 12 chemicals and found that 11 of them are endocrine disruptors. I believe they found these chemical to cause significant increase in cancers, liver disease, etc.

B. The authors then tested for these chemical additives in two Colorado counties – one county which is heavily fracked, and one county which is not fracked. They also sampled the Colorado river. What they found was that the heavily fracked county was significantly and broadly contaminated with these 11 chemical additives. The un-fracked county was not contaminated. And the Colorado river was moderately contaminated.

You should note that this study only looks at what I consider the lesser pollution problem – contamination from the chemical additives. The larger problem is the chemicals which are brought up from the shale through the fracking process. The VOC's, heavy metals, methane itself, and radium. These were not part of the University of Missouri study.

2. The next is a scary set of studies that are only indirectly related to fracking. To try to say it simply, we all have an outmoded understanding of genetics. We think that only DNA can be passed from parents to children. And that only mutations – a relatively rare event – can change that inheritance. The pinnacle of this thinking is beautifully expressed by Richard Dawkins in his book The Selfish Gene. (Thesis – we are all just conduits for the gene to reproduce itself).

But there is a paradigm shift occurring in biology. And it is quite credible, with experiments that are unrefuted, though not much published in the press. Apparently, there are mechanisms for inheritance of traits that do not come from the DNA or from DNA mutation. And they are able to respond rapidly to environmental changes.

The overall mechanism is through influencing gene expression – that is causing changes in the way the genetic "book" is "read", rather than changing the DNA itself. For example, a grasshopper and locus are genetically identical, yet they have quite distinct physical (and social) characteristics. Their genetic book is read differently, when environmental conditions (drought) change.

One particular mechanism that has been identified is that some type of chemical called methylates can attach themselves to the eggs and or sperm. It has been proven in experiments that they attach for generation after generation, down to at least the great grandchild level.

What these chemicals appear to do is block the expression of some of the DNA, thus changing the way it is read.

And here is the punchline, as you may have guessed already. The type of chemicals we are dealing with in fracking – the so-called endocrine disruptors – appear to cause these methylate attachments. They block certain gene expressions in ways that are harmful not just to you, and not

022382

Cheyenne Adams

I'm not going to comment about anything I found in the rules and regulations. I'm going to comment about what I didn't find. Throughout the entire document, there is not a single citation or reference to any scientific literature or publications. In fact, on the third page it explicitly states "Published studies or reports, and sources of underlying data, used to compose this rulemaking: None." As a student in the sciences, I find this disrespectful at best, dangerous at worst. This is simply not acceptable. The information is available, and I demand that it be referred to when making decision that effect the health and livelihood of the public and the land.

On the first page of a search for scholarly journal articles with the search term "hydraulic fracturing," I found this information:

"The EPA admits that many recent reports [of hydraulic fracturing] suggest impacts to drinking water " (Weinstein 2013). I would like the IDNR to cite this publication.

"Hydraulic fracturing poses environmental risks to drinking water supplies" (Weinstein 2013). I would like IDNR to cite this publication.

"Despite the risks that hydraulic fracturing poses to water supplies...the United States chose to significantly reduce federal involvement in fracturing regulations when Congress passed the Energy Policy Act of 2005, which specifically exempted "underground injections" from the Safe Drinking Water Act" (Weinstein 2013). I have to wonder why underground injections would need to be exempt from SDWA unless it posed a threat to the drinking water, and I would like IDNR to address this when they cite this publication.

"Hydraulic fracturing may pose a threat to groundwater resources if fracturing fluid or brine can migrate through fault zones into shallow aquifers. Diffuse methane emissions from the gas reservoir may not only contaminate shallow ground- water aquifers, but also escape into the atmosphere where methane acts as a greenhouse gas" (Kissinger et al. 2013). I would like IDNR to cite this publication.

"Seismic activity is a known side effect of fracking...Seismologists believe, however, that a bigger danger is posed by the injection of this wastewater back into the earth because it can reach the fault line and cause more significant earthquakes. Multiple states have recently reported substantial earthquakes, some as high as 5.1 magnitude" (Kerner 2012). According to the US Geological Survey, an earthquake at this magnitude is expected to cause damage to poorly constructed buildings, may cause damage to all other buildings, and may result in a few casualties. I would like IDNR to cite these publications.

I'll paraphrase a list of "The most important gaps and shortcomings" of hydraulic fracturing:

- Not enough reliable field data
- Not enough information on the role of fault zones
- Models need to be established for the migration of fracturing fluid and brine
- The movement of displaced brine needs to be quantified
- Not enough is known about the release mechanisms of methane from the rock phase
- Capillary pressure-saturation relationships and relative permeability saturation relationships need to be established for the migration of methane through the overburden

• Models for the propagation and flow of fractures need to be improved
I would like IDNR to cite this publication.
(Kissinger et al. 2013)

Finally, from an analysis of attempted fracking regulation: "A moratorium followed by dedicated national environmental standards directed at hydraulic fracturing would be the most appropriate and effective solution" (Downing 2011). I would like to see IDNR try to cite this publication in their rules and regulations on fracking.

Although there is obviously much more information available I don't have time to tell you everything in these four minutes, the information is clear: fracking contributes to drinking water contamination with known human carcinogens, ecological damage, green house gas emissions more potent than carbon dioxide, and dangerous levels of seismicity. The conclusion in the literature is that a moratorium on fracking is the most appropriate response. I encourage IDNR to try to cite these publications in their regulatory rules. Until all of these concerns can sufficiently be accounted for in the regulatory rules, which I assure you they cannot, I demand a moratorium on fracking.

I have included my references at the bottom of this document and I encourage all of you to read and cite the scientific information about hydraulic fracturing, which should have been done before the rules were drafted. I shouldn't have to do your homework for you.

References:

Weinstein, Mark. 2013. Hydraulic fracturing in the united states and the european union: rethinking regulation to ensure the protection of water resources. *Wisconsin International Law Journal* 30(4):881-911

Kissinger, Alexander, et al. 2013. Hydraulic fracturing in unconventional gas reservoirs: risks in the geological system, part 2. *Environmental Earth Science* 70:3855-3873.

Kerner, Kathleen. Fracturing the environment? Exploring potential problems posed by horizontal drilling methods. *University of Baltimore Journal of Land and Development* 1:235-245.

Earthquake Facts and Statistics. United States Geological Survey. 29 November 2012. Retrieved 18 December 2013.

Downing, Yangmay. 2011. Hydraulic fracturing and protection in law from negative effects in new zealand. *New Zealand Journal of Environmental Law* p. 243-276.

## YOU'VE BEEN FRACKED

(Lyrics and Music by Edith O. McCrea)

A E A
I am a fracking company; I own the U-S-A.
E
I want your land, so lend a hand and sign the deed today
D A
I'll give you lots of money if only you will ask
E A
And you won't know until I go that you've--been--fracked!

D A
Chorus: I'll poison all your water, contaminate your land
D A E
I'll make you sign a contract you don't really understand
D A
I'll dig a well straight down to hell and turn your water black
A E A
And when I'm done, I'll cut and run, 'cause you've--been--fracked!

E A
My drills go down a mile and they crack the Earth in two
E
This sometimes causes earthquakes, but there's nothing I can do.
D A
An earthquake is an act of nature; that's just a simple fact
E A
I can't be sued, so you are screwed, 'cause you've--been--fracked!

E A
To get the gas out of the shale, I shoot some water down
E
It's full of deadly chemicals that go deep underground
D A
It mixes with more toxins and then comes flooding back
E A
But that's OK with EPA, so you've--been--fracked!
(Chorus)

A E A
You say your family's on this land since eighteen twenty-two,
E
But now you need the money and there's nothing else to do.
D A E
You're lucky that you've got a choice your great-grandfathers lacked
A E A
Just sign the row and soon you'll know that you've--been--fracked!

E A
You say that you've been feeling bad since I began to drill.
E
You say your cattle all are dead and all your kids are ill.
D A
Your land's not worth a penny; you wish you hadn't cracked.
E A
Well, ain't that nice, but don't think twice, 'cause you've--been--fracked!
(Chorus)

Jeanne Fehe

## TAKE BACK THIS LAND FOR YOU AND ME

(To the tune of "This Land is Your Land" by Woody Guthrie.
New Lyrics by Rich Fedder)

As I was hiking and they were drilling
And the sun was shining while the corn was wilting
I made a promise we're all fulfilling:
Take back this land for you and me!

Chorus 1: This land is your land, this land is my land
From the Shawnee Forest to the southern wetlands.
From the Wabash River to the Mis-sis-si-ip-pi
This land belongs to you and me.

In the depths they fracture the shale formations
And claim the bedrock of our proud nation
But up above them, they don't own nothing
This (whole!) land belongs to you and me.

Chorus 2: This land is your land, this land is my land
From the Shawnee Forest to the northern tar sands
From the Hudson Valley to the Texas prairie
This land belongs to you and me.

In the forest bottoms, a deer was drinking
As an uncapped well-head was slowly leaking
And the poisoned waters set me to thinking:
Wasn't this land made for you and me?

Chorus 3: Stop fracking on your land, stop fracking on my land
From California to the New York Islands
From the redwood forests to the Gulfstream waters
Take back this land for you and me!
Take back this land for you and me.

Tabitha Tripp

I live another 45 minutes south of here. When I took the time to drive all the way to Springfield last spring, to talk to legislators (who were always too busy to make time to talk,) it was a long trip and I am dedicated to protecting our communities.

I have been in this campaign to stop fracking for 22 months working with SAFE, IPA, Heartwood Forest Council, Vineyard Indian Settlement, RACE and the Shawnee Chapter of the IL Sierra Club.

You have seen me at each one of the hearing, Why?--because it is that important to us down here. It's not enough to get a news report- we want to know exactly what happened.

Activist Don West says, "The abuse of the land has always gone hand in hand with the abuse of the people, It's easy to take and frack or mine someone's land if we have convinced the world- through news--that it's inhabitants are disposable, poor white trash or in essence a Bunch of hillbillies"

I am native of southern Illinois, I am a graduate of SIU. I am a mother and a poet and we live on a 5th generation family farm with a deep well for water. I live in the boonies and often I don't even have internet.
But that does not make us expendable to Oil and Gas industry. I might be a hillbilly, but I am proud of it.

It does not make us any less significant. This department and the state have done exactly that- deemed us disposable.

Sacrifice Zones have been determined throughout Southern IL as economically depressed and in need of stimulation via fracked wells and hydrocarbon extraction. Leaving us with ruined water, worthless land and health effects as far as the eye can see into the future, we will be no better off than when we started extraction technology 200+ years ago.

Not the stimulation my children were hoping for!

Officials and agencies entrusted to protect public health and the environment, have gutted laws and created industry loopholes. You've sold us out, just like our legislators did.
These rules do NOTHING to uphold the already lax safety guarantees set forth in Public Act 98-0022. That LAW states Section 1-75.2 All phases of HVHF shall be conducted in a manner that shall not pose a significant risk to public health, life, property, aquatic life or wildlife. There is NO part of regulation that will successfully allow safe fracking.

At the very least- if I am going to be reading the rules again, comparing them to the law passed in May and then substantiating my comments to prove the incompetency of these rules during this joyous holiday season, then the least I could do is bring you a partial list of scientific research as a my gift to you.

This compilation of papers includes:

- Radioactivity in Shale Deposits
- USGS maps 100 year flood plain and Liquefaction maps due to Earthquakes
- Several research papers on Fracking induced Seismicity
- OSHA regulations on Exposure to Silica Dust and Toxic Chemicals
- American Journal of Nursing Research on Fracking and Public Health
- Research on Waterless Fracking
- Peer Reviewed Publication Research on Air Quality near Fracking operations
- FWW: The New Global Water Crisis and water demands and Climate Change scenarios
- NRDC's research on disposal of radioactive liquified oil field waste

By light of the yule log, I will be reading the ACLU's guide to civil liberties to my children, because I am pretty sure at this point, the only way to maintain our right to a healthy environment, Article XI of the IL constitution, will be to defend those rights by force against our government and the corporations who have hijacked our democracy.

Quoting Don West "In a hungry world the struggle between oppressor and oppressed is unending. The inevitable question "which side are you on?"
To be content with things as they are, to be "neutral" is to take side with the oppressor who wants to keep status quo.
To challenge the power of the oppression is the poet's responsibility. Such action will preserve and build faith and hope in humanity. Nothing-NOTHING raises the spirit of the people more."

Happy Holiday!

Jessica Bradshaw

December 19, 2013

Dear IDNR:

My name is Jessica Bradshaw. I am a member of the City Council here in Carbondale. I want to make clear that I am just speaking for myself here, not speaking on behalf of the City or the Council.

First, I must say that, from the very beginning of reading the proposed rules for hydraulic fracturing, I had an issue with Item #11, Statement of Statewide Policy Objective. This simply says that "This rulemaking does not affect units of local government." I think that fracking would very much affect units of local government. Even if fracking does not happen anywhere near Carbondale, we will be affected if, for example, an injection well causes an earthquake, as we are in a major fault zone. In fact, we are in between two fault zones! It could affect every local government in Southern Illinois, and the state, if there was a big earthquake.

Second, we will be affected if the area runs out of fresh water. This is the issue that concerns me the most, because we only have so much usable water, and regionally, we have already seen some severe droughts. In fact, last summer, coal plants near Sparta had to halt operations for a while due to drought. If we don't have enough water to keep already existing operations running, then how in the world are we going to cope with the increased demand that hydraulic fracturing would bring?

I am also concerned about the effect that water shortage and pollution may have upon on our regional tourism industries. Southern Illinois is home to a burgeoning wine industry, and lately, breweries, too. That's not to even mention all the natural beauty we have. I would hate to see fracking destroy that.

Third, I'd like to speak about local control, specifically, about control for those who do not live in a city with zoning or other code enforcements. The proposed rules, in section 245.10, allow for *municipalities* to have some say over drilling, but not counties. I am glad that this provision is in there, but we have a lot of areas where there are no cities or municipalities. Counties control their own roads, water, and taxes; they should also have some say in whether fracking is allowed in their jurisdiction (with home-rule municipalities being able to decide, too, obviously.) I would prefer it if the state would just pass a moratorium, but in absence of that, I think it's important that we let all levels of local government have control, and I commend IDNR for including this provision. I just think it needs to be stronger.

Another major concern I have is with the chemical disclosure rules, under section 245.210. Companies must disclose what chemicals they're going to use, so that local doctors and nurses have access to that information, in order to treat their patients. It's that simple.

In addition, under section 245.270, on Public Hearings, the rules first say that "any person having an interest that is or may be adversely affected [by a fracking permit], can petition the Department for participation in a hearing." But then subsection 245.270(a)(6) goes against that, saying that the request for hearing must be served upon the Hearing Officer, the Department, and the applicant. This makes it harder for the public to participate, which is inconsistent with the intent of the law.

Finally, I have an issue with the timing of this comment period. Not only is it the holiday season, but it is also the time of year when many municipalities have to deal with property tax changes. I think that the comment period should be extended, at least a few weeks, to allow county and municipal authorities time to review it.

Thank you for your time and consideration. And I hope you enjoy your visit to Southern Illinois, and Carbondale, and have an opportunity to explore our beautiful region.

Sincerely,

Jessica Bradshaw
512 N. Carico St. Apt. A
Carbondale, IL 62901
618-203-9626
jbradshaw@ci.carbondale.il.us

Audrey Sweet

I read through the majority of the regulatory act and can tell that a lot of thought went into this. I do still have some concerns and would like to comment on a few things that caught my attention.

I did not see anything regarding water rights in this act.
To ensure there is enough fresh, uncontaminated drinking water for the citizen, for the crops, and the environment. I would like to see that all the current in stream and consumptive uses already in place get their allocation of water before the fracking companies do, especially in a drought year.

**Section 245.830:** Covers **Reserve Pits**
Which are to be used for **TEMPORARY** storage when there is "a lack of capacity for tank storage"
*This is not acceptable and fracking companies should be required to have extra storage tanks on hand beyond their initial estimates for such situations.*
*What does **TEMPORARY** mean? 1 day? 1 week? 1 year? 1 decade?*
*This must be defined.*

**245.850 Flowback storage, disposal, recycling**
Contaminated water is to be removed from well site within 60 days after the **COMPLETION** of fracking operations. It goes on to state that within 7 days of **COMPLETION** the contaminated water stored in the **TEMPORARY** pits should be moved to above-ground tanks.

*Now, how is **COMPLETION** defined?*
*I wouldn't be surprised if well sites can remain **active** even if they haven't been used for 10, 50, 100 years if they **intend** to return and frack more.*

*I feel that the initial permitting process, should include a time period in which the fracking companies can have access the land. This time frame should be a reasonable amount of time for the companies to extract their projected amount of natural gas, while also respecting the land owner's right to solace, and the environment's right to recover. The **COMPLETION** of the project should then be **defined** as **no later than** the permitted time allocated to the project.*

**245.940 Disposal & Recycling**
**D)** Contaminated water can be treated and reused in future fracking projects.
*If this can be done, it should be mandatory. Companies should not be permitted to take more fresh water if they can reuse the water they already have.*

*Which leads me to question the fate of this toxic brine.*
*Will our children and our grandchildren be stuck cleaning up this fracking mess?*
*Will these well sites and "temporary" contaminant pits be the superfund sites of tomorrow? Will these fracking companies bow out after they've filled their pockets or*

*declared bankruptcy after the cost of clean ups have exceeded their acceptable profit to loss ratio?*

*To prevent this, I would like the state of Illinois to require fracking companies to take full responsibility for returning the contaminated water they use to a condition equal to or better than it was when they received it.*

*This is no small task as most of you know. It takes a lot of energy to transform even saltwater into potable drinking source, not to mention needing to remove all the **UNDISCLOSED** chemicals. Only wealthy countries with access to large amounts of **oil and gas** can undergo the desalinization process. If these fracking companies were required to return the water they used back to a potable source, I doubt they would continue with business as usual... because they would ultimately be using that natural gas they just extracted to transform the water back to what it was. This makes no sense.*

*The wars of the future will be over water, not oil or gas. By allowing fracking into our state, Illinois is pre-emptively declaring war on itself by compromising its most valuable non - renewable resource.*

*I hope that the IDNR and the State of Illinois have the foresight to protect its citizens and natural resources for future generations.*

*Thank you!*

Audrey Sweet

Dennis Connolly

In regards to Section 245.200 Registration Procedures, Illinois Register, notice of proposed rule (C) proof of insurance to cover injuries, damages, or loss related to pollution in the amount of at least $5,000,000 per occurrence, is wholly inadequat this need to change to $500,000,000 per occurrence. Considering earthquakes in this seismic sensitive area between 2 major historical earthquake fault lines. A single residence can cost $5,000,000.

Now factor in the cost of the inevitable permenent ground water contaimination of documented cases in Pennsylvania, North Dakota, Colorado and Texas. Proof of insurance now needsto be raised to $5 billion and be retroactive through the next 7 generations. Consider property values become next to worthless in this contaiminated industrial danger zone. Consider the future generations and ~~their~~ their health plus lack of livelihood.

Subpart F. Water Quality

Section 245.600 Water Quality Monitoring

I see no planned baseline water testing north, south east or west of each fractured well also no 30day follow up of water testing of adjacent wells. I suggest an independent agency overseen by a volonteer group. This testing is to be paid for by the company fracking. Any contaimination needs an immediate court order to halt all fracking activity.

I considered these regulations to be an assault on democracy.
Hydraulic Fracking is an Energy Negative Extractive technology and that means it uses more energy than it produces. Please consider Biogas Technology instead. Biogas methane is powering a pottery kiln locally at present. I also have a biogas pit at my home and I will be more happy to share information with the State of Illinois. I researched this with the Chinese Biogas Manual.

This area is also a major species migration habitat. The IDNR has not considered a flock landing in a fracking pond.

Dennis Connolly

022394

Nick Smaligo

I've been to three of these meetings so far. They are ridiculous.

It's a farce: we repeat things you already know, as if the number of times we say them has anything to do with their truth. It doesn't make sense: if there are problems that are repeated less often, that doesn't make them less dangerous. A tally is not an adequate way to evaluate these concerns.

Pretty much everythings been said. You've got the dirty dozen list. You know about earthquakes, radiation, V.O.C.s, methane, water overuse + contamination, healthcare concerns over chemical disclosure, the sexual abuse statistics that these pillaging mercenaries leave in their wake. Its all been said, or it is all easily available. Whats the point of us getting up here, one person after another, to keep having the same complaints tallied?

If you were serious about researching this, all you would have to do is stop listening to the people who stand to make money from it, and start listening to the people who are either suffering from it or really studying it; stop *listening* to the PR agencies and these fake good ol' boys on their payroll. These guys who sit here at these meetings smirking, mocking people who are afraid for their health and livelihood. They come up here telling us they're "mom and pop" gas drillers against regulation. Its bullshit. We all know these corporations are only interested in profits, and they'll say anything to get them. They don't care about this area, its people, or its future.

At the start of each hearing, you say the DNRs job is to make fracking "environmentally sound." *It simply cannot be made environmentally sound.* Even if you could draw up rules that make fracking safe, protecting the well casings from earthquakes and rust for years, decades, centuries to come – which, I want to emphasize, you cannot do – but if you could draw up these fantasy regulations, guess what? We all know you don't have the resources to monitor and enforce them!

So these proceedings are ridiculous. They are pantomimes of a democratic process, put on to makes us feel like our voices were heard. But you've already decided that fracking is inevitable. That ship has sailed, you've said.

You are just doing your jobs. But there is contradiction in your job: on the one hand, your job is to make sure the environment of Illinois is protected from dangerous toxins and preventable disasters for present and future generations; on the other hand, your job is to make sure fracking starts in Illinois as soon as possible. Its one or the other. If you do the second job – the job thats been bought and paid for by the industry– then you aren't doing your first job, protecting the people and resources of Illinois.

But you can do your first job. You can go to Springfield and say: "we need more research, we recommend a two year moritorium to really investigate this process." Better, you can say: "we have become convinced that this process is fundamentally unsafe and cannot be regulated in a way that protects the people and ecology of Illinois," you can say: "as people who have been invested with power and responsibility for the safety of others, we cannot in good conscience allow Illinois to be fracked." You can say those things.

Little survey. If you're convinced we need either a moratorium or an outright ban on Fracking, and you want to see these gentlemen return to Springfield and say so, please stand up.

You say take it up with your representatives. A number of dedicated people in this audience worked themselves to frustration and tears doing just that. They don't listen to us. Maybe they'll listen to you.

You say its going to happen, its just a matter of how; we say, it can't happen safely, and we won't let you invite this danger into this region.

You say the decision has been made; we say the decision is illegitimate because it was made by excluding the people who stand to suffer its consequences.

You say the ship has sailed; we say its sailing in the wrong direction, its sailing toward storms, and we need you to help turn it around.

You say "fracking is inevitable," we say "fracking is impossible."
As long as that is the divide between us, then its hard to see what we have left to say to one another.

So I'm going to turn around. Let's make this meeting ours. At all these hearings, people have been getting up and speaking to these guys. But they seem to have already made up their minds. Maybe they'll surprise us. But we can't assume they will.

We don't want this regulated. We want it prevented. And as you all know, its going to take us organizing ourselves to stop it. A lot of people have come with a lot of important things to say. I'm suggesting that when you come to speak, consider speaking to all of us. If you have problems with the rules, then say them. But if you object to the very idea that this can be safely regulated, then say that too. If you think they should go back to Springfield and tell them that we need a moratorium for more research or an outright ban, then show them your backs. They'll still record it. They'll still listen. But let's make this meeting ours. Let's show them that we refuse to accept that this inevitable, that we've resolved to make it impossible.

Local Elder Resident and Published AUTHOR
~~Monitoring Water for Pollution~~
Strongly reflects my own concerns
Korina Lang read
David E. Christensen

December 19, 2013

My name is David E. Christensen. I am a retired Geography professor (SIUC). I received my Masters and PhD degrees from the University of Chicago. I taught geography for a year at universities in the United Kingdom and China and for summers in Canada and Malaysia.

For your information professional Geographers are concerned with the human use – and misuse – of the surface of the Earth, and that concern includes thousands of feet below the surface and the atmosphere. That concern includes activities that relate to the well-being and survival of humans and other living things with which we share this planet and on which we depend.

For two centuries the amount of CO2 in the atmosphere has steadily increased to the point of endangering living things, including humans. Climate change is real and near an unknown tipping point. That knowledge is based in part on the chemistry of the air going back 800,000 years (Antarctic Ice cores)..

My concern with hydraulic fracturing ("fracking") is long term. After our two centuries of "creaming off" the "easy to mine and drill" fossil fuels (coal and oil) we have entered into more and more expensive modes, the latest being horizontal fracking. Yes, there has been fracking at the bottom of bore holes for decades, but the major change came only about a dozen years ago at the turn of this century when horizontal fracturing (out 2 miles from the bore hole!) and the rising cost of prospecting and production (and renewed prospects for generous profits) opened the huge reservoir of oil and gas in shales thousands of feet below Earth's surface.

I need not review with you details about the many controversial aspects of fracking. You know them well:

The use and contamination of vast amounts of limited fresh water resources,

The problem of disposal of the toxic contaminated water that rises with released oil and gas through the bore hole,

The contamination of ground water resources as remaining toxic fluids, oil and gas rise randomly to the surface for miles around the bore hole,

The record of increasing low and mid-level earthquakes causing damage to infrastructure and structures on or near the surface, jeopardizing and disrupting the health and lives of humans at the surface.

The use of natural gas from fracking over the next decades or century would only exacerbate our already precarious situation in regard to $CO_2$ in the atmosphere and climate change.

Just because the fracking technology has been invented and can increase the production of oil and gas that provides jobs and profits for a while does NOT justify its use if it puts the health, well-being and survival of the human species and our accumulated civilization at risk. (Humans also invented nuclear bombs but must not use them for similar reasons!)

We should not be playing games with fracking rules. More rules and nickel and dime fines for environmental damages are part of the game. We should not even be considering a moratorium. Fracking technology very simply should NOT be used.

We should be intensively researching and developing alternative energy sources and dealing realistically with the Earth's overpopulation.

David E. Christensen, Ph.D.
Carbondale, IL

We should not have to prove this process safe - at all cost ~~of~~ to us

The industry should have to prove it is SAFE

Beth Koehler

Id like to thank you all for sitting through the public comment period and I'm also grateful for this oppurtunity to speak for myself and many people of So IL who are unable to be here. Its a very busy time. I can't think of anything more important then to ensure that the water we drink, the air we breath and our soil is protected. This is the proposed job of the DNR in Illinois. The proposed regulations of fracking that has been submitted falls miles short of protecting our resources. The loopholes that serve the oil and gas industry are numerous, too many to count. And I know that as they stand that there will be accidents, leaks, poisoned, water, and families negatively impacted. and as we have seen in pennsylvania, colorado, and north dakota the Oil & gas industry will not be held accountable.

I will focus on a few points in the regulations that demonstrate this lack of accountability & lack of protection to our resources.

1. In Section 245.6 for Water Quality Monitoring

022400

The industry is aloud to select its third party engineer or geologist to conduct sampling and testing of water sources. This allows a fracking company to have select an individual who's scientific methods in testing may serve the industry. Shouldn't the DNR appoint their own person and laboratory to this for more objective results.

2. Also landowners have the right to reject water quality testing if they want and then fracking companies do not have to provide sampling to the DNR. Water that flows through a property does not stop at the boundary. Water testing should be the law. An individual should not have the right refuse. Water is a shared resource.

3. Also in the same section individual land owners may sign a nondisclosure agreement c̄ the Fracking Company where they do not have to submit water quality testing results to the DNR unless they find contamination.

022401

Again we have the proposed regulations allowing the industry to regulate its own water testing. No one from the outside or the DNR stepping in to make sure the water is strictly monitored. (You can bet that most landowners either refused testing or signed a nondisclosure built right into their contract & may not even know it). No one reads the fine print.

4. The fracking companies only are required to keep there water quality test results for 1 year following completion of testing. Then what? Can they destroy the records in case they are held accountable for contamination of water later. Hmmm?

5. Testing of water has only to be within 1500 feet of a vertical well. Again does contaminated water know that it needs to stay within this boundary.

022402

These proposed protections are laughable if their intention is to actually protect us. But the people of southern Illinois are not laughing.

I am a registered nurse and I work in an acute care setting here in Southern Illinois. Close to half of my patients have worked in coal mines & are now afflicted with COPD. I watch them day in and day out spend there last days struggling to breathe. They are victims of an industry that didn't protect them. They were willing to take the risk to feed their families. These industries including the Oil & Gas industry that is currently implementing hydraulic fracturing in other States do not have a good track record of protecting the environment or people. They have no gain in doing so. Please IDNR reform these regulations, or better yet instate a moratorium until we have formal data.

022403

My name is Kosie Tripp.
It's spelled K-O-S-I-E T-R-I-P-P

We live off well water. Don't frack our water or it will be gone forever and we won't have any left.

I am only 8.
I want to have clean water when I am old, and I don't want cancer from the toxic chemicals they are putting in the water and ground.

I want clean air to breath too.

Fracking causes bad earthquakes. I don't want to be part of that either. Those are scary.

I saw Santa and he said the rules are naughty.

For Christmas I asked for renewable clean energy, like solar and wind.

I am wishing for a frack free happy new year.
Thank You.

William Joy

As a student at SIUC studying Forestry we learn about community resource MGMT. I realize this is not a community based resource MGMT plan but the IDNR should take steps to involve the community in a deeper way. My concern regards Section 245.270 addressing how to make residents aware of both the bill and the process. During my education I have learned the importance of community outreach and as a potential future employee in the field of resource MGMT I am displeased with the IDNR's process of community communication. This process seems to neglect a vast majority of those affected by the proposed bill. These traditional meet and greet sessions are just one step that should be taken, along with a list of others. Hearings such as this one are great for those who are already aware of the proposed bill but those who are unaware remain nameless and clueless to the dangers of fracking. WE LACK THEIR INPUT In order to fully ensure residents are aware of how fracking permits and operations will affect them the IDRN needs to immerse themselves in a more holistic fashion through reachout and communication. There was a case study that looked at community involvement in a Cache River restoration project that can shed light on this situation. Although these two cases are very different in resource MGMT goals there are many similarities. Once action has been taken many residents will realize they have been left out of decisions made that greatly affect their lives. In the case of the Cache River study, many residents formed a strong distrust and resentment towards the IDNR for a lack of communication. All members of the community had different ideas of what should happen and very few were looked at. This case was for a restoration project, the proposed bill in front of us is the exact opposite, a destruction project, so the fallout ~~for~~ FROM IDNRs limited public input will leave the residents of IL with a bad taste in their mouth, and not just from their poisoned water.

Taylor Sprehe

AMBIGUOUS, PRONE TO CIRCUMVENTION, ~~lacking in [illegible]~~, IRRESPONSIBLE DRAFTSMANSHIP. These are the words that come to mind when reading these proposed rules.

1 ■ We sit on the New Madrid Seismic Zone (New Madrid Fault Line) which is responsible for four of the largest earthquakes in North American history. The number of earthquakes in North America have increased six fold over the last 12 years when compared to the last 100 years. U.S. Geological Survey says ~~they are~~ this rise is "almost certainly man-made". ONE CANNOT IGNORE THE STARK CORRELATION BETWEEN THE RISE IN NUMBER OF EARTHQUAKES AND THE RISE OF HYDRAULIC FRACTURING. ON TO THE SPECIFICS...

2 ■ §245.1120(c) Fines to companies in violation of rules range from fifty to five-hundred dollars, ~~not exceeding one thousand dollars per day~~. These fines are ridiculously low and have absolutely no punitive value to major corporations. Here's a relevant analogy, the average net income per household in Carbondale is $27,882. The fine for not maintaining your lawn in the city of Carbondale ranges from fifty to seven hundred dollars per violation. Halliburton and Exxon, who are major players in the fracking industry net nearly one billion dollars each year, yet are subject to lesser fines for violations that could result in major environmental damages. AND DAMAGES TO THE HEALTH OF THE LOCAL POPULACE.

3 ■ §245.210(a)(11) This section does not include requirements to ensure that storage tank capacity is accurately calculated. This has the serious potential to lead to unnecessary use of EMERGENCY open air overflow pits that the ~~enabling statute~~ ACT EXPLICITLY says should be for "temporary storage" as "reserves". Moreover, the ~~enabling statute~~ ACT says the overflow should be removed "within seven days". However, the drafters of these rules have interpreted this to mean within seven days after completion of the fracking operation. Fracking operations can last for over a month, and if the quote "reserves" are allowed to be kept on site for the entire duration of the operation, the storage of the overflow is by definition no longer quote "temporary", which the ~~enabling statute~~ ACT clearly mandates.

4 ■ §245.730 Regarding trade secret disclosure to health professionals. The proposed rule says that the department quote "may" provide information to health professionals who need it in the case of emergencies. However, the ~~controlling~~ Act uses the term "shall" in §1-77(L) to describe the duty owed by the department to health professionals. Moreover, health professionals may call the department quote "during normal business hours." IF THIS RULE IS PROMULGATED AS CURRENTLY WRITTEN, An

022406

apology is owed to all those who have emergency needs outside the DNR's normal business hours. One more point on this section is that there is no time limit for a response by the department. In the case that the department cannot or will not respond with the information needed by the health professional, again this is in an emergency situation, the health professional is directed to contact the trade secret holder. However, within this draft of the rules, there is no way for the health professional to know who the trade secret holder is. Here is a hypothetical situation that outlines the problems within this section alone: a truck carrying fracking waste water is traveling down highway 51 swerves to miss a dear, crashes and spills its contents on the road. A motorcyclist comes around a curve and slides out on the wastewater, ~~being contaminated by~~ COMING INTO CONTACT W/ numerous unknown chemicals. This person has no way to know, neither does their doctor, what chemicals they have just come into contact with. The doctor calls the department of natural resources, however it is not during their regular business hours. The only other person left for him to call to find out what toxic chemicals have just contaminated a motorcyclist, an ambulance, and a hospital, is the trade secret holder, however there is no way for the doctor to know who that is, let alone what number to reach him at. The doctor is then forced to give treatment without the proper and relevant knowledge because no one has the duty to furnish that information outside of regular business hours.

- These are only four of the twenty four major problems that have been brought to my attention regarding these proposed rules. I am a first year law student at SIU and even I can see these glaringly obvious loopholes. As a member of the public and a resident of the state of Illinois, I ask you to put a moratorium on this practice until all [redacted] issues have been properly addressed. Happy Holidays.

Treesong

IDNR Public Hearing: Proposed Hydraulic Fracturing Regulatory Act administrative rules
December 19, 2013 in Carbondale, Illinois

Comment submitted by:
Treesong (this is my full legal name)
2030 S Illinois Ave #9
Carbondale, IL 62903

The IDNR has been given an impossible task: the task of making fracking safe. Many of us in this room are also facing what seems like an impossible task: the task of convincing the IDNR that the proposed rules are broken.

As representatives of the IDNR, you have been tasked with promoting public safety for present and future generations. Fracking poses an imminent threat to the health and safety of people I know personally right here in Southern Illinois. It also poses a threat to many of our livelihoods that are derived from agricultural and recreational uses of the natural riches and wonders of Southern Illinois. Your proposed rules are woefully inadequate to protect my friends and neighbors from poisoned wells, poisoned farms, poisoned air, and the many other environmental and social hazards associated with fracking.

I've submitted numerous comments about the details of these administrative rules. The take home message, however, is this: fracking is not safe and cannot be made safe by a haphazard set of rules with no real budget or plan for enforcement. A certain percentage of these fracking wells will fail. Once that contamination has been unleashed, there's no taking it back. Present and future generations will suffer for it.

The proposed administrative rules place the people of Illinois – my beloved friends and neighbors – in grave danger. As public servants dedicated to the stated mission of the IDNR, I urge you to take whatever actions necessary to ensure that fracking does not come to Southern Illinois. That may involve declaring that there is no current technology for safe fracking in Illinois, publicly calling for a ban, or resigning your posts in protest of the impossible task you've been given. Whatever it takes, I urge you to do everything in your power to stop this dangerous industry from coming to Southern Illinois.

Having said that, I must admit that I am also realist and know that you will probably not do any of those things. If you do not heed our comments, then it is we, the people of Illinois, who must take up the mission you have abandoned. In the end, it is we, the people, who must protect ourselves, our communities, and our land from the menace of fracking. And so, I urge my fellow Illinoisans to join me in resisting fracking in Southern Illinois. Resist with your comments, resist with your letters, resist with your voices. And if fracking does come to our region, resist with your bodies in acts of nonviolent civil disobedience. If the IDNR does not do its duty to protect the public, it is up to us to do so. I hope and pray that it doesn't come to that, but if it does, I will be there, and I ask you to join me. Thank you.

Paula Bradshaw
Green Party
Carbondale

Dec 19, 2013

Over much opposition, Illinois representatives passed a fracking bill, which they assured us was the most restrictive in the country.

Now, IDNR has presented us with the rules supposedly enforcing that law. Yet, the department, whose job it is to protect the environment & resources, wrote rules which don't even encompass the entire law, with absurdly low penalties, in case of violations.

It makes me wonder just who wrote those rules? And with whose input? These rules are so biased in favor of the fracking companies, and so anti-citizen, that it seems that frackers must have been allowed into the process.

As an ER nurse, I am appalled that frackers are not compelled to disclose the chemicals they use. This is in violation of established

022409

section 245.210

Haz Mat rules. Every chemical must have a MSDS listing specific hazards. Yet, local firefighters have been told that the company will handle any fires internally. What about ER personnel, who will handle the victims? We need to know the hazards.

The train that exploded in Canada was carry fracking chemica according to a train safety expert that I talked with. The massive fireball + widespread destruction proves their danger.

Jan Thomas

Comment to be submitted to the IDNR, 12/19/2013

Happy Holidays! And I would like to start by asking the IDNR to extend the comment period, scheduled to end January 3, 2014, into February 2014, to give citizens adequate time to fully evaluate and respond to the issues raised by these rules, and spend the holidays with our families and friends rather than studying and writing.

My name is Jan Thomas and I am from Murphysboro where my husband and I are the proprietors of the Douglass School Art Place. We rent studios to artists, provide a public access venue for art exhibitions and performances, and have our own art glassblowing studio. "The Doug" is housed in Murphysboro's historic segregated elementary school, the Frederick Douglass School, which was the educational home for hundreds of students from 1897-1966. In the twenty years we have stewarded the school, dozens of alumnae have returned and reunioned, telling countless stories of what the school meant to them in their lives. We are in process of applying for Historic Preservation Status for the school. But let's face it, the Doug is a huge pile of bricks, critically vulnerable to earthquakes. Our concern is that fracking, and specifically, waste injection wells, will induce the big earthquake that has been lurking in the New Madrid earthquake fault for two hundred years, and reduce our beloved art place to a pile of rubble.

According to the U S Geological Survey, "The strongest earthquakes recorded in the continental US....were centered in eastern Missouri near the border with Kentucky and Tennessee. In the winter of 1811-1812, a series of three earthquakes of magnitudes 8.4 to 8.7 and maximum intensities of XI occurred near New Madrid, Missouri. These shocks were so strong that observers reported that the land distorted into visible rolling waves. They changed the course of the Mississippi River; they made church bells ring in Boston and Washington, D.C. Because the surrounding area was mostly undeveloped at the time, few deaths were reported and these events stirred relatively little attention then." Today is a different story; thousands of people live and work here and the potential for loss of life and property has exponentially grown. And we also now know that another major earthquake fault, the Wabash, lies a short distance to our east.

The IDNR rules, as proposed, make very little allowance for this critical issue. The "traffic light control system" allows for up to four fracking induced earthquakes of up to magnitude 4.9 before an injection well must be shut down, even near these serious fault lines. 4.9 doesn't seem like much, although it can cause property damage and injuries, but truly nobody knows what IS the likelihood of more serious quakes near these known serious fault lines. Especially as there are no rules for allowable injection pressures and volumes of waste water. That there is a correlation between these values and the quantity and strengths of induced quakes has been known since the 1960's when the first induced quakes were confirmed near Denver, Colorado; they resulted from a deep injection well drilled by the US Army at the Rocky Mountain Arsenal for injection of waste chemicals. That well was closed in 1967, but anomalous earthquakes continued for several years. What have we learned in this intervening half century?

According to the U.S Geological Survey (USGS), the problem is escalating, with more than 300 earthquakes above a magnitude 3.0 occurred from 2010-2012 in the midwest and east, compared with a much lower national average rate of 21 earthquakes per year observed from 1967-2000, before high volume horizontal fracking appeared on the stage, a five-fold increase.

There is also no requirement in the proposed rules for adequate seismic monitoring near each proposed well, which the USGS says is necessary to truly ascertain whether and to what extent the injection well is responsible for any induced quakes. And there is no requirement for well operators to maintain insurance to potentially compensate property owners for damages and injuries caused by induced earthquakes. We don't even allow people to drive a CAR without adequate insurance.

Stanford University geophysicist Mark Zoback is a proponent of fracking who nevertheless acknowledges the dangers of induced seismicity, and recommends these minimum precautions:

1. Avoid injection into active faults and brittle rock. I think this includes a requirement for the IDNR to consult with the Illinois State Geological Survey, which was mandated by the regulatory law passed last spring by the Illinois General Assembly, but apparently was not done. How else are danger areas to be identified?
2. Select formations for injection where pore rock pressure will not be changed by injection, and limit injection rates and volume.
3. Require seismic monitoring arrays to be installed where injection is being practiced.
4. Establish protocols in advance to define how operations will be modified or curtailed if seismicity is triggered, including clear requirements for reducing injection rates, or stopping injection altogether, if seismicity is being triggered.

To which I would add:

5. Establish some significant fines for violations which lead to seismic events. As it stands now, these multi-billion dollar companies will be fined the cost of a take-out meal and a movie for violations which could cost southern Illinoisans their lives and livelihoods. How can we think that they will take that seriously?
6. Require insurance/bonding adequate to cover earthquake damages to individuals, businesses and public institutions.

Thank you in advance for the work you will be doing to fix these problems.

Jan Thomas
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Sarah Shelton

Hello There. I first want to thank you for listening to me and all the people here tonight who are voicing their concerns about these Illinois regulations on hydraulic fracturing. When I started to look into the regulations, I began to learn more about how the process of how fracking actually works. Yes, I knew that fresh water and hundreds of chemicals were being injected into the ground to produce hydraulic fractures that will excrete natural gas. I heard it was going to bring jobs... and that with a crippling economy, this is something that Illinois law makers and rule makers, like yourself, are looking to ~~to~~ help pull us out ~~of debt~~. I appreciate the gesture, but the process of safe fracking is impossible ~~something that has the potential to destroy our lives and homes forever and~~ I have you and the rest of IDNR to thank for bringing this to my attention. Let me explain.

Section 245.600(b)(1) of the proposed rules provides for the testing and monitoring of water sources within 1,500 feet of the well site. But the proposed rules ~~do~~ does not provide for testing along the horizontal line of the well bore, which I've learned can extend for up to two miles from the well site. This is a seems like a blantant disregard of the known risk of the underground migration of that toxic chemicals that are injected into the ground, especially when hydraulic fracturing involves the use of explosive charges and especially in areas known for the risk of higher-magnitude earthquakes.

But as I began to look more into these regulations I found that if residents near a fracking site are not "provided" testing and monitoring of their water, then it's up to the resident to do so. I ~~looked into~~ the cost of getting your water tested is ~~checked and that's~~ close to $400. This is extremley expensive and more money than you are actually going to fine these oil companies for "violations" that range from $50 to ~~$2500~~ $500, as stated in section 245.1120.

Throughout my learning process of these regulations of fracking, I've learned that there are 596 toxic chemicals that the public does not have to know about, I keep reading the word radioactivity throughout these regulations... and that freaks me out, fracking causes earthquakes and can contaminate the water. This is crazy and now I'm absolutely convinced that there can be safe fracking and that fracking does not need to come to Illinois.

In reading these regulations I keep seeing terms like toxic fluids, earthquakes, radioactivity, water contamination, repeatedly. And this makes me realize there can not be a safe way to regulate fracking. ~~these things.~~ Because you are here ~~to learn about~~ for us to comment on specific rules I will talk about

022413

If you're tired & pissed off let's ban together to ban fracking. If these guys won't help us, let's ourselves.

## Statement by Brent Ritzel • IDNR Hearing, SIU Carbondale, 12/19/13

Thank you very much for your time. I do NOT envy y'all. You have been given the impossible task of regulating a technology that has already been exempted from 7 different major and essential environmental and public health protection laws…

Clean Water Act,
Safe Drinking Water Act,
Resource Conservation and Recovery Act,
Comprehensive Environmental Response, Compensation, and Liability Act
National Environmental Policy Act
Emergency Planning and Community Right-to-Know Act.
The Superfund Law

Fracking was obviously never really supposed to be regulated, but it seems to me that if you were tasked with such a project, the FIRST STEP would be put all those protections back in that the Halliburton Loophole removed.

A couple of weeks ago completed a research study entitled "Fracking Industrialization and Induced Earthquakes," which took a comprehensive look at more than fifty years of studies regarding the known connection between disposal of wastewater in deep-injection wells and induced earthquakes.

What propelled me into researching and writing "~~Fracking Industrialization and Induced Earthquakes~~" was my attendance at the July 18, 2013 Fracking Conference at Rend Lake College, which was sponsored by Illinois DCEO, and witnessing a presentation by Robert Bauer of the Illinois State Geological Survey. For the event the presentation had the straightforward title "Hydraulic Fracturing, Horizontal Wells & Unconventional Oil/Gas Resources," however in its YouTube treatment it was given the title "Are Environmentalists's [sic] Concerns Over Fracking Valid?"

Now instead of addressing the real and substantive concern of damaging wastewater induced earthquakes as large as magnitude 5.7, Bauer tells audience that fracking process does not induce felt earthquakes.

Bauer Completely Avoided the fact that Fracking Wastewater Disposal has led to 6 to 9-fold increase in felt earthquakes in Midcontinent region,
WHILE mocking any concern over earthquakes as fracking only creates earthquakes that are the equivalent to the force of an apple hitting the ground from a 3-foot drop.

In reality, what seismologists and geophysicists have learned is the following…

Midcontinent 3.0+ earthquakes:

| | |
|---|---|
| 1970-2000: | 21 /yr |
| 2001-2008: | 29 /yr |
| 2009: | 50 |
| 2010: | 87 |
| 2011: | 134-188 |

But they've known about this phenomena, and the mechanisms underlying it, since 1966…

Another one of Bauer's Slides Reads: "Induced Seismicity Potential in Energy Technologies - National Research Council report 2012: Current process of hydraulic fracturing a well does not pose a high risk for inducing FELT seismic events…"

Bauer got this quote from page 85 of the 265 page report. Just three pages later, starting on page 88, is an in-depth analysis of felt earthquakes induced by fracking wastewater disposal in injection wells.

The problem here, once again, is that we have Government pretending right along with industry that there is not a single negative consequence of fracking industrialization… and is altering the science accordingly.

What are we supposed to do when our government misinforms us, misleads us, so that we are less equipped to protect ourselves from obvious risks to public health and safety?

The level of mass industrialization of rural American due to fracking is truly unprecendented in American history. Regulating fracking is an absurd notion, and that has been demonstrated by the practice of other states, due to both staffing issues and the lethargic enforcement activity of states. While Texas had over 13,000 wells drilled in 2012, oil & gas companies were caught in 55,000 violations of state fracking laws, with only 2% of those violations actually being enforced.

The only way that extraction industries exist at all is by leveraging risk. Corporations much prefer leveraging the risk of others, rather than taking that risk on themselves. That is standard operating procedure for oil & gas extraction companies ~~like oil & gas~~, because their real and actual costs of doing business with so called externalities internalized, is always far greater than any revenues that can be generated from such activities.

~~EXAMPLE OF COAL:~~

~~Harvard Medical School Study~~

~~State of Illinois's deal with coal~~

However, they are open for business if they can find someone to take on that risk for them… this is where the government comes in and provides them with the perfect solution: we won't make you clean up after yourselves, and you pass those exorbinent costs onto the unsuspecting public in the form of degradation of their environment and compromising their personal health.

We are not just merely the collateral damage of the toxin-laden extraction processes of fossil fuel industries, we are THE COLLATERAL ITSELF that allows this transaction to take place between the state and the industry.

We are human bargaining chips, and our value to the industry is in our declining health, our increasing hospital bills, our rising insurance premiums, and the funerals of those most vulnerable among us. As long as the oil & gas industry does not have to clean up after itself, those are the costs that we, THE PEOPLE, will be paying.

The strongest regulations would result in none of us dying from fracking, and the only way to achieve that end is to ban fracking, which is not only *the only* rational choice to make, but it is also the only constitutional and moral choice to make. Let us never forget that Article XI of the Illinois Constitution guarantees our "right to a healthful environment for the benefit of this and future generations." That would make fracking… an epic fail.

Peace out.

Chelsee Bradey

They say that this is inevitable. That horizontal hydraulic fracturing is our future, that somehow loose regulations will spare us from watching this beautiful place that we grew up in, or traveled to, turn into a toxic wasteland. They try to tell me that my family will be safe, that our wells will not be affected by the hundreds of chemicals that they plan on pumping into the ground. They say that the soil and the stream that we've built our farm around will remain as clean and usable as it is today. They also say that if they do, by chance, poison our water they will kindly give us at least $50 to make up for the damages.

For those of you that have built your homes and raised your families in this area, especially those of you that do not get your water from the city, but instead have a well on your property please remember this.

Do not lease your land to a hydraulic fracturing company.

Fifty dollars will not come close to covering the cost of having to get your water delivered to you on a truck for the rest of your lifetime, because no one will ever want to purchase your land once it has been depleted of its resources.

Even with this being said chances are you do not own your mineral rights, which means that even if you don't lease your land, according to them this doesn't matter, because they don't want your land, they want the minerals beneath it.

If you don't own these rights you can wake up one morning to find a natural gas well being built on your property even if you didn't approve of this.

Even more importantly, if you do get your water from a private well I urge you to look into purchasing your water rights. This way if their prophecy comes true, and your water becomes contaminated you can sue the natural gas companies for everything you will be put through.

They say that their regulations will prevent us from ending up like those in Oklahoma. They say that even though they are creating mini earthquakes beneath the ground, we will not be affected. For those of you that are not from this area, we live on a major fault line. Not that many years ago I was woken up in the middle of the night by an earthquake. It will happen again, and it will be worse than the last one. You cannot be here in this room today and tell me that it is okay for me to sit back and watch all of the fresh water springs, lakes, streams, and swamps that I spent every long day of my childhood playing in, be destroyed.

And that it is economical.

New information is being leaked everyday about how **un**economical hydraulic fracturing really is. The conservative business magazine Forbes argued a while back that the cost-effectiveness of fracking was a fantasy and that "we can expect some staggering investment errors" because what it's all about is "some very stupid money chasing, an **illusion** that will surely end in tears." The head of Shell Oil said recently that investing $24 billion in fracking was one of his biggest regrets, as he writes down huge losses along with other operators like H.P. Billiton, Chesapeake, Encana. Some CEOs have even lost their jobs over it.

Hydraulic fracturing, like extracting tar sands oil, is very expensive. It is also very short-lived. Production declines by as much as 50 per cent or more in the first year, as much as 80 per cent by the second. To keep gas coming you have to keep fracking. The industry — even at a loss — has flooded North America and driven prices below the cost of production.

For those of you that are in support of hydraulic fracturing because America will have its own source of

022416

natural gas, used solely for the purpose of powering our country, that is also a fantasy.
All of it will not stay here, there is already talk of building terminals to ship gas overseas from North America.
They say that this will be our future, and that it has to happen but it doesn't. They may have their forces but I've met many people along the way that lose sleep at night for building the roads and foundations for these plants. We are prepared to join together and do whatever it takes to prevent this from taking place in this area. We are prepared to join together in a barricade to protect the resources and natural beauty that belong to us.

Sarah Baumgartner

IDNR proposes to fine violators of the rules from $50 to ~~$2,500~~ $500 per violations. Most of the companies that will be conducting the hydraulic fracturing make tens of millions of dollars, or in many cases even more. "Accidents" are inevitable if hydraulic fracturing were to take place, and the evidence behind this statement is roaring through the Earth, from the mouths every being that now has to live with the after effects of fracking. Such minor penalties for violation of water resources are not worth the repercussion of an inevitable accident.

The well being of the people rests in the quality of fresh water. We can't make new water, and we cannot depend on melting glaciers, or shipping our water in by trucks. How can these huge companies threaten our water supply and not be considered a public health threat to the nation? Man thinks whatever witty laws he creates are somehow superior to the laws of Mother Nature, but the laws of nature will surely deflate the laws of man. Here in Southern Illinois many people are living off potable well water in the areas of proposed fracking sites. Some of these people are my family and friends. We are harboring the confluence of the Mississippi and the Ohio River. If one water body, whether it be aquifer, stream or river, is polluted all water bodies will be affected by the inevitable effects of hydraulic fractruring. The confluence of the Mississippi and Ohio River are part of a major watershed that travels through many states, nurturing birds throughout their migration, feeding the bellies of fishermen, and harmonizing with the Gulf of Mexico.

For those of you who are not familiar with the Cache River wetlands, it is home to Cypress and Tupelo tress that have lived many millennia. It has experienced its own fight, and has made a phenomenal recovery. The Cache River wetlands are a gold mine of bio-diversity, and shelter a very special bird that has barely fought its way off the endangered species list. That bird is the Prothonotary Warbler, people come from all over to see this bird, and they ~~only~~ nest along the swamps of the Cache River. As do Great White Egrets, Belted Kingfishers, and Barn Owls. Over 300 different birds migrate along the Mississippi and Ohio River to nest or pass through Southern Illinois. If the watersheds were contaminated not only will it affect the health of a human body, but also it will greatly affect these birds, and they will not return.

We are here to join hands in solidarity with the people of New Brunswick, Oregon, Pennsylvania, Alberta, New York, Oklahoma, United Kingdom, and Romania. There are thousands of hands locking together to barricade the road that would allow such an ethically blind industry to poison the waters, air, and soil. The people behind these companies need to remember, they are only human and they are part of the congruent system we call Earth. Hydraulic fracturing will not happen in Southern Illinois and we will join hands until this heinous act ends throughout the World. We are strong. We came here to fight.

No Fracking

My opposition t o Fracking relates to my concern about global warming. I feel we have to acknowledge the ~~the reality that, in addition to GW and the~~ indisputable fact that polar icecaps are melting at unprecedented rates. Fracking poisons the ground under our feet. This is not ~~just about~~ only Antarctica.
GW* is a huge problem in its scope, ~~and~~ it effects the health of this planet, our home, and all of our lives as individuals. It is easy in the face of such a HUGE problem to DENY that it is real. However, denial is never a responsible action. If one is diagnosed with heart disease it is not wise to deny the problem and ignore the symptoms, as the result my be death.
If money and RESOURCES ARE FOSCUSED ON ENERGY SOLUTIONS, THEY NEED TO BE SUSTAINABLE AND NON POLLUTING. Start up costs to enact a less traditional plan to produce energy would be high, but it is what is necessary to be sustainable.
Fracking is supported only by those who have something to gain financially, regardless of its effects on the local population and environment. Decisions need to be made for long term health of the whole.

Patty Weyhrich
pweyhrich711@hotmail.com
December 19, 2013

Problem is toxins released ~~to a given area~~ to the air + water will not stay confined

Problem: toxins released into the air and water will not stay confined to a given area.

*GW = Global warming

Judy Jordan from Anna

*My comment is on the loophole exemption for non water fracking Non-Section 145.100 Applicability*

We are ~~additionally~~ very concerned that the Department has not adequately specified how it will address those types of hydraulic fracturing operations in which water is not the base fluid or not the only base fluid – for example, fracturing operations using nitrogen or carbon dioxide (gas fracs) or fracturing that uses mixtures of gas and water (e.g. foam fracs, mist fracs). There are several issues that must be addressed.

One ~~issue~~ is that the law defines the applicability threshold using gallons of base fluid. Gallons are unit of volume used to measure liquids. As such, it is not clear how the applicability threshold should be calculated for base fluids that are gases, or mixtures of gas and liquid. The situation is complicated by the fact that nitrogen used in fracturing is typically transported as a liquid but injected as a gas. The concern is that, if non-water base fluids are accounted for as liquid gallons, the gallonage total will fall below the applicability thresholds, even though the fracturing job is comparable in scale – and therefore risk – to a water-based frac in terms of chemical use, pressures, or other measures. We note, in this regard, that although the legislature provided no scientific support for the selection of the chosen threshold numbers and did not explain the origin of these numbers, we have surmised that the origin of the 80,000 gallons per stage and 300,000 gallons total thresholds are likely derived from New York's proposed regulations. However, New York derived these thresholds from a very limited analysis of volumes of base fluid used in *water-based* fracturing – not gas-based fracturing. Water based - NOT gas.

Thus, the Department needs to come up with an appropriate means to express the threshold of applicability as it applies to non-water fracs. The key parameter for developing a comparable threshold should be identifying comparable risk. Addressing the problem by simply converting the water-based thresholds from gallons to cubic feet or another unit of volume appropriate to measure gases is not scientifically sound and does not sufficiently manage risk. A threshold derived in this way would be completely arbitrary and wholly divorced from the real environmental and health risks posed by such non-water fracs. Thresholds for gas-based fracs must be developed independently based on an evaluation of risk and field data from gas-based fracs.

In addition I would like to add that it is known that all U.S. politicians from the president to the local city council [illegible] only consider events which will occur in the next 90 days and the effects of fracking will be years coming. But I would like for you in adopting rules to consider not the next 90 days but your personal reputation or legacy. Maybe it will be 10 years, maybe it will be 50, maybe I will be dead, maybe you will be but do you want future generations, your own grandchildren, 22420

To look back on this. To look back on you, with the same ~~hatred~~ shame. The same horror

The same hatred we now look back on people of the 50s [fifties] who were spitting on black children? Do ~~not~~ ~~then~~ not enact legislation which will ~~result in possible short term gains~~ cause your own grandchildren to ~~hate you~~. Think of you with shame, horror, and hatred.

~~Because~~ We ~~don't~~ may not think about future generations, but they will never forget us

- The wars of the future will be over water
- Over a year ago, Insurance companies in Saline County cancelled earthquake insurance on some homes & raised premiums on other.

622421

[1] Gas Technology Institute. November 23, 2010. New Albany Shale Gas Project, Final Report. Research Project to Secure Energy for America Project: 07122-16.
[2] Calculations assume: 1 scf nitrogen gas = 7.48 gallons nitrogen gas; 1 scf nitrogen gas = 0.01074 gallons liquid nitrogen
[3] See, e.g. Davies, R. J., Mathias, S. A., Moss, J., Hustoft, S., & Newport, L. (2012, in press). Hydraulic Fractures: How far can they go? *Marine and Petroleum Geology.;* Fisher, K., & Warpinski, N. (2012). Hydraulic-Fracture-Height Growth: Real Data. *SPE Production & Operations*, *27* (1), 8-19.

- A 2 year moratorium is certainly not an unreasonable request — → A ban would be the morally right thing to do

- I understand that you are concerned about the economy but communities in which hydraulic fracturing occur are Poorer when the companies finish & leave

- If insurance companies cancell earthquake insurance, then who will cover the costs when earthquakes occur? 5 million per incident? Not even close to enough.

022422

A 2 year Moratorium is NOT an unreasonable request

Dec. 19, 2013

Comment Submission for High-Volume, Horizontal Fracturing Draft Rules

The comment I have this evening is regarding the fact that there are no rules banning the use of highly toxic chemicals in the process. How can D.N.R. allow the use of all the very toxic chemicals being injected into our earth and still be protecting our natural resources.
The list of chemicals used is in the 100s. Why aren't these being regulated?

Lucia Amorelli
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62958

022424

My name is Luke Schroeder. I'm a Carbondale resident and SIU student. My comment is in regards to Section 245.900e of the proposed Rules. This section allows gas companies to be exempt from regulation of runaway natural gas and hydrocarbon fluids in the case that the regulation is "economically unreasonable" or is not "cost effective". This might not be so concerning if the terms "cost effective" and "economically unreasonable" were defined in the rules--but they are not. Because of this gas companies will be given the privilege of defining what these terms mean. Further, lack of clarity in this section of the rules could allow gas companies to legally pollute if they've determined not doing so would be "economically unreasonable". Section 1-53 of the regulatory bill requires that fracking operations be conducted in a "manner that will protect the public health and safety and prevent pollution." It does not say that fracking operations will be conducted in a manner that will protect the wallets of the gas companies at the expense of the environment.

Please do not give the gas companies the privilege of defining these terms. In their minds, protecting public health and safety and preventing pollution may be things that they feel are "economically unreasonable" and may not be things that they feel are "cost effective". The costs of the inevitable damages from fracking on the environment and on southern Illinois residents must be quantified, and these costs must be paid by the gas companies.

**My comment pertains to the definition of "Aquatic Life".**

**In Section 245.110** of the Proposed Hydraulic Fracturing Regulatory Act administrative rules, it states: "Aquatic life" means all fish, reptiles, amphibians, crayfish, and mussels.

**The Problems with this section are:**

First, this definition is too narrow and does not include many other species that may be important to an aquatic ecosystem. Aquatic life cannot be understood apart from the larger aquatic ecosystem which sustains it. And second, freshwater ecosystems, the limnology, not only include fauna, but also flora (plants), micro/macro invertebrates, oxygen levels and algae, for example.

**Why these are problems:**

First, by exclusively focusing on a limited definition of "aquatic life" it unnecessarily narrows the impact to the larger ecosystem that sustains it. Second, by the time a fish kill occurs, pollution caused by fracking will have reached a critical stage, causing havoc across the larger ecosystem and third, it neglects the biological criteria for the protection of aquatic life.

**The Revisions Needed:**

The definition of "aquatic life" must be broadened to include "aquatic ecosystems" and specific scientific standards must be developed to include: a) Biological standards, b) High quality water resources, c) Modified or limited water resources, and d) Stressor identification.

Why is this important to me?

I feel that humans on a whole tend to forget we are not the only species living on this planet and that we must recognize the "non-charismatic" creatures to be just as important if not more so, as the larger "fish, amphibians and reptiles" use these creatures as food sources, both in water and on land, as in the case of terrestrial insects having aquatic larval stages, like dragonflies, damselflies, mayflies, and stoneflies to name a few.

Humans are a part of the ecosystem and what is destroyed on a microscopic level will eventually destroy us as well. If we don't stop this foolishness, your children, my children, our grandchildren will pay the price of power mad megalomaniacs who love money more than the air they breathe and the water they drink.

**"...When law and morality contradict each other, the citizen has the cruel alternative of either losing his moral sense or losing his respect for the law. These two evils are of equal consequence, and it would be difficult for a person to choose between them."**

**Frédéric Bastiat**

When the USGS regulates water they look at it as all being from the same source because there's no way to keep all the water separate. It can't be done. How will IDNR make decisions about fracking chemicals based on scientific research when that data doesn't exist in a single location with compatible formats across Illinois to analyze groundwater-quality?

The report below is concerned with the increase in chloride in shallow water sources.

In the Southern Illinois University, RG 32 Office of Sponsored Projects Administration, Series IV: Illinois Groundwater Conservation Consortium Files, Walt Kelly gave his talk at the Illinois Groundwater Consortium meeting on 4-22-2003. He said:

"It is clear from our analyses that the regional shallow groundwater quality in northeastern Illinois has been degrading over the last several decades, especially in the collar counties (DuPage, Kane, McHenry, and Will). It appears widespread road salt runoff may be a prime culprit in this degradation as evidenced by the rapid increase in chloride concentrations. The shallow aquifers are likely to be heavily exploited in the next few decades in the collar counties due to residential and commercial development. It would be prudent for governing bodies in northeastern Illinois to take steps to improve protection of shallow groundwater resources and limit surface-derived contamination. Because of slow travel times in groundwater, however, it will likely be many years before the chloride concentrations return to pre-1960 levels even with effective protection strategies.

He didn't get funding for the grant he was proposing. So can we assume data doesn't exist in a single location with compatible formats across Illinois to analyze groundwater-quality?

***C'mon we don't even regulate salt on the roads going into the water. Do you really think we can regulate 600 toxic chemicals rusting through metal and crumbling concrete thousands of feet below the aquifers?***

Fracking is the largest engineering projects humans have ever attempted. The scope is immense. The scale in terms of time, resources, and (catastrophic) results makes me wonder how any company make promises regarding fracking.

Louis W. Allstadt, an executive vice president of Mobil Oil who ran the company's exploration and production operations in the western hemisphere works against the fracking industry in his retirement. He describes the problems we face:

"... What you [also] don't know [is that] when you plug that well, how much is going to find its way to the surface without going up the well bore. And there are lots of good indications that plugging the well doesn't really work long-term. There's still some pressure down there even though it's not enough pressure to be commercially produced. And sooner or later the steel casing there is going to rust out, and the cement sooner or later is going to crumble. We may have better cements now, we may have slightly better techniques of packing the cement and mud into the well bore to close it up, but even if nothing comes up through the fissures in the rock layers above, where it was fracked, those well bores will deteriorate over time. And there is at least one study showing that 100 percent of plugs installed in abandoned wells fail within 100 years and many of them much sooner."

Concrete crumbles. Steel rusts. In the United States since the year 2000, sixteen bridges have collapsed. The Federal National Bridge Inventory reports 85,000 U.S. bridges are in bad shape and need to be replaced. The fracking industry uses concrete and steel to keep deadly chemicals out of our drinking water. They bury steel pipes thousands of feet underground, use a little firecracker to put holes in the metal, fill them with fracked water, effluents and sand, put them under a tremendous amount of pressure, wait for 20% to 80% of the toxic and radioactive wastewater to come out, and then seal the rest of the water inside the steel pipes with an inch of concrete. You don't have to worry that fracked water is poisoned with more than 600 toxic and radioactive chemicals. Out of sight is outta mind.

Why are we betting against a natural process everyone understands and expecting everything to work out to our advantage? All steel rusts. Doesn't that single fact unhinge all the fracking science? They repaint the Eiffel Tower every 7 years with 60 tons of paint to preserve it. Who is going to check the steel pipes in a few generations when all the fracking money is gone and the pipes are still down there in the dark getting rustier and rustier and rustier? Don't be fooled. They are going to hand this problem back to you and you're the one who will have to find the solution. Not them. They're in it for the money and if you'll sell your water cheap, they'll certainly take that to the bank.

Louis Alstadt also says:

" I think we have wasted a lot of time that should have gone into seriously looking into and developing alternative energies. And we need to stop wasting that time and get going on it. But the difficult part is that the industry talks about, well, this is a bridge fuel [that] will carry us until alternatives [are developed] but nobody is building them. It's not a bridge unless you build the foundations for a bridge on the other side, and nobody's building it.

http://truth-out.org/news/item/17605-former-mobil-vp-warns-of-fracking-and-climate-change

* Earthquakes go hand in hand with fracking. Since we are between two active earthquake zones, you're going to want to take a look at Brent Ritzel's report. Here's the link.

http://fullerfuturefest.com/fracking-industrialization.../

* The USGS says we should treat water as if it is all coming from the same source because it does. We can't keep it separate. Fracking operations dump 10 trillion gallons of toxic liquids into Class II injection wells using broad expanses of the nation's geology as an invisible dumping ground. Add that to the 20 trillion gallons that are polluted by agriculture and pharmaceutical companies and we have a problem.

* The Bonds the fracking companies put up to do the work won't be high enough to clean up the environment; if anything goes wrong it'll be up the taxpayers to flip the bill.

* Your infrastructure is going to be undermined. That goes for roads, utilities, health care and police.

http://fullerfuturefest.com/special-roadway-degradation-costs-due-to-mass-fracking-industrialization/

* Crime rates are going to sky-rocket ... especially crimes against women because of the kinds of people these jobs attract. They are drifters with high risk jobs, working hard and playing harder.

* Fracking is a 24 hour round the clock operation. The noise is not going to end. The lights are never going to go off. The industrialization of your lives will be complete. I guess with fracking industrialization operations a mile apart, there won't be much wilderness left even in rural areas. National parks aren't even safe.

* When the fracking lottery comes to town, some people will make money selling their mineral rights. Some people will get poisoned. Doctors won't know what people are poisoned with because the industry doesn't want to divulge the ingredients of its fracking effluent. They're protected as trade secrets. Rest assured with hundreds of toxic ingredients, fracking effluent is even more toxic once you put those poisons together. Many ingredients have 10 serious health side effects on their own.

http://www.chicagotribune.com/health/la-sci-fracking-health-20131217,0,3773489.story?fb_action_ids=10202011715109678&fb_action_types=og.recommends&fb_ref=s%3DshowShareBarUI%3Ap%3Dfacebook-like&fb_source=aggregation&fb_aggregation_id=288381481237582

* And you know we're going to run out of clean water, right? According to the United Nations, water use has grown at more than twice the rate of population increase in the last century. By 2025 and estimated 1.8 billion people will live in areas plagued by water scarcity with two thirds of the world's population living in water-stressed regions as a result of use, growth, and climate change.

The millions of gallons needed for each frack are purchased from local suppliers; this water typically originates from aquifers

http://ga.water.usgs.gov/edu/earthgwaquifer.html

When a water-bearing rock readily transmits water to wells and springs, it is called an aquifer. Wells can be drilled into the aquifers and water can be pumped out. Precipitation eventually adds water (recharge) into the porous rock of the aquifer. The rate of recharge is not the same for all aquifers, though, and that must be considered when pumping water from a well. Pumping too much water too fast draws down the water in the aquifer and eventually causes a well to yield less and less water and even run dry. In fact, pumping your well too fast can even cause your neighbor's well to run dry if you both are pumping from the same aquifer.

http://en.wikipedia.org/wiki/Ogallala_Aquifer

The USGS has performed several studies of the aquifer, to determine what is coming in (groundwater recharge from the surface), what is leaving (water pumped out and baseflow to streams), and what the net changes in storage are (rise, fall or no change — see figure above).

Withdrawals from the Ogallala Aquifer for irrigation amounted to 26 km3 (21,000,000 acre·ft) in 2000. As of 2005, the total depletion since pre-development amounted to 253,000,000 acre feet (312 km3).[5] Some estimates indicate a remaining volume sufficient for as little as 25 years. Many farmers in the Texas High Plains, which rely particularly on the underground source, are now turning away from irrigated agriculture as they become aware of the hazards of overpumping.[6]

http://www.nytimes.com/2013/05/20/us/high-plains-aquifer-dwindles-hurting-farmers.html?pagewanted=all&_r=0

"...That's prime land," he said not long ago, gesturing from his pickup at the stubby remains of last year's crop. "I've raised 294 bushels of corn an acre there before, with water and the Lord's help." Now, he said, "it's over."

"...And when the groundwater runs out, it is gone for good. Refilling the aquifer would require hundreds, if not thousands, of years of rains."

* Accelerated decline in aquifer storage

According to a 2013 report by research hydrologist, Leonard F. Konikow,[16] at the United States Geological Survey (USGC), the depletion between 2001–2008, inclusive, is about 32 percent of the cumulative depletion during the entire 20th century (Konikow 2013:22)."[16] In the United States, the biggest users of water from aquifers include agricultural irrigation and oil and coal extraction.[17]"Cumulative total groundwater depletion in the United States accelerated in the late 1940s and continued at an almost steady linear rate through the end of the century. In addition to widely recognized environmental consequences, groundwater depletion also adversely impacts the long-term sustainability of groundwater supplies to help meet the Nation's water needs."[16]

16 Konikow, Leonard F. (PDF). Groundwater Depletion in the United States (1900–2008) (Report). Scientific Investigations Report. Reston, Virginia: U.S. Department of the Interior, U.S. Geological Survey. pp. 63.

17 Zabarenko, Deborah (20 May 2013). "Drop in U.S. underground water levels has accelerated: USGS". Washington, DC: Reuters.

* Not to mention that natural is gas is the dirtiest fossil fuel when it comes to emitting methane in the atmosphere. Scientists agree that once the atmosphere hits CO2 concentrations of 450 ppm within 30 years "really bad things will start to happen including more dangerous storms, prolonged droughts, torrential rains and coastal flooding."

http://ecowatch.com/2013/07/09/peak-water-what-happens-when-wells-go-dry/

* June 2013 was the 340th consecutive month of above-average global temperatures

http://www.ncdc.noaa.gov/sotc/global/2013/6

Here's another recent story along those lines

http://www.bloomberg.com/news/2013-07-16/exxon-secrecy-over-ruptured-pipeline-may-mask-national-danger.html

"The world has quietly transitioned into a situation where water, not land, has emerged as the principal constraint on expanding food supplies."

http://ecowatch.com/2013/peak-water-what-happens-when-wells-go-dry/

"Brown warned that many other countries may be on the verge of declining harvests."

http://www.guardian.co.uk/global-development/2013/jul/06/food-supply-threat-water-wells-dry-up#comment-24941512

This is the playing field you should be considering when you start storing an endless supply of poisoned water for eternity. Check out these Mollewide Plate Tectonics Maps showing global paleogeography for the past 600 million years.

http://www2.nau.edu/rcb7/mollglobe.html

* The IDNR regulating radiation doesn't keep it from hurting anyone. If we want to find out what's beyond the Thunderdome, we're going to have to take care of the next generation. Not give our children harder problems to solve than the ones we have.

I support these regulations bc I believe that fracking

Open Will

Only 1 fracking reg

1 Pits [illegible]

Can cause just as much GHG emissions or more as Closed systems are much better increase yield rather than it go into then air

2 Disclosure Good

3 Recycling program

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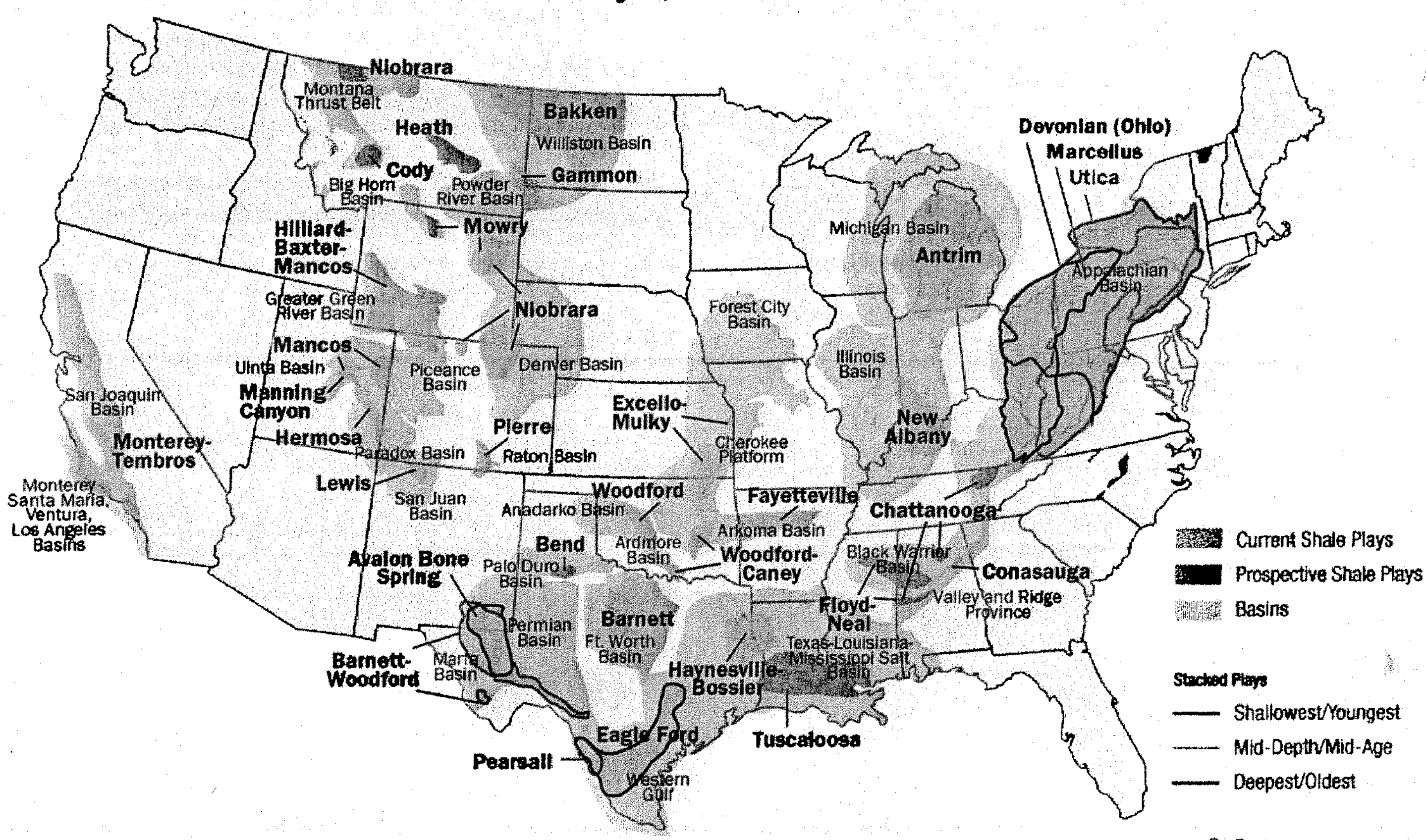
## Shale Plays, Lower 48 States



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My comment is on the definition of high volume horizontal hydraulic fracturing (HVHF) operations in the Illinois Hydraulic Fracturing Act [PA98-002, §1-5] and in its supporting Rule (§245.100(a)]. Pertaining to Non Water Fracks, the rule states "pressurized application of more than 80,000 gallons per stage or more than 300,000 gallons total of hydraulic fracturing *fluid*." It is clear from the overall framing of the law that the General Assembly is referring to gallons of water as "fracturing *fluid*" and expected the IDNR to work out the details on other base fluids. Instead, IDNR copies the definition for HVHF without respect to other methods of fracking. No other base fluids or formulas for converting non-water fluids to water gallon equivalents are provided in the Rule.

Water does not work well in shallow fracks and, as a result 100% nitrogen fracks are typically used in these close to the surface fracks. Apparently, there is not enough pressure in these shallow wells to drive frack water quickly back to the surface. Water therefore has time to interact with clay and cause swelling, and the swelling reduces the recovery efficiency of a well (Walser 2012; Ditoro 2012). Hence, the turn to nitrofracs which have been employed in Indiana, Tennessee (Little 2010), and Kentucky (Brashear 2012)

To become liquid nitrogen is cooled to -320°F. When it is pumped into the well liquid nitrogen quickly converts to a gas; *the expansion ratio during the liquid to gas shift is **1 to 696.5*** (Material Safety Data Sheet 1995). It is the gas, not the liquid, that fractures the rock. To compare 1 gallon of liquid nitrogen to 1 gallon of water is therefore absurd. There are other issues: a greater probability of "out of formation" fracks with the attendant risk of water pollution, especially in these shallow fields, and the high probability that raw methane will be vented into the atmosphere during well completion. I will present these issues in another letter.

**Conclusion: IDNR must provide formulas in revised rules for converting all non-water base fluids into water gallon equivalents.**

**Notes**

[1] This standard is informed by a growing and extensive body of evidence on the height of hydraulically induced fractures. See: Davies, Richard J. et al. 2012 (April). "Hydraulic Fractures: How Far Can They Go?" *Marine and Petroleum Geology* http://www.dur.ac.uk/resources/dei/JMPG_1575.pdf ;

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**Compliments of** William C. Rau, Spokesperson, Illinois People's Action & Professor Emeritus, Illinois State University, 313 Vista Drive, Bloomington, IL 61701-2123

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022435

Analytical Concerns to IL Hydraulic Fracturing Rules:

1. Metals tested should be indicators of both general groundwater quality and potential indicators for use to answer an inquiry concerning potential impact from hydraulic fracturing activity. As such, general water quality guidelines and typical indicators of deep formation waters would include the addition of Boron, Sodium, Potassium and Strontium to the list of metals indicated. Also, metals such as chromium, selenium, cadmium, lead, mercury, and silver are typically not indicators of either general groundwater quality or of deep formation waters and should be considered for removal from the Illinois list. The addition of mercury specifically, an indicator of industrial activity generally unrelated to oil and gas exploration, adds a more significant cost to the analytical suite with little benefit to the purpose of this program.
2. The list of anions suggested, chloride and sulfate, should also include Bromide. Bromide can be a general indicator of deep formation waters and is not typically associated with shallow groundwater aquifers.
3. Radiochemistry indicators gross alpha and gross beta – This non-specific testing may lead to some ambiguous concerns and may not be the most suitable analysis to address concerns related to Naturally Occurring Radioactive Materials (NORM). Typically of concern from deep shale formations are the water soluble daughters of Uranium and Thorium which are radium 226 and radium 228. These can be detected by gross alpha/beta testing, but this testing is not specific for only these water soluble isotopes. Positive results on Gross Alpha/Beta analyses can often occur form the presence of Potassium 40, which may simply be an indicator of presence of fertilizer residue in groundwater wells and not indicative of any activity related to oil and gas exploration. It is highly unlikely that water soluble isotopes from deep shale formations would be present in shallow groundwater aquifers, and unless other markers indicate the potential (previous data in other regions correlate the likelihood of radium detections with increased TDS levels and increased concentrations of Barium, with which radium co-precipitates), it is probably not a good use of analytical dollars to routinely test for radium and simple gross alpha/beta testing is not specific enough to be of general use.
4. Turbidity should be evaluated, and if turbidity exceeds a nominal value (generally 10 NTUs), metals should be filtered and analyzed as dissolved. The purpose of the evaluation is to evaluate the quality of the groundwater aquifer near radius to the proposed well pad. Metals that may be adsorbed onto solids or particulates introduced into the sample from the well bore may not give a true indication of the actual groundwater concentrations.

Not an analytical issue, and one we may want to ignore and let others address, but their number of samples and radius limits are pretty overboard. They say 1500', but then say that if no sources are found extend past 1500' until a source is found without putting a limit on that. The purpose is to evaluate the groundwater in the vicinity of the proposed well pad and if you extend out 1 mile or more from that location for your baseline sample I am not certain there is any relevance there. Also, there are no limits on the number of sources to test within that 1500' radius. At some point, if all sources penetrate the same aquifer, there is an "overkill" in both number of samples and cost to the program that becomes a burden unnecessarily I believe. 5-10 sources within that radius are more than sufficient to characterize the groundwater.


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ILLINOIS COALITION
AGAINST DOMESTIC VIOLENCE

One Mission, One Voice

To: The Illinois Department of Natural Resources
From: The Illinois Coalition Against Domestic Violence
Date: December 17, 2013

## On the HFRA Administrative Rules

Good evening, gentlemen. As I stated, my name is Noelle Dupuis, and I am the Director of Policy and attorney with the Illinois Coalition Against Domestic Violence. You might guess (and you would be correct) that our domestic violence organization feels it has little business instructing members of a department tasked with developing environmental regulations how to do their job. As an attorney, I understand the concept of talking past the point of contention, so I am not here to pretend our organization has the skill or knowledge to comment on the IDNR's draft regulations with any authority.

However, as an attorney, I also understand the concept of bolstering the credibility of one's witnesses. One argument we often hear in support of lax fracking regulations cites the number of jobs the new drilling process will bring into the state, insisting that fracking means a much-needed boon to our economy and therefore the citizens of Illinois.

But let's start with a narrative of how fracking affects rural communities in other states. Almost overnight, the populations of these small towns expand astronomically into what many journalists have called a modern "wild west" environment. Desperate for work, most of the men hired to do this hard physical labor come from other states. Unable to find affordable housing, these men are supported by oil companies in building shelter. They sponsor the creation of what the New York Times calls "man-camps" – thousands of trailers springing up from nowhere to house up to 6,000 men, according to reports.

As one would imagine, the crime rates in these communities skyrocket. In North Dakota, instances of forcible rape increased by 17.4% in 2012, reaching a state record of 243 reported rapes. In Williston, ND, assault and battery rose 171%. In that same year, the local domestic violence shelter reported that 83% of its clients were new to the area. This shelter was called on to provide 323% more nights of shelter to victims from 2009 to 2011. Law enforcement for the town now receives a report of rape once a week.

But it isn't just crimes against women that dramatically surge as fracking becomes the norm. In Watford City, ND and Roosevelt County in Montana, arrests increased by 565% and 855% respectively. Federal prosecutors report that boomtowns attract Mexican cartels to traffic methamphetamine and heroin. Law enforcement agencies state that DUIs and other alcohol-related incidents occur "at all hours of the day" in Williston. Towns in North Dakota that had eradicated prostitution now see organized rings busted with sting operations. A study from Food and Water Watch found a 17.1% increase in disorderly conduct arrests in Pennsylvania communities. The outcry from overworked law enforcement has lead the Department of Justice to announce last June that it will spend half a million dollars investigating the correlation between violence and the oil industry.


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www.ilcadv.org ~ ilcadv@ilcadv.org ~ phone: 217-789-2830 ~ TTY: 217-241-0376

All of these statements are supported by sources as reputable as the New York Times, CNN Money and ABC News, and I include such documentation with my testimony today. But why? Why does the Coalition feel it is important for you to know these facts when the IDNR is in no position to offer us the resources our domestic violence shelters will need when fracking inevitably begins in Illinois?

Because we believe in supporting our community partners who make up the population of the state that we call home. The people who have testified before you requesting strict regulations and harsh penalties for the oil companies that will frack our land are the ones who have been here all along, and they are the ones who will be left picking up the pieces long after the boom is over. They are our policemen and our prosecutors, our victim advocates and shelter volunteers, our doctors and our teachers. They are the ones whose testimony should carry the most weight with the IDNR – not that of the oil companies which will be at best invasive species to our state, and certainly not that of the few citizens who believe misguidedly that the jobs created by fracking will largely go to our residents. As you redraft these regulations, the Illinois Coalition Against Domestic Violence strongly urges you to regulate with the people of Illinois at the forefront of your minds.

## Hydraulic Fracturing and Violent Crime

- The Department of Justice announced in June it will spend half a million dollars investigating the correlation between violence and the oil industry.[1]

**In Illinois**

- All of southern Illinois is serviced by a total of 8 ICADV domestic violence programs, 3 of which are located in the greater St. Louis region.
- In southern Illinois, one program may service up to 9 different counties with emergency shelter for only about a dozen victims at any given time.

**In North Dakota**

- North Dakota saw a **statewide 7.2% increase in violent crime** in 2012.[2]
- 23,647 men were arrested in 2012 for various crimes, including rape, drug abuse, prostitution, and 'other' sexual offenses.[3]
- Instances of **forcible rape increased 17.4% in 2012**, reaching a state record of 243 reported instances of rape.[4]
- Aggravated assaults across the state rose from 289 in 2003 to 1,071 in 2012.[5]
- **In Williston**, located in a heavily fractured area, **assault and battery rose 171%.**[6] Crimes reported to police nearly tripled to over 16,000.[7] During the summer of 2012, the local police department received **1,000 9-1-1 calls during 3 months alone** compared to 4,000 between 2007 and 2009.[8]
    - Williston's local domestic violence shelter reported that at least **80% of victims served in 2012 were new to the area.**[9] This shelter is the only resource for victims in 11,000 square miles, serving a population of 30,000 people with emergency shelter space for only 11 victims at a time.[10] It spent $4,000 on emergency shelter at hotels for victims it could not accommodate between January and June of 2013.[11] Additionally, the resources expended to help victims relocate back home rose from $2,500 in 2011 to $13,000 in 2012.[12]
- **In Dickinson** – also located in a heavily fractured area – the community saw a **300% increase in assaults and a 314% increase in sexual offenses** in 2012.[13] The Criminal Investigations Unit in Dickinson is notified once a week that a new sex offender is moving to the area.[14] Individual police officers' workloads have increased so that one officer is now doing the work of four.[15]
    - Dickinson's local domestic violence shelter can provide in-house emergency shelter for only 18 victims in a county with a population of 24,199.[16]
- **In Grand Forks**, the local domestic violence shelter has seen a **30% increase in shelter nights** in the first nine months of 2013 alone.[17] It has 20 beds available for a county population of 67,472.[18] The city council voted this year to increase the program's budget by $23,000.[19]

**In Pennsylvania**

- In Bradford County, the local abuse and rape crisis center has reported an **increase in unknown assailant rape.**[20] The center has also confirmed an increase in domestic violence - primarily from gas industry families.[21] Its domestic violence program served **213 new victims in 7 months** versus 271 new victims during entire previous year.[22] The increase of **48 new child victims of sexual assault** served since 2009 was a major deviation from previous years.[23]
- Cases of **gonorrhea and Chlamydia have increased by 32.4% in heavily fractured counties**, with said increase 62% greater in rural fractured communities than rural non-fractured communities.[24]

**In Wyoming**

- In Sublette County, a report from the SocioEconomic Task Group found that **the increase in crimes and arrests over 6 years has a high statistical correlation with gas field activity.**[25] Crimes against people nearly doubled, most of which were assaults.[26] Within four years, **arrests have increased by 94%.**[27]
  - Clients served by the local domestic violence program in Sublette County have more than tripled since 2000.[28]

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[13] April Baumgarten, *Dickinson Crime Rates Increasing*, The Dickinson Press (2011) <http://www.thedickinsonpress.com/event/article/id/53283/>.

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[21] *Id.*

[22] James Loewenstein, Abuse & Rape Crisis Center reports "alarming" increase in the number of sexual assault victims, The Daily Review (2011) <http://thedailyreview.com/news/abuse-rape-crisis-center-reports-alarming-increase-in-the-number-of-sexual-assault-victims-1.1131154>.

[23] *Id.*

[24] *The Social Costs of Fracking: A Pennsylvania Case Study*, Food and Water Watch (2013) <http://www.scribd.com/doc/170377773/The-Social-Costs-of-Fracking>.

[25] *Monitoring Plan and Report*, SocioEconomic Task Group (2006) <http://www.sublettewyo.com/DocumentCenter/Home/View/364>.

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CAWS NORTH DAKOTA
ending sexual and domestic violence

# OIL PATCH FACTS

Oil discovery and development is helping grow communities and industry in western and central North Dakota. **The impact of more people affects sexual assault and domestic violence work, from shelters to client load.**

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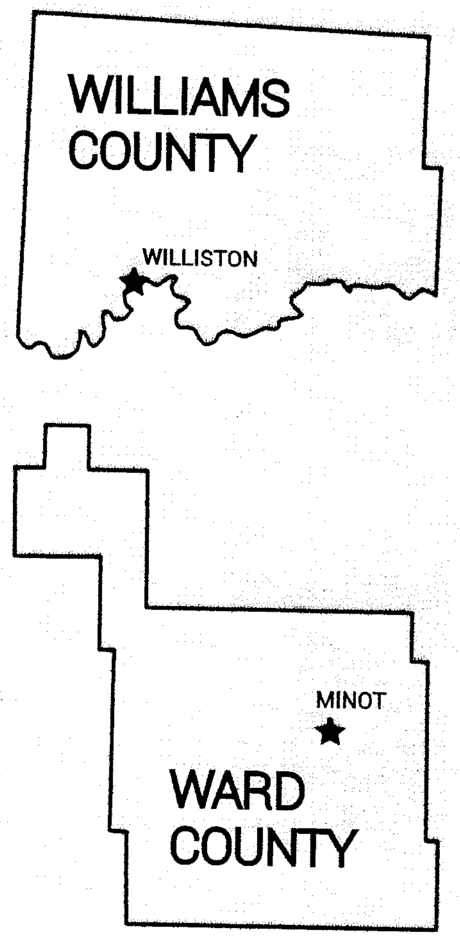



## NIGHTS OF SHELTER

In 2009, victims of domestic violence received **340** nights of shelter at a cost of **$30,600.** In just two years, that number jumped to **1,440**, at a price tag of nearly **$150,000.**

That's a **323%** increase in nights of shelter provided and a **370%** increase in budget

## MEALS PROVIDED AT SHELTER

In 2009, the Domestic Violence Crisis Center in Minot provided **7,464** meals at its shelter residence. For 2012, they are on track to serve **8,332** meals. The total number of clients served in 2009 was **1519.**

In just two years, the number has grown to **1865.**

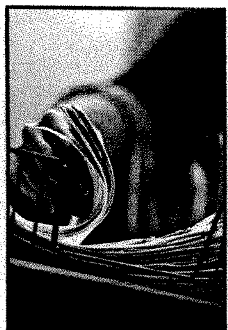
That's a **11.6%** increase in number of shelter meals served and a **22%** overall increase in client load

CAWS NORTH DAKOTA
ending sexual and domestic violence

# 2011-2012 FACT SHEET

The mission of CAWS North Dakota is to provide leadership and support in the identification, intervention, and prevention of sexual and domestic violence. **Here's a look at some of the ways our work is connected.**

## IDENTIFICATION



### BALANCING THE BOTTOM LINE:

The annual cost of **lost productivity in the United States due to domestic violence is estimated at $727.8M** with more than 7.9 million paid workdays lost per year

### TRAINING LAW ENFORCEMENT:

From Jan. 2011-Oct. 2012, **177 law enforcement officers were specially trained** in sexual assault and domestic violence focus areas, like model policy and victim response

## INTERVENTION

### GROWING TOGETHER:

**In Stark County, 80% of client load last year was impacted by oil,** meaning either the abuser worked in the oil field or victims in abusive relationships moved to the area to work in the oil industry

### RESPONDING TO SEXUAL ASSAULT:

Finalized sexual assault model policy for law enforcement, with **22 agencies attending trainings that previously had no formal sexual assault response policy**

## PREVENTION

### WORKING WITH MEN:

**One of only 23 initial Engaging Men grantees to work with men as allies** with a project addressing social norms and men's socialization in energy industry communities

### PASSING LEGISLATION:

Initiated and lobbied to pass **SB 2245, which extends unemployment benefits to victims of sexual assault or domestic violence** (NDCC 52-01-01, 52-04-07, 52-06-02)

CAWS North Dakota 525 N. 4th St. Bismarck, ND 58501 1.888.255.6240 www.ndcaws.org

The New York Times



November 30, 2013

# As Oil Floods Plains Towns, Crime Pours In

By JACK HEALY

SIDNEY, Mont. — One cold morning last year, a math teacher jogging through her hometown in eastern Montana was abducted, strangled and buried in a shallow grave. Charged in her death were two drifters from Colorado, drawn to the region by the allure of easy money in the oil fields.

One hundred fifty miles away, in a bustling oil town in North Dakota, a 30-year-old man disappeared one afternoon from the street where he had been putting in water and sewer pipes, leaving behind a lunchbox with his paycheck inside and a family grasping for answers. After months of searching, his mother said she now believes her son is gone, buried somewhere on the high plain.

Stories like these, once rare, have become as common as drilling rigs in rural towns at the heart of one of the nation's richest oil booms. Crime has soared as thousands of workers and rivers of cash have flowed into towns, straining police departments and shattering residents' sense of safety.

"It just feels like the modern-day Wild West," said Sgt. Kylan Klauzer, an investigator in Dickinson, in western North Dakota. The Dickinson police handled 41 violent crimes last year, up from seven only five years ago.

To the police and residents, the violence shows how a modern-day gold rush is transforming the rolling plains and farm towns where people once fretted about a population drain. Today, four-story chain hotels are rising, and small apartments rent for $2,000 a month. Two-lane roads are jammed with tractor-trailers. Fast-food restaurants offer $300 signing bonuses for new employees, and jobs as gas station attendants can pay $50,000 a year. Workers flush with cash are snapping up A.T.V.s, and hotel menus offer crab and artichoke dip and bac dates.

Amid all of that new money, reports of assault and theft have doubled or even police say they are rushing from call to call, grappling with everything from ba shoplifting to kidnappings and attempted murders. Traffic stops for drunken or reckless driving have skyrocketed; local jails are spilling over with drug suspects.

Last year, a study by officials in Montana and North Dakota found that crime had risen by 32 percent since 2005 in communities at the center of the boom. In Watford City, N.D., where mile-long chains of tractor-trailers stack up at the town's main traffic light, arrests increased 565 percent during that time. In Roosevelt County in Montana, arrests were up 855 percent, and the sheriff, Freedom Crawford, said his jail was so full that he was ticketing and releasing offenders for minor crimes like disorderly conduct.

"I don't have nowhere to put them," Sheriff Crawford said.

Officials say that most of the new arrivals are hard workers who are simply looking for better lives, and that much of the increase in crime has resulted from population growth: Waves of new residents inevitably mean more traffic crashes and calls to 911.

Police and sheriff's departments are responding by hiring more officers, in part with new tax revenue but often not fast enough to keep pace with their booming populations. In Dickinson, for example, the population has surged to an estimated 25,000 from 16,000 in 2000, with new hotels, condominiums and extended-stay inns being built every week. The city's police department has 38 officers, but Sergeant Klauzer said it would need to add 12 more to keep up with the growth. Each detective's caseload has doubled.

Once a month, Sergeant Klauzer receives a phone call from a mother looking for news about her son, Eric Haider, the 30-year-old pipe layer who vanished in May 2012, one of several disappearances in the region. Mr. Haider hated the tiring three-hour commute to his job in Dickinson, but the town's breakneck growth meant steady work and money to support his daughter, said his mother, Maryellen Suchan.

The family has made buttons and printed fliers with Mr. Haider's brown-bearded face, and has silk-screened T-shirts with the words "Have You Seen My Son?" The police dug up the streets and searched with dogs. As hopes dimmed, Mr. Haider's family began asking hunters and oil workers to look out for shallow graves. Not a trace has been found.

"It's a living nightmare," Ms. Suchan said. "There isn't a single day that we don't think of him, talk of him. I don't have an end."

Federal prosecutors say the boom's riches have attracted opportunists and criminals. Mexican cartels and regional methamphetamine and heroin traffickers have proliferated, hoping to tap the same sources of wealth that have turned farmers into millionaires and shaved unemployment rates to as low as 0.7 percent.

"It's following the money," said Michael W. Cotter, the United States attorney for Montana. "I hate to call the cartels entrepreneurs, but they're in the business to make money. There's a lot of money flying around that part of Montana and North Dakota."

Over the last year, the police and prosecutors in North Dakota, Montana and Canada have tried to crack down on drug traffickers and the most violent offenders systematically with an effort they call Project Safe Bakken, named for the rich oil formation under the plains. The F.B.I. is adding a handful of agents to the region. Federal officials have charged more than two dozen people they say were trafficking drugs into the area.

As more families arrive, domestic-violence shelters are also filling up, often with similar stories of troubled migrations. Families arrived hoping for $20-an-hour jobs, but discovered that modest homes rent for $2,000 and that things like gasoline and dinner cost more. The stresses of life piled up. Alcohol and drugs added to the problem. Old patterns of domestic abuse crossed state lines.

In Dickinson, mothers in the shelter sleep on couches with their children. In Williston, the small Family Crisis Shelter has added four sets of bunk beds and turned its living room into a bedroom to accommodate more people. The executive director, Lana Bonnet, said that 83 percent of her clients were from out of town, and that many had sought refuge after being choked, threatened with a gun or beaten until bones broke or teeth fell out.

While the raw numbers of murders and rapes remain low, every few months seem to bring an act of violence that flares like a gas flame on the dark prairie, shaking a community and underscoring how much life here is changing.

In Dickinson, it was the rape of an 83-year-old woman, who the police say was attacked inside her home by a 24-year-old man who had come to town looking for work. In Culbertson, Mont., it was a man who was beaten with brass knuckles by a group of drug dealers and left for dead along the side of a road. In Sidney, it was the murder in January 2012 of Sherry Arnold, the 43-year-old schoolteacher abducted during her Sunday morning jog.

Hundreds of people searched for Ms. Arnold in frozen fields, neighborhoods and ditches until her body was found in North Dakota, near a line of trees planted as a windbreak by farmers. After receiving a tip, the police arrested two men, Lester Van Waters Jr. and Michael Spell. Mr. Van Waters has pleaded guilty, and Mr. Spell is expected to go on trial in January. His lawyer has said Mr. Spell is mentally disabled.

After Ms. Arnold's killing, there was a run on pepper spray and stun guns in Sidney, and the town offered martial arts classes to women. Mayor Bret Smelser, who attended the same Lutheran church that Ms. Arnold did, said his wife had bought a small handgun to help her feel safer when he was away.

"Nobody knew anybody anymore," he said. "We were a community that never locked our doors. That's all changed."

# Domestic violence on the rise in oil country

## Housing, funding, drug problems major contributors

**September 3, 2013**

FLINT McCOLGAN (fmccolgan@minotdailynews.com) , Minot Daily News

Save | Comments (6) | Post a comment |

The astonishing growth of the oil-fueled western North Dakota economy has provided many opportunities for people from all over to find high-paying jobs in the industry. The accompanying growing pains have also choked city infrastructure and squeezed out much of the traditional way of life there.

One such negative impact on the rise is domestic violence.

"We really started noticing the numbers going up in 2009," said Lana Bonnet, director of the Family Crisis Shelter in Williston, who has been with the organization since 2006. The shelter offers housing, support and resources for an area of 11,000 square miles and an estimated population base of 30,000 people.

**Article Photos**

This modest building in Williston, capable of hous...

In 2012 the shelter served the needs of 262 victims and 130 victims so far from January to June this year, which is the latest



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victims so far from January to June this year, which is the latest data Bonnet had to look up.

By Bonnet's estimation, the shelter has seen maybe 45 days of non-consecutive vacancies since that year, saying that services have "just been non-stop."

The shelter itself has room for 11 people, all women and children. They assist men, too, but have to put them up in local hotels rather than the shelter itself.

The problem with that, though, is that despite new hotels and motels going up all the time in the area, they're not willing to work with the shelter for reduced rates, Bonnet said, "Because they can get the dollar amount they ask for" from the oil companies or other companies in the area making enough profit to afford the hotels.

The shelter has already spent more than $4,000 from January to June 2013 for hotel needs, but men don't make up a large part of their clientele. Instead, a big portion of their budget goes to relocating out-of-state women back to their hometowns.

"The biggest issue and the reason we send people back home is because there is no affordable housing," Bonnet said. "They come here thinking they could make a better life for themselves and their families."

With apartments still within the upper $2,000 per month to the $3,000 per month range, too many are priced out. And, for the housing contracted to oilfield companies, if there's a problem in the relationship the woman and the children will be the ones who have to leave for the man to continue to work.

Bus fare and other relocation costs incurred by the shelter rose from $2,500 in 2011 to over $13,000 in 2012. Costs are already over $5,000 through June of this year.

Speaking out: Contributing factors

"There's more strangulations, there's more violent assaults," Bonnet said. "There's contributing factors. Alcohol, drugs, overcrowding, homeless, we have a lot (of people) living in campers and RVs."

Then the stressors come out like cramped spaces, alcohol usage, crying children all making for an unstable mix.

"I don't know why it's getting more violent, but it is," Bonnet said.

"The first time I sought help was 14 years ago at this shelter," said April Stevens, who was working as the residential supervisor at the shelter at the time of this interview, and had been in the position since April. She has now left the state to start anew somewhere far from the man controlling her life for that whole time. "I left him in February. He pulled a gun on me high on methamphetamine."

The February leave was the final break of four total. She had made it out in May 2012 for a while and even got a good-paying job to support herself and her children until she slipped on a wet floor and damaged her back so badly that she was out of commission for a while and had to come back to him in November for support.

"I didn't have any other choice," she said. "I didn't think I did, anyway."

She was willing to speak with The Minot Daily News because she is "not ashamed" of her story and wanted to help shed light on the growing abuse in the region.

Stevens was born in Montana, along its border with North Dakota, and grew up in both states and is no stranger to the oilfield.

"As a matter of fact my whole life my dad was an oilfield welder," she said. "I was raised on rigs."

"I did think things were going to be better," she said. "Fortunately, or unfortunately, I got pregnant. He would drug me and make sure I got pregnant. He knew that would make me stay

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and it did for a long time."

That child will be 12 in September and will have moved away with her by now. Her other three children are adults and she is now a grandmother.

There's been a protection order against the man for a while now after their last altercation.

"He took after me with a shotgun and said he was going to shoot me in the basement and that it wouldn't be murder because the shells were loaded heavy and there'd be nothing left of me but bits."

Methamphetamine usage on the part of the man was a major contributor to her own abuse, she said. The women she got to support from her time working at the shelter shared many experiences and also talked a lot about the stress they were under.

She points to the lack of homeless shelters in the region as well as the "outrageously expensive" housing still available as ways stress can creep in. In fact, that's why she's moving away, she said, because she can't afford to live there anymore.

"If I wasn't married, I couldn't work at this job," Bonnet agreed, saying that her income is only supplementary to her husband's and that they couldn't afford to live there on her salary.

Stevens thinks that deposit funding would help a lot in terms of affordability of housing there.

"The landlords kind of lead you on a little bit, you know. Not a whole lot," Stevens said, although adding that it's not all their fault. "They're overwhelmed and it takes a very long time to get their paperwork done. ... It's heartbreaking."

Daycare availability is another oft-cited problem that keeps many women from the work they need.

"They're full," Bonnet said. "Daycares just cannot take anymore children so they're on a waiting list." She added that there's a waiting list for a lot of needs in the area.

"All of the resources that I can refer them to are overwhelmed," Stevens said of the victims she speaks with. "Breaking the cycle. That's a huge thing but I'm not sure that's something that the community can do ... Once you get in that cycle it's just so hard. It's like a love addiction."

Funding needs

The costs of feeding and housing so many people, nearly without break, throughout the year adds up and most of that comes from federal and state grants, but those haven't yet caught up to the increased demand in the area, according to Bonnet. Instead, funding becomes more community-based.

"Our tri-county area is great," Bonnet said. "They do give, not only donations (of food and items) but also money donations."

She even said that oilfield companies, which are often seen as the enemy by locals over their increased housing costs and the like, are "giving us huge donations."

There is a very generous anonymous donor who wants his money spent directly on the victims and their children, and then there's even a yearly St. Patrick's Day fundraiser put on by the Booze Fighter Motorcycle Club Badlands Chapter, which gave $25,000 to the shelter this year.

Bonnet said increased contributions by as little as $30,000 to $40,000 total per year would help them out tremendously.

Breaking the cycle

As for Stevens, she's out. But she learned a lot when she finally broke the cycle.

She said that support groups for the women helped a lot and that more are needed to reach the most people to share stories and strategies now that the whole thing has become much more a

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strategies now that the whole thing has become much more a community issue as institutional help is so overwhelmed.

"We have a Boundaries Group and ... we have a good turn-out for that," Stevens said. "It teaches you to put up a boundary so that you don't over-extend yourself ... it changes your thinking pattern so that you can learn to say no. ... I was controlled because I wasn't allowed to say no."

She's learned to say no and has helped others along the way.

"We become a family through our common trials and suffering and then figure out that we are not alone. We come in broken and leave victorious, because of each other," she said.

"Lana taught me how to have a whole new attitude," she said. "I'm putting on my repaired wings and I'm flying. I'm going for it."



**Minot Daily News**

301 4th St SE , Minot, ND 58703 | 701-857-1900

The New York Times

January 15, 2013

# An Oil Town Where Men Are Many, and Women Are Hounded

By JOHN ELIGON

WILLISTON, N.D. — Christina Knapp and a friend were drinking shots at a bar in a nearby town several weeks ago when a table of about five men called them over and made an offer.

They would pay the women $3,000 to strip naked and serve them beer at their house while they watched mixed martial arts fights on television. Ms. Knapp, 22, declined, but the men kept raising the offer, reaching $7,000.

"I said I make more money doing my job than degrading myself to do that," said Ms. Knapp, a tattoo artist with dark streaks in her light brown hair, a bird tattoo on her chest and piercings above her lip and left cheekbone.

The rich shale oil formation deep below the rolling pastures here has attracted droves of young men to work the labor-intensive jobs that get the wells flowing and often generate six-figure salaries. What the oil boom has not brought, however, are enough single women.

At work, at housing camps and in bars and restaurants, men have been left to mingle with their own. High heels and skirts are as rare around here as veggie burgers. Some men liken the environment to the military or prison.

"It's bad, dude," said Jon Kenworthy, 22, who moved to Williston from Indiana in early December. "I was talking to my buddy here. I told him I was going to import from Indiana because there's nothing here."

This has complicated life for women in the region as well.

Many said they felt unsafe. Several said they could not even shop at the local Walmart without men following them through the store. Girls' night out usually becomes an exercise in fending off obnoxious, overzealous suitors who often flaunt their newfound wealth.

"So many people look at you like you're a piece of meat," said Megan Dye, 28, a nearly lifelong Williston resident. "It's disgusting. It's gross."

Prosecutors and the police note an increase in crimes against women, including domestic and sexual assaults. "There are people arriving in North Dakota every day from other places around the country who do not respect the people or laws of North Dakota," said Ariston E. Johnson, the deputy state's attorney in neighboring McKenzie County, in an e-mail.

Over the past six years, North Dakota has shot from the middle of the pack to become the state with the third-highest ratio of single young men to single young women in the country. In 2011, nearly 58 percent of North Dakota's unmarried 18-to-34-year-olds were men, according to census data. That disparity was even starker in the three counties where the oil boom is heaviest — there were more than 1.6 young single men for every young single woman.

And most people around here say the gap is considerably larger. Census data mostly captures permanent residents. Most of the men who come here to work maintain their primary residences elsewhere and split time between the oil fields and their homes. And women note that many of the men who approach them are married.

Some women have banked on the female shortage. Williston's two strip clubs attract dancers from around the country. Prostitutes from out of state troll the bars.

Natasha, 31, an escort and stripper from Las Vegas, is currently on her second stint here after hearing how much money strippers made in Williston on a CNN report last year. Business in her industry is much better here than in the rest of the country, she said. She makes at least $500 a night, but more often she exceeds $1,000.

"We make a lot of money because there's a lot of lonely guys," she said.

On a recent night at City Bar in nearby Watford City, the only women in the long, wood-paneled room were two bartenders and the woman running the karaoke. Under flashing lights, some of the male patrons huddled at the bar, while others played games like simulated buck shooting and darts.

Zach Mannon, 23, who has been working in the oil patch for three years, said he once bumped accidentally into a woman in a bar packed with men. He excused himself, he said, but then her boyfriend came over and accused him of grabbing her buttocks. He denied it. The man insisted they step outside, so they did, but 14 of Mr. Mannon's co-workers from his rig came along. The man backed down, they talked things over and no punches were thrown.

For Mr. Mannon, having women around was more about finding sanity than a soul mate.

"Out here, you can't tell a guy, like, 'I had a rough day,' " Mr. Mannon said. "They're going to go, 'Everyone has a rough day. Get over it, you sissy.'

"The bartender," he added, nodding toward the bar, "she's the friendliest gal in the world. Every time I go in, she goes, 'How was your day, Zach?' I say, 'Ah, it was long; it was cold out.' She actually listens."

But sensitivity is often absent here when men discuss women. Here, men talk of a "Williston 10" — a woman who would be considered mediocre in any other city is considered a perfect 10 out here.

"I've noticed my standards dropping," said Ian Hernandez, 24, who moved to Williston from Chicago a couple of months ago. "I just went home two weeks ago. I saw the girls I had planned to see. That, hopefully, should hold me off until I go back next time in two months or so."

Some men have forced themselves on women.

Jessica Brightbill, a single 24-year-old who moved here from Grand Rapids, Mich., a year and a half ago, said she was walking to work at 3:30 in the afternoon when a car with two men suddenly pulled up behind her. One hopped out and grabbed her by her arms and began dragging her. She let her body go limp so she would be harder to drag. Eventually, a man in a truck pulled up and began yelling at the men and she got away, she said. The episode left her rattled.

Going out alone is now out of the question, and the friend she moved here with no longer has much time to spend with her because she has since found a boyfriend and had a baby. Ms. Brightbill said she has difficulty finding other young single women with the freedom to hang out. And, she said, finding good men does not come easy.

"It's just people trying to have sex," she said.

But some women have taken aggressive steps to protect themselves.

At the urging of her family, Barbara Coughlin, 31, who recently moved to Williston after her 11-year marriage ended, is now getting her concealed weapons permit so she can carry a Taser. Ms. Coughlin, who wore silver glitter around her eyes at work as a waitress on a recent day, said her mother and stepfather, who live here, advised her to stop wearing the skirts and heels she cherishes, so she does not stand out like "a flower in the desert," as her stepfather put it. Her family hardly ever lets her go out on her own — not even for walks down the gravel road at the housing camp where they live.

"Will I stay for very long? Probably not," she said. "To me, there's no money in the world worth not even being able to take a walk."

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*Kevin Quealy contributed reporting.*

abc NEWS

# North Dakota Oil Boom: The Dark Side

## Traffic, Crime and Noise Blight Williston, N.D., 'Kuwait on the Prairie'

**By ALAN FARNHAM**

**Feb. 2, 2012 —**

The good things the North Dakota oil boom has brought to little towns like Watford City, N.D. (population 1,744), you probably can guess. The bad? Maybe not.

Before the boom, the number of registered sex offenders in Watford City stood at zero. Today? Twenty-eight.

Williston ("Kuwait on the Prairie"), Watford City and their neighboring towns in North Dakota sit atop the biggest lake of oil to be discovered in North America since Alaska's Prudhoe Bay in 1968. That lake holds, by some estimates, 25,000 square miles oil. Eleven billion barrels of it can be tapped by using existing technology. Every day, about 100 new wells are drilled by some 150 oil companies that have moved here since 2006.

With the boom have come jobs and opportunity and money. Property values have skyrocketed.

Unemployment in North Dakota is 3.7 percent -- lowest in the nation. Williston's rate is 9/10 of one percent.

In many ways, life is better than before the boom: The public playground in Williston has a new jungle gym designed to look like an oil derrick and a teeter totter that looks like an oil pump. All in all, the playground has been beneficiary of $460,000 in improvements, all them of paid for by the local oil companies.

Thanks to the influx of workers, local merchants now sell more beer and bread and haircuts.

"We've got more retailers and more restaurants," says Williston Mayor Ward Koeser.

So, what's the bad news?

Rising rents mean families who have lived in these towns for decades now cannot afford to stay in the houses they called home. People who've never had to wait in line at the post office or the movies now have to wait. Noise is up, traffic up, congestion up. Crime, too.

"We never had any sex offenders before," complains Watford City mayor Brent Sanford. "That is, unless somebody local had had a rape or some kind of deal."

While the 2010 census says Watford City's population is 1,744, locals believe the number now may be as high as 7,000. An army of itinerant labor, almost all of it male, has flooded the region, attracted by the promise of good wages and lots of work. So-called "man-camps" -- prefab compounds thrown up overnight to feed and house these male workers -- dot the landscape.

022455

"They're all over the place," complains Sanford.

Mayor Koeser says Williston has 5,000 to 6,000 guys living in man-camps a few miles outside of town.

"When they come in to go to the bar, they don't always behave themselves," he says.

The proliferation of man-camps has become such an issue that Watford City last year imposed a moratorium on building any more of them.

"I moved here to get away from crowding, from commuter traffic," says Sanford. "It was peaceful. You'd drive the highway and see maybe one other car every 10 miles. Now you can't even count them. We've got 10,000 trucks a day, bumper-to-bumper. It's very nerve-wracking, very dangerous. Fatal accidents are up."

Dan Kalil, commissioner for the county where Williston sits, testified recently before the North Dakota legislature about the oil boom's impact.

"Our quality of life is gone -- absolutely gone," he said. "My community is gone, and I'm heartbroken. I never wanted to live anyplace but Williston, N.D., and now I don't know what I'm going to do."

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AMERICA'S BIGGEST BOOMTOWN

# Crime turns oil boomtown into Wild West

By Blake Ellis October 26, 2011: 6:46 AM ET

WILLISTON, N.D. (CNNMoney) -- As oil companies pump more and more crude out of the ground and workers from around the country arrive to cash in on the black gold rush, a new wave of crime has taken over the **once quiet towns** of Northwestern North Dakota.

Within the last few months, a Watford City pharmacy was robbed of $16,000 in narcotics, four people were stabbed at a local strip club in Williston, a semi truck crashed into an RV full of people sleeping and the first prostitution ring in decades was busted.

Last year, the number of criminal incidents reported to the Williston Police Department nearly tripled to 16,495. But that's only a fraction of the lawlessness the police have seen this year.

"The numbers we are seeing for this year will blow these out of the water," said Lieutenant David Belisle.

In a single month this summer, the department received 1,000 calls -- compared to the 4,000 calls it received in the three-year period between 2007 and 2009. This year, 9-1-1 calls to the department have already more than tripled last year's call volume, he said.

**America's Biggest Boomtown**

Thefts at residences and retailers -- especially jewelers and convenience stores -- have jumped precipitously, with police responding to 40% more burglar alarms last year than the previous year.

Many of the thieves are looking for prescription drugs like Oxycontin -- which are being stolen from residences and drugstores.

Josslyn Finck, the manager of Barrett's pharmacy in nearby Watford City, said someone recently torched the steel door of her pharmacy and stole $16,000 of narcotics in the middle of a power outage. Before this year, small incidents of shoplifting -- like someone pocketing a Chap Stick -- were the only crimes she had encountered.

The break-in at Barrett's was one of a string of similar incidents at pharmacies that began this year, said Detective Lieutenant Mark Hanson, who has worked 34 years as an officer and was born in Williston.

According to the police department, prescription drug abuse and prescription forgery are on the rise and a growing number of oilfield employees are failing their urinalysis tests.

Alcohol-related incidents are also surging. And since oilfield employees work around-the-clock shifts, police have to remain constantly vigilant.

"Our D.U.I.s are ranging throughout all hours of the day, our alcohol-related assaults are ranging throughout the day, our foot pursuits and vehicle pursuits are ranging throughout the day," said detective David Peterson.

Assault and battery incidents in Williston rose 171% to 38 charges last year. Two years ago, there may have been three-to-four violent crimes a week. Now, it's an average of two or three a night.

"Violent crimes in our night clubs, family violence -- all of that has increased," said Peterson. "We get calls from people who are going home at night after the club has closed and they're at an intersection and somebody they don't even know will pull up beside them, maybe make a comment to them, and then physically assault them."

The **lack of housing** seems to be a huge driver in the uptick in violence, said Peterson.

**Locals to big oil: We want our town back!**

"What we have here is a lot of people who are working who don't necessarily have their own home to go home to at the end of the day where mom and the kids are at," he said. "I think the tensions, and the stressors, are greater for that person living under those conditions."

Those tensions and stressors have also helped revived an age-old profession: prostitution.

The small towns surrounding the Bakken formation haven't seen prostitution since the last oil boom in the 1980s, said Hanson. But just this month, a prostitution ring of four women was busted through a sting operation by the Williston Police Department, and several other rings are currently being investigated.

"Where there's money and there's men around that are here by themselves -- and men do outnumber the women considerably in the area right now -- that's something that's going to happen," said Hanson. "And I expect more of it."

Reports of rape, which were rarely reported before the boom, now occur once a week in Williston, said Peterson (but he stressed that these are typically rapes conducted by someone who knows the victim).

The police department is struggling to keep up.

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Last year, the Williston Police Department added five officers, bringing its total ranks to 26. It plans to add another six at the beginning of next year. But bringing in new recruits has been tough.

"It's an explosive growth rate where our administration is doing the best job it possibly can to staff for our needs, but it's a staffing nightmare," said Peterson.

Until the infrastructure catches up and the police force has the bandwidth to take preventive measures instead of simply reacting to the steady flow of criminal reports, it's hard to be optimistic about reducing the amount of crime in the area.

"It's a rat race every day, and the rats sometimes win," said Hanson. "We're almost to the point of being overwhelmed, and a lot of times we are."

*Are you living in a boomtown? If you know of an area where jobs are plentiful and high paying, and resources and housing are scarce, e-mail* ***blake.ellis@turner.com*** *for the chance to be included in an upcoming story on CNNMoney.* ■



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ILLINOIS COALITION AGAINST DOMESTIC VIOLENCE

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Director of Policy

# NRDC/ELPC DRAFT LIST OF ISSUES
# 11-25-14

## *I.* ***MAJOR ISSUES OF LEGAL INSUFFICIENCY OR DIMINISHED PROTECTION***

### Section 245.100 Applicability

There are two major problems with this section: the unauthorized constraint on the reach of the Act's retroactivity, and the lack of means to address fracturing that does not use solely water.

*1. Retroactivity*

With respect to retroactivity, this section limits coverage of previously-commenced fracturing operations to those operations that "have occurred since June 17, 2013." The Act, however, contains no such time limitation on retroactivity. It states at Section 1-20 that the Act "applies to all wells where high volume horizontal hydraulic fracturing operations are planned, *have occurred*, or are occurring in this State" (emphasis added).

We understand that applying the Act to operations that commenced in the past is potentially complicated; and we are not advocating that the Act be interpreted to reach back to require remedial changes to activities that were permitted prior to the Act's effective date. However, the Department should require reporting of past activities that are covered pursuant to the applicability threshold (*e.g.*, the Campbell well), and require that ongoing activities comply with the Act to the extent feasible – for instance, the operator would not have to go back and re-perform drilling activities that did not conform to the Act, but would have to comply with ongoing obligations such as air emissions control requirements associated with production and post-frack reporting.

*2. Non-water fracks*

We are additionally very concerned that the Department has not adequately specified how it will address those types of hydraulic fracturing operations in which water is not the base fluid or not the only base fluid – for example, fracturing operations using nitrogen or carbon dioxide (gas fracks) or fracturing that uses mixtures of gas and water (e.g. foam fracks, mist fracks). There are several issues that must be addressed.

One issue is that the law defines the applicability threshold using gallons of base fluid. Gallons are unit of volume used to measure liquids. As such, it is not clear how the applicability threshold should be calculated for base fluids that are gases, or mixtures of gas and liquid. The situation is complicated by the fact that nitrogen used in fracturing is typically transported as a liquid but injected as a gas. The concern is that, if non-water base fluids are accounted for as liquid gallons, the gallonage total will fall below the applicability thresholds, even though the fracturing job is comparable in scale – and therefore risk – to a water-based frack in terms of chemical use, pressures, or other measures. We note, in this regard, that although the legislature provided no scientific support for the selection of the chosen threshold numbers and did not explain the origin of these numbers, we have surmised that the origin of the 80,000 gallons per stage and 300,000 gallons total thresholds are likely derived (albeit not entirely accurately in the case of the 80,000 gallons) from New York's proposed regulations. However, New York derived these thresholds from a very limited analysis of volumes of base fluid used in *water-based* fracturing – not gas-based fracturing.

Thus, the Department needs to come up with an appropriate means to express the threshold of applicability as it applies to non-water fracks. The key parameter for developing a comparable threshold should be identifying comparable risk. Addressing the problem by simply converting the water-based thresholds from gallons to cubic feet or another unit of volume appropriate to measure gases is not scientifically sound and does not sufficiently manage risk. A threshold derived in this way would be completely arbitrary and wholly divorced from the real environmental and health risks posed by such non-water fracks. Thresholds for gas-based fracks must be developed independently based on an evaluation of risk and field data from gas-based fracks.

The rules must also specify whether the threshold volume for nitrogen, carbon dioxide, or other non-water base fluids applies to the liquid or gas phase of those fluids. For example: 1 million scf of nitrogen gas ≈ 7,480,519 gallons of nitrogen gas ≈ 10,739 gallons of liquid nitrogen. Specifying the phase on which the threshold volume is based is necessary to prevent creative accounting.

This issue is not merely academic - both gas and foam fracks are routinely used in the New Albany Shale (NAS) and in fact may be more successful and more widely used than water-based fracturing due to the unique properties of the formation.[1] For example, a NAS well in Christian County, KY was stimulated with a gas fracture treatment using approximately 1 million standard cubic feet (scf) of nitrogen gas per stage for eight stages, for a total of approximately 8 million scf of nitrogen gas. Two wells in McLean County, KY were stimulated with mist fracture treatments composed of 92% to 99% nitrogen gas and 8% to 1 % water, using approximately 2 million scf of nitrogen gas per stage for nine stages, for a total of approximately 18 million scf of nitrogen gas per well. The proposed regulations provide no guidance as to how the 80,000 gallon/stage and 300,000 gallon total thresholds should be applied to these gas-based fracturing jobs. (Further information concerning these fracks is being developed in connection with our formal comments.)

**<u>Section 245.230 Permit Application Receipt and Department Review</u>**

Subsection 245.230(e) should provide that the Department's 60-day review period does not begin to run until the application is deemed complete by the Department. Otherwise, the system invites abuse by applicants who will sandbag public participation by submitting a deficient application, and failing to correct the deficiency until after the public comment period has run (or nearly run). The completeness determination should assess not only whether all of

[1] Gas Technology Institute. November 23, 2010. New Albany Shale Gas Project, Final Report. Research Project to Secure Energy for America Project: 07122-16.

the technical components of the application are present – *i.e.*, sections (1) through (28) as required by Section 1-35 of the Act – but whether the substance of these components reflects the requirements of the Act and regulations as well, and provides sufficient factual detail.

There may be multiple ways that this interface between a completeness determination and the 60-day permit review period can be structured. One option is to (i) expressly allow the Department to make an initial completeness determination during the 5-day review period described in Section 245.240, and if a deficiency is found to notify the applicant that the 60-day review will not commence until it is cured ; and (ii) allow the Department to identify a deficiency in the application at any subsequent time during the 60-day review period, and toll the running of the 60-day review period until it is cured (this would also require tolling of the public comment period and rescheduling of the hearing).

This solution is entirely consistent with the Act, which clearly specifies the elements of an application (which, as discussed below, should be fleshed out by the rules), and does not contemplate that the Department review an application that does not contain those elements.

**<u>Section 245.270 Public Hearings</u>**

The Act's provision affording public hearings are critically important to ensuring that the public has the ability to fully understand hydraulic fracturing permits that may affect them, and challenge them if appropriate. We are therefore concerned that some aspects of the draft rules governing hearings could potentially undercut the robust public participation envisioned in the statute.

The following is a list of problems we identified with the public hearing language in the draft:

1. *Intervention petitions*

Subsection 245.270(a)(6) requires that the intervention request be served upon the Department, the hearing officer, and the applicant. However, Act Section 1-50(b) says only that the applicant must petition the Department. This additional requirement could create a barrier to participation by unsophisticated *pro se* litigants.

2. *Hearing location*

We do not think it appropriate that 245.270(b)(2) gives the Department broad discretion to hold hearings outside the affected counties. It is imperative that the hearings be held in the county where the well will be located. A location outside the affected county could create an enormous barrier to participation by ordinary citizens, who may not have the resources or time or child care options for out-of-town travel. It limits their ability to call local witnesses, who may have critical information but be unable or unwilling to come to Springfield. And it makes it impossible as a practical matter for interested neighbors to attend and observe the hearing, defeating the purpose of ensuring transparency in the permitting process.

It should not be difficult to identify locations where hearings can be held in affected counties. Courthouses, schools, and in some cases county board offices or town halls generally have space that could accommodate a hearing. Additionally, we request that the Department make an inquiry into the cost and availability of web-based technology to allow the Department to appear remotely at a hearing being held in the affected county if travel there is logistically impossible. Not all such technology is expensive, and it may in fact prove less expensive than travel in some circumstances.

*3. Department's presence at hearing*

The rules should contain an express obligation that the Department testify and be available for cross-examination. Without such testimony, a primary purpose of the hearings – to vet the permit application and ensure transparency – is gutted. Accordingly, subsection 245.270(g)(6) should be amended to specify not merely that a representative from the Department appear and "be given an opportunity" to provide evidence, but that the representative shall testify under oath. Furthermore, the provision should require that the Department provide a person or persons with knowledge of any specific issues raised in the hearing request, if it has one (we note that such a requirement would encourage the level of specificity that the Department appears to be seeking with its problematic hearing request requirements).

*4. Citation to legal basis*

In subsection 245.270(a)(3)(e), the rules should specify that the hearing requestor state the statutory or regulatory basis for the request "if applicable" rather than "if known." Nothing in the statute limits the basis for hearing requests to those grounded in specific legal provisions – a citizen who "is or may be affected" by hydraulic fracturing operations may simply want to raise questions or obtain further information about the operations and their potential impacts. The language change we are suggesting will help clarify that.

*5. Failure of permit applicant to appear.*

With respect to subsection 245.270(f), allowing a permit to issue where a permit applicant has failed to appear at a hearing would gut the purpose of the public hearing requirement. In the event the failure was due to an emergency or circumstances beyond the applicant's control, the hearing should be rescheduled, and the applicant deemed to have consented to an extension of the 60-day time window to accommodate that rescheduling. If the applicant cannot show good cause for failure to appear at the hearing, the application should be denied.

*6. Burden of proof*

The provision concerning burden of proof, subsection 245.270(i), does not make sense in context, and reverses the burden that otherwise applies to permit applicants to demonstrate that they are entitled to a permit. To the extent hearing requestors raise legitimate questions as to whether a permit should be issued, or issued with particular conditions, it remains the applicant's responsibility to address those questions to the satisfaction of the Department. It is not the hearing requestor's burden to prove that the issues raised are worthy of consideration; and nor is it the job of the hearing officer to render an ultimate determination concerning the permit.

In this regard, unlike in a typical adjudicatory hearing, the hearing officer will not necessarily be called upon to make a recommendation as to the ultimate issue whether the permit should issue, or what conditions it should include. Permittees' concerns will likely vary widely, from overarching issues relating to health and safety to requests for particular technical conditions; and in some cases, hearing requestors will simply be seeking to have their questions answered. The concept of burden of proof will not necessarily be relevant in many instances.

*7. Hearing decision*

For the reasons discussed with respect to subsection 245.270(i), it is inappropriate for the hearing officer's report to render decision on the issues raised at the hearing. The purpose of the hearing is to allow citizens to elicit information, raise issues of importance, and develop the administrative record. The hearing officer's job should be to report the proceedings back to the Department, and make recommendations as appropriate.

*8. Post-hearing corrections*

Subsection 245.270(n), allowing the applicant to attempt to correct deficiencies identified at the hearing, places no time limit on such correction; nor any obligation on the part of the Department to provide public notice of such correction. Accordingly, applicants could in principle provide information to the Department on Day 59 of the permit issuance period, and the public would not find out about it until long after the permit had been issued. This provision should specify a time window for applicants to provide corrections and provide that the post-hearing public comment period must remain open for a sufficient number of days after that time window in order to provide the public adequate time to meaningfully review and comment on those corrections. For example, a time window for corrections of five days following the conclusion of the hearing would be appropriate with a post-hearing public comment period of 15 days, so that commenters would then have 10 days of the post-hearing comment period to address the new information.

*9. References to decision timeline*

In multiple places, subsection 245.270 employs the phrase "Taking into consideration that the Department shall have no more than 60 days" to make a decision...." These references create potential confusion, as it is unclear whether that reference is intended to shorten any of specific timeframe or otherwise limit any right.

**<u>Section 245.330 Permit Modifications</u>**

This section explicitly narrows the language of the counterpart section of the Act, 1-55. It also sets up a system that keeps citizens largely in the dark about changes to permits that may well be significant.

Critical to this section, and in particular to citizen participation, is the distinction in Act section 1-55(c) between modifications representing a "significant deviation" and all other modifications. The Act states, "If the Department determines that the proposed modifications constitute a significant deviation from the terms of the original application and permit approval, or presents a serious risk to public health, life, property, aquatic life, or wildlife, the Department shall provide the opportunities for notice, comment, and hearing required under Sections 1-45 and 1-50 of this Act"

The statute does not define or limit the circumstances in which a permit modification constitutes a "significant deviation," but rather leaves the term open ended. While it would not be inappropriate for the regulations to explain that term and give examples of significant deviations, the draft rules radically circumscribe that term, giving it a narrow and exclusive meaning that is nowhere found in, or supported by, the statute. Specifically, the draft rules would define as a significant deviation *only* those modifications that "propose[] to move the well, including the horizontal well bore, add new horizontal well bores, or add length to any existing or planned horizontal well bores." While these circumstances would certainly constitute significant deviations, so would many others. For instance, a modification that resulted in significantly more water use, or water use from a different source, would be a significant deviation, even if the increased use fell short of a "serious risk" to public health or the environment. Accordingly, we recommend the following language to define a significant deviation: "A permit modification shall be treated as a significant deviation from the original permit if the proposed actions or potential impacts of those actions may differ materially from those associated with the original permit application." To the extent specific examples are used to further flesh out this definition, those examples must be framed non-exclusively, *i.e.*, employing the language "including but not limited to...."

In addition, adding new horizontal well bores, identified in the draft regulations as a permissible type of modification, requires an entirely new permit under the statute. *See* Act Section 1-30(b) ("If multiple wells are to be stimulated using high volume horizontal hydraulic fracturing operations from a single well site, then a separate permit shall be obtained for each well at the site").

The following additional changes should be made:

*1. Sections modified*

Subsection 245.330(b)(1) states, "Sections of a permit modification application that are not the subject of a proposed deviation from an original permit are not required to be completed." This language should be modified to state that sections "that are not *impacted by*" the proposed modifications need not be completed. It is entirely possible that a potential significant impact of a modification would not be the "subject of" the modification but rather a consequence of it.

*2. Serious Risk*

Subsection 245.330(d) seems to imply that a permit modification that poses a "serious risk" to public health or the environment could nonetheless be granted without changes that eliminate that risk. But Section 1-53(a) of Act, incorporated into the draft regulationss at subsection 245.300(c)(4), makes clear that no permit may issue unless the high volume horizontal hydraulic fracturing operations at issue "are reasonably expected to be conducted in a manner that will protect the public health and safety and prevent pollution or diminution of any water source." The following language should therefore be added to this subsection: "Such modification shall not be granted unless the proposed action is modified so that the criteria set forth in subsection 245.300(c)(4) are met."

*3. Notice and publication*

Additionally, it is important the any and all modification requests be posted on the Department's website; and all persons who received special notice of the original permit application, or were party to a hearing concerning it, should receive notice as well. All such persons should also receive notice of the Department's determination as to whether the modification will be treated as a significant deviation (and that determination should likewise be posted on the Department's website).

**Section 245.620 Rebuttable Presumption of Pollution or Diminution**

The rebuttable presumption in the Act is broadly framed to apply whenever pollution or diminution of water quality occurs within the specified distance of HVHHF operations. While Act section 1-80 requires that sampling data be generated that may show whether pollution or diminution has occurred, section 1-85 governing the presumption does not reference the section 1-80 testing requirements at all, or otherwise limit the sources of sampling data that may be used to prove the pollution or diminution has occurred.

A number of provisions in the draft rules nonetheless inappropriately purport to limit evidence triggering the presumption to the section 1-80 sampling results. The particular provisions of concern are as follows:

a. *245.620(b)(2)* – the word "the" before "baseline water quality data" should be stricken to make clear that any baseline water quality data, not just the data collected pursuant to the Act's requirements, may trigger the presumption.
b. *245.620(b)(4)* – this section should preferably be amended to mirror subparagraph (b)(2) (amended per above recommendation), *i.e.*, state that "water quality data obtained up to 30 months after commencement of HVHHF operations shows that pollution or diminution of water quality has occurred with respect to one or more parameters" set forth in the relevant section of the Environmental Protection Act regulations referenced at 245.610(e).
c. *245.620(c)(4)* – this section is superfluous, as well as confusing for the reason specified below. If the water quality data (broadly defined per above) do not show pollution or diminution, then there is no presumption to rebut. The relevant concept

from the statute that should be reflected here, and is not, is from subsection 1-85(c)(3), specifying that the presumption can be rebutted if it can be affirmatively established that the pollution or diminution had an identifiable cause other than HVHHF operations.

An additional problem with the current wording, aside from the narrowing of the statutory basis for the presumption, is that it treats the parameters being sampled for pursuant to section 1-80 as though they are congruent with the parameters for pollution or diminution, which they are not. The section 1-80 parameters are intended to be *indicators* of the presence of contamination from hydraulic fracturing, not an exclusive list of the possible contaminating constituents. Some, like dissolved methane, propane, and ethane, are not themselves causes of pollution or diminution pursuant to applicable regulations, but rather provide information for tracking the source of contamination. Failure to make this distinction will cause significant confusion.

To illustrate how severely the Department's unauthorized limitation of Act Section 1-85 has curtailed its scope, we offer the following list of chemicals that are covered by the statutory definition of "pollution or diminution" that should therefore also be subject to the presumption according to the plain language of Section 1-85. Shown capitalized in red are the few constituents that remain subject to the presumption under the Department's truncated interpretation:

- Detection of any: **BENZENE**, any other carcinogen
- Preventive Response Criteria at 35 IAC 620.310(a)(3)(A)(i): para-dichlorobenzene, ortho-dichlorobenzene, methyl tertiary butyl ether (MTBE), phenols, styrene, **TOLUENE, ETHYLBENZENE, XYLENES**,
- 35 IAC 620.410: (a) antimony, **ARSENIC, BARIUM**, beryllium, **CADMIUM, CHLORIDE, CHROMIUM**, cobalt, copper, cyanide, fluoride, **IRON, LEAD, MANGANESE, MERCURY**, nickel, nitrate as n, perchlorate, Radium-226, Radium-228, **SELENIUM, SILVER, SULFATE**, thallium, **TDS**, vanadium, zinc; (b) Acenaphthene, Acetone, Alachlor*, Aldicarb, Anthracene, Atrazine, Benzene [repeat], Benzo(a)anthracene*, Benzo(b)flouranthene*, Benzo(k)floranthene*, Benzo(a)pyrene*, Benzoic acid, 2-Butanone (MEK), Carbofuran, Carbon Disulfide, Carbon Tetrachloride, Chlordane*, Chloroform*, Chrysene*, Dalapon, Dibenzo(a,h) anthracene*, Dicamba, Dichlorodiflouromethane; 1,1-Dichloroethane, Dichloromethane*, Di(2-ethylhexyl)phthalate*, Diethyl Phthalate, Di-n-butyl Phthalate, Dinoseb, Endothall, Endrin, Ethylene Dibromide*, Flouranthene, Flourene, Heptachlor*, Heptachlor Epoxide*, Hexachlorocyclopentadiene, Indeno(1,2,3-cd)pyrene*, Isopropylbenzene (Cumene), Lindane (Gamma-Haxachlorocyclohexane), 2,4-D, ortho-Dichlorobenzene, para-Dichlorobenzene; 1,2-Dibromo-3-Chloropropane*; 1,2-Dichloroethane*, 1,1 Dichloroethylene, cis-1,2-Dichloroethylene, trans-1,2-Dichloroethylene, 1,2-Dichloropropane*, Ethylbenzene, MCPP (Mecoprop), Methoxychlor, 2-Methylnaphthalene, 2-Methylphenol, Methyl Tertiary-Butyl Ether (MTBE), Monochlorobenzene, Naphthalene, P-Dioxane*, Pentachlorophenol*, Phenols, Picloram, Pyrene, Poly-chlorinated Biphenyls (PCBs) (as decachloro-biphenyl)*, alpha-BHC (alpha-Benzene hexachloride)*, Simazine, Styrene, 2,4,5-TP (Silvex),

Tetrachloroethylene*, Toluene, Toxaphene*, 1,1,1-Trichloroethane; 1,1,2-Trichloroethane; 1,2,4-Trichlorobenzene; Trichloroethylene*; Trichlorofluoromethane; Vinyl Chloride*, Xylenes; (c) 1,3-Dinitrobenzene, 2,4-Dinitrotoluene, 2,6-Dinitrotoluene, HMX (High Melting Explosive, Octogen); Nitrobenzene; RDX (Royal Demolition Explosive, Cyclonite), 1,3,5-Trinitrobenzene; 2,4,6- Trinitrotoluene (TNT); (d) [repeats]; (e) **PH.**

- Chemicals with 35 IAC 720 Groundwater Cleanup Objectives (not already listed above): Aldrin, Bis(2-chloroethyl)ether, Bis(2-ethylhexyl)phthalate (Di(2-ethylhexyl)phthalate), DDD, DDE, DDT, 1,2-Dibromoethane, 3,3'-Dichlorobenzidine, Dieldrin, Hexachlorobenzene, Alpha-HCH, N-Nitrosodi-n-propylamine, 2,4,6-Trichlorophenol, Bromodichloromethane (Dichlorobromomethane), Bromoform, Butanol, butyl benzyl phthalate, carbazole, 4-Chloroaniline (r-Chloroaniline), Chlorobenzene (Monochlorobenzene), Chlorodibromomethane (Dibromochloromethane), 2-Chlorophenol (pH 4.9-7.3), 2-Chlorophenol (pH 7.4-8.0), 1,1-Dichloroethane, 2,4-Dichlorophenol, 1,2-Dichloropropane; 1,3-Dichloropropene (1,3-Dichloropropylene, *cis* + *trans*); Diethyl phthalate; 2,4-Dimethylphenol; 2,4-Dinitrophenol; Di-*n*-octyl phthalate; Endosulfan, Hexachloroethane, Isophorone; Methyl bromide (Bromomethane); Methyl tertiary-butyl ether; Methylene chloride (Dichloromethane); 2-Methylphenol (*o*-Cresol); *N*-Nitrosodiphenylamine; *N*-Nitrosodi-*n*-propylamine; Pentachlorophenol; 2,4,5-Trichlorophenol (pH 4.9-7.8); 2,4,5-Trichlorophenol (pH 7.9-8.0); 2,4,6-Trichlorophenol (pH 4.9-6.8); 2,4,6-Trichlorophenol (pH 6.9-8.0); Vinyl acetate; Boron, **CALCIUM;** Chromium, ion, hexavalent; **MAGNESIUM,** phosphorus, potassium, sodium.

We note that at least some of these excluded constituents are found on FracFocus, indicating that they have been used in fracking operations.

**Section 245.730 Trade Secret Disclosure to Health Professional**

The proposed language concerning disclosure of trade secret-protected information to health professionals is neither consistent with the statute nor protective of the public. In the first instance, it is unacceptable that the introductory language in section 245.730 provides that the Department "may" provide information to health professionals who demonstrate a need for it. Section 1-77(l) of the Act is clear is that this information *shall* be provided as needed.

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Additionally, section 245.730 sets up a system fails to assure that the necessary information is available in the event of an immediate health threat. Our specific concerns are as follows:

- *Limitation to "normal business hours."* Subsection 245.730(b)(1) provides that a health professional may call the Department during "normal business hours" in the event of an emergency. For an emergency that occurs after hours, evidently the only recourse is to call the trade secret holder (who is, as discussed below, nowhere identified publicly). This is inadequate. The Department should provide a 24-hour hotline for emergency calls pursuant to this section.

- *Lack of a time limit for the Department's response.* The Department should abide by the same 3-hour time limit for a response that applies to trade secret holders pursuant to 245.730(b)(2).
- *Need for identification of the "trade secret holder."* Subsection 245.730(b)(2) allows a health professional to seek the necessary information from a "trade secret holder," but there is no means provided for the health professional to know who the trade secret holder is, or what phone number to use to reach it. The rules should require that the name and contact 24-hour contact information for the trade secret holder be provided at the time trade secret protection is requested. The Department's answering machine should direct callers to that information. The information should also be provided in advance to first responders in the vicinity of a fracking operation.

Finally, we note that the requirement in subsection 245.730(e) that health providers report to the trade secret holder the names of persons to whom the protected information was disclosed is found nowhere in the statute. It is inappropriate to burden health professionals with such an obligation in the absence of statutory authorization to do so.

**Section 245.210 Permit Application Requirements**
**Section 245.850 Hydraulic Fracturing Fluid and Hydraulic Fracturing Flowback Storage, Disposal or Recycling, Transportation and Reporting Requirements**

The combination of lack of standards for calculating the size of wastewater storage tanks, and the extended timeframe allowed by the Department for removal of wastewater in the reserve pit, is a dangerous combination that could be used by operators to facilitate routine use of the reserve pits in a manner not contemplated by the statute. The clear intent of the statute is to ensure that wastewater is stored in tanks except in the emergency event of an unforeseeable overflow, in which case it is preferable that the overflow go to a pit than simply spill on the ground. But in such event, the overflow is expressly required in the statute to be removed within a week. Through omission and misinterpretation, the regulations are not implementing this statutory directive.

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Section 245.210(a)(11), requiring that an applicant submit a Hydraulic Fracturing Fluids and Flowback Plan, states that "[t]he plan shall describe the capacity of the tanks to be used for the capture and storage of all the anticipated hydraulic fracturing flowback and of the lined reserve pit to be used, if necessary, to temporarily store any flowback in excess of the capacity of the tanks." However, it needs to, but does not, include requirements to ensure that tank capacity is accurately calculated. Specifically, this section should establish a method for tank capacity calculation, and that method should include a margin of safety. Without such method, there is nothing in the regulations to prevent operators from underestimating the size of the tanks they need, so as to make routine use of the reserve pit for the resulting overflows. Operators presumably have an economic incentive to do so in order to hold down the cost of tank storage.

Compounding this incentive is the Department's weakening of the statutory directive that fluids deposited in a reserve pit be removed within 7 days (Section 1-75(c)(5). The regulations fail to require such prompt removal, allowing, at subsection 245.850(c), the overflow to remain in the reserve pits until 7 days "after completion of high volume horizontal hydraulic fracturing operations." Certainly on a multi-well pad, hydraulic fracturing operations can continue for a month or more, meaning that the flowback fluid could be left sitting in the reserve pit, creating environmental risk, for much longer than a week.

## *II. ADDITIONAL SIGNIFICANT CONCERNS*

### Section 245.110 Definitions

- *"Aquatic life."* The definition of "aquatic life" is too narrow, and does not include many macroinvertebrates and other species that may be important to an aquatic ecosystem. We recommend adopting the definition contained in the Pollution Control Board's water pollution regulations: "Aquatic Life" means native populations of fish and other aquatic life." 35 Ill. Adm. Code 301.220.

- *Other undefined terms.* We note generally that our comments below reference numerous terms that require further definition, *e.g.*, "wholly contained," "cost effective," "competitive value," *etc.* Those definitions could, as appropriate, be included in section 245.110.

### Section 245.200 Registration Procedures

- *Registration updates (245.200(f)).* It is unclear to us why a registrant should be afforded a full 60 days to notify the Department of a change in information. If such a change occurred during the course of permit application review, the public might well not find out about it until after the comment period was closed.

### 245.210 Permit Application Requirements

- *Directional drilling plan (245.210(a)(4)) and Scaled plat maps, diagrams, or cross sections (245.210(a)(7)).:* These sections do not explicitly require that the applicant provide a map that depicts the exact location of the wellbore, *i.e.*, draws it on the map from beginning to end. This information is critical to specific notice and standing, which reference persons within 750 feet of the wellbore.
- *HVHHF operations plan confining zone definition (245.210(a)(6)(A).* It is our assumption that the Department intended the phrase "if known after reasonable inquiry" to apply only to the last item on the list of information required concerning the confining zone, *i.e.*, "susceptibility to vertical propagation of fractures, of the confining formations" (since the other information should be readily available in all circumstances). That intent should be clarified by amending the language as follows: "…transmissive faults, fractures, and water or water source content; and susceptibility to vertical propagation of fractures~~,~~ of the confining formations~~,~~ if known after reasonable inquiry
- *Documentation of failure to disclose in application (245.210(a)(8)).* The Department should specify the type of documentation that must be provided that will support a claim that disclosure of chemicals cannot be provided with the application "to the Department's satisfaction."



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- *Disclosure of anticipated concentration in base fluid (245.210(a)(8)(D)).* The Department should clarify in the regulations exactly how they want operators/service companies to calculate percent by mass for purposes of this provision.
- *Water use self-certification (245.210(a)(9).* The Department should, on its website, post or provide a link to any previous review undertaken by a Soil and Water Conservation District, pursuant to Section 5 of the Water Use Act of 1983, concerning the effect of any proposed water withdrawal via high capacity well upon other users of the water.
- *"Wholly contained" (245.210(a)(10)(A)(vi)).* Here and elsewhere where the term "wholly contained" is used, it must be defined. In particular, it should be established that a water body is "wholly contained" on single property only if it has no hydrological connection, perennial or otherwise, to a water body outside that property.
- *Recycling (245.210(a)(10)(B)).* Considerably more detail is needed to define associated requirements and protections. For example, the regulations need to specify what tests will be conducted on recycled water, and require that any contaminants be disclosed pursuant to subsection (8) as "intentionally" added to the base fluid. The regulations should also specify the requirements for disposal of waste material removed in the recycling process.
- *Plan requirements (245.210(a)(10)-(15)).* Although the draft regulations add significant detail to the statutory requirement that the applicant submit a traffic management plan, the draft does not provide this kind of definition of the required contents of other types of plans required in the application. We identified the following places where such planning definition is critically needed:
  - *Water source management plan (245.210(a)(10)(A)(iv) and (v).* These subparagraphs requiring water use minimization and protection of aquatic life are critical to protection of water resources. However, unless the Department better defines their terms, they will be difficult to apply and enforce. In particular, the Department should clarify the elements of a showing that fresh water withdrawals have been minimized "as much as feasible," and the types of measures that must be evaluated in order to minimize impacts on aquatic life.
  - *Containment plan (245.210(a)(13)).* The Department should require that, as part of the containment plan, applicants evaluate different containment practices and equipment that could be used at the site, and utilize the most effective containment practices/equipment that are technically/economically feasible. We would be happy to discuss specific suggestions with you.
- *Access roads (245.210(a)(21)).* While it is good that the Department included a requirement that access roads be located as far as possible from occupied structures, places of assembly, and property lines of unleased property, to ensure that this has been done, and provide the public with ready means to evaluate compliance, these features should be included on the map required under 245.210(a)(7).
- *Contractor information (245.210(a)(26)).* It is not clear to us that this section covers all of the personnel that should be identified. Is it possible that a contractor/service provider could be heavily involved at the site, *e.g.*, supplying fracking chemicals and such, but not be "performing" the HVHHF operations?

**Section 245.220 Permit Bonds or Other Collateral Securities**

- *Cash securities (245.220(c)(1)).* The Department should specify a requirement that the cash be kept secure and not used for any other purpose.

**Section 245.250 Public and Governmental Notice by the Permit Applicant**

- *Documentation of public notice (245.250(b)).* This subsection inexplicably gives the applicant 35 days following the Department's receipt of the application to submit documentation that public notice requirements were complied with. Yet by the time the 35 days have elapsed, the public comment period will have nearly run – meaning that if public notice were not properly effectuated, this deficiency would not become apparent until citizens who did not receive notice have already effectively missed their comment opportunity. It is easy for applicants to notify the Department effectively immediately (within 24 hours) of completion of a particular notice requirements. Documentation of specific notice should be done as soon as that notice is put out, and a separate deadline (the day of or after the last public notice in a newspaper) can be established for documentation of general notice.

**Section 245.300 Permit Decision**

- *Public health and safety criterion (245.300(c)(4).* This subsection establishes as a criterion for permit issuance that the operations are "reasonably expected to be conducted in a manner that will protect the public health and safety and prevent pollution or diminution of any water." This criterion should specify that one of the factors that may be considered is the applicant's history of serious violations. Otherwise, there is no obvious specification of the context in which that important information should be considered (although the reference could also be included in subparagraph (c)(8).
- *Failure to abate (245.300(c)(6)).* The limitation of this subsection to violations "specified in a final administrative decision of the Department" is an unnecessarily narrow limitation. If an applicant has a history of unabated violations identified in inspections by the Department, even if those violations have not been finally resolved, it would be inappropriate to grant a permit to that applicant.

**Section 245.400 Setbacks**

- *Waiver for wholly-contained water sources (245.400(a)(4).* This provision needs to make clear that any waiver of the required setback by a landowner be set forth on a form provided by the Department. Allowing permit applicants to bury such a waiver in a lease invites abuse.

**Section 245.410 Access Roads, Public Roads and Topsoil Conditions**

- *"Similar characteristics" (245.410(d)).* The regulations should specify what constitutes "similar characteristics" to clarify the clause in this subsection that requires reclamation of the site with "topsoil of similar characteristics of the topsoil removed."

## Section 245.510 Well Drilling, Storage, and Disposal of Drilling Waste

- *Storage of drill cuttings (245.510(a)).* It is not clear whether the drill cuttings will need to be tested for contamination prior to storage. If so, they should also be tested for radioactivity.

## Section 245.520 Cement Requirements

- *Industry standards (245.520 various places).* Industry standards should be referenced non-exclusively, *i.e.*, "including at minimum but not limited to" the documents incorporated by reference in section 245.115. There should also be a mechanism created to periodically update the referenced industry standards.
- *Prior submission (245.520(h)(3)).* Cement job jobs and compressive strength tests should be submitted prior to fracturing.
- *Excess cement (245.*530(i)). The regulations should make clear that no approval of a different amount of excess cement than that specified in this subsection (minimum of 25%) will be granted unless the operator runs a caliper log to determine more accurate hole volume/ required cement volume.

## Section 245.530 Surface Casing Requirements

- *Surface casing depth (245.530(a)).* Regarding the requirement that surface casing be set to a depth prior to encountering any hydrocarbon-bearing zones, the Department should require that, if such zones are encountered, drilling must stop and surface casing must be set and cemented before drilling deeper. The regulations should further require that all such zones be reported to the Department.
- *Borehole circulation (245.530(d)).* The Department should require that applicant circulate at least two hole volumes of drilling fluid and ensure that the well is static and all gas flows are killed.
- *Cement specifications (245.530(h)(1)).* What is the basis for the requirement of "Class A cement, with a minimum density of 14.5 lbs./gal."?

## Section 245.540 Establishment of Internal Mechanical Integrity Testing

- *Non-cemented strings (245.540(c)).* The Department needs to add the MIT protocol for non-cemented strings. For non-cemented completions, the test pressure must be a minimum of (i) 70% of the lowest activating pressure for pressure actuated sleeve completions or (ii) 70% of formation integrity for open-hole completions, as determined by a formation integrity test
- *Test results (245.540(d)(1) and (2*)). Subparagraphs (1) and (2) appear to be contradictory. The results of the test should definitely be submitted prior to fracturing. Also, the Department should add the word "within" before "30 days."

**Section 245.550 Installation and Testing of Blowout Prevention Equipment**

- *Training (entire section).* The Department should adopt regulations to set out standards for acceptable training programs for installation/testing/use of blowout preventors.

**Section 245.560 Intermediate Casing Requirements**

- *245.560(k):* Temperature logs are not an equivalent substitute for a CEL.
- *245.560(l):* This subparagraph is inappropriate. Getting returns to the surface is not necessarily evidence of a complete bond.

**Section 245.570 Production Casing Requirements**

- *Production casing (245.570(a)).* Regarding the requirement that production casing must be run and fully cemented to 500 ft above the top perforated zone, the Department should clarify that cementing must also be in accordance with subsection 245.520(c)(3), as well as specify circumstances in which deviation from the requirements of 245.520(c)(3) might be allowed (*e.g.*, lost circulation). DNR should further specify that, if compliance with the requirements of 245.520(c)(3) is not possible, multi-stage cementing must be used to isolate any hydrocarbon- or fluid-bearing formations or abnormally pressured zones and prevent the movement of fluids. The Department should add that if potential flow zones, productive zones, *etc* are open above this, then the cement needs to extend 500' above the top of that zone. Same language as 245.560(b)(4). Lastly, if the second sentence is intended to accommodate open hole completions, i would probably be easier to specify that, for cemented well completions, the production casing must be landed and cemented into or below the target formation and for open-hole completions the production casing must be landed and cemented into or above the target formation. Then the cementing requirements in (a)(1) would work for either case, and (a)(2) could be deleted.

**Section 245.580 Establishment of Formation Integrity**

- *Failed tests (entire section).* Department should add that add that in the case of a failed test, remedial measures must be performed.
- *245.580(d)(1) and (2):* As with 245.540(d)(1) and (2), the two subparagraphs appear to conflict. Also, the Department should add the word "within" before "30 days.."

**Section 245.600 Water Quality Monitoring**

- *Reporting of pollution or diminution (245.600(a)(7)(D)).* This section should clearly state that the report to the Department and the Agency must state which specific standards or criteria are exceeded.
- *Posting of baseline sampling results (245.600(b)(4)).* Allowing 7 days to post the sampling results means that in most cases, the public will not see them until after fracking has commenced – meaning, among other things, that property owners would not have the opportunity to perform their own sampling should they see the need to supplement the

required sampling performed by the applicant. The sampling results, which can be required to be provided in electronic form, could easily be posted by the Department within 24 hours.

- *Post-frack sampling results (245.600(c)(2)).* This section should clarify that the post-frack sampling results, like the pre-frack results, will be posted on the Department's website.

**<u>Section 245.615 Procedures</u>**

- *Determination of pollution or diminution (245.615(b)).* This provision should specify that the determination will be made available on the Department's website.

**<u>Section 245.720 Department Publication of Chemical Disclosures and Claims of Trade Secret</u>**

- *Posting of master lists (245.720(a)).* It is unclear why the Department needs 21 days to post a master list on its website. Since the lists will be provide electronically, and with a redacted version in the event trade secret protection is claimed, we see no reason the lists cannot be posted much more promptly, within no more than 48 hours.
- *Trade secret claim procedures (245.720(c)).* There are numerous terms and concepts pertinent to the trade secret determination process that require further elaboration in the rules. These include, among others, a definition of "competitive value," and a description of the type of showing that must be made to demonstrate that the information at issue has such value. The US EPA EPCRA regulations at 40 CFR 350 subpart A provide valuable guidance for fleshing out the language of the Act, in ways that are entirely consistent with it. We recommend in particular that the Department review the detailed showing required in 40 CFR 350.7, and import those requirements here as appropriate.

**<u>Section 245.810 Surface Equipment Pressure Testing</u>**

- *Anticipated surface treatment pressure (245.810(b)).* The Department should specify that the injection lines and manifold, associated valves, fracture head or tree and any other wellhead component or connection not previously tested must be tested with fresh water, mud, or brine to 110% of the maximum anticipated surface treatment pressure.

**<u>Section 245.815 Notice and Approval Before Commencement of High Volume Horizontal Hydraulic Fracturing Operations</u>**

- *Plugging of abandoned wells (245.815(b)).* The Department should clarify what specifically the permittee needs to show in order to establish that it properly plugged the abandoned wells as required.

**<u>Section 245.825 General Fluid Storage</u>**

- *"Compatible" (245.825(a)(2), (c)(1)).* The regulations should clarify what is "compatible" for purposes of provisions that tanks and "piping, conveyances, …must be constructed of materials compatible with the composition of the fracking fluid…." Specifically, the

Department should clarify that "compatible" includes being resistant to corrosion, erosion, swelling, or degradation that may result from such contact.

- *Corrosion inspection (245.825(a)(5)).* The Department should define what is meant by the requirement that above-ground tanks be "routinely" inspected for corrosion, *i.e.*, specify a time interval.
- *Secondary containment (245.*825(b)). The Department should require that secondary containment be designed and constructed in accordance with good engineering practices, including: (a) Using coated or lined materials that are chemically compatible with the environment and the substances to be contained; (b) Providing adequate freeboard; (c) Protecting containment from heavy vehicle or equipment traffic.

**Section 245.835 Mechanical Integrity Monitoring**

- *Continuous monitoring (245.835(a)).* This section should require that the continuous monitoring and recording of the pressures in each well annuli, surface injection pressure, slurry rate, proppant concentration, fluid rate, and the identities, rates, and concentrations of all additives (including proppant).
- *Cessation of operations (245.835(b)(1)).* This is confusing. Recommended language is as follows:

  If during any stimulation operation the annulus pressure:

  (i) increases by more than 500 pounds per square inch as compared to the pressure immediately preceding the stimulation, or
  (ii) exceeds 80% of the API rated minimum internal yield on any casing string in communication with the stimulation treatment,

  the operation must immediately cease, the operator must take immediate corrective action and orally notify the authorized officer immediately following the incident.

- *Remedial action (245.835(c)).* The Department should also clarify that the "remedial action" required in such circumstances under this subsection must include an evaluation of whether contamination may occur (specifically, operators must take all necessary steps to evaluate whether injected fluids or formation fluids may have contaminated or have the potential to contaminate any unauthorized zones). If that assessment indicates that fluids may have been released into protected water or any unauthorized zone, the regulations should require that operators notify the Department within 24 hours, take all necessary steps to characterize the nature and extent of the release, and comply with and implement a remediation plan approved by the Department. If such contamination occurs in protected water that serves as a water supply, the Department should require that a notification be placed in a newspaper available to the potentially affected population and on a publically accessible website and that all known users of the water supply be individually notified immediately by mail and by phone.

**Section 245.845 Management of Gas and Produced Hydrocarbons During Flowback**

- *"Economically unreasonable" (245.845(c).* The term economically unreasonable needs to be defined with specific criteria. Without further definition, the term will function as an all-purpose loophole from methane capture requirements.
- *Flaring waiver criteria (245.845(c)(1) and (2)).* The general criteria for when a waiver of the flaring requirement is appropriate should be further defined.

**Section 245.850 Hydraulic Fracturing Fluid and Hydraulic Fracturing Flowback Storage, Disposal or Recycling, Transportation, and Reporting Requirements**

- *Flowback water testing requirement (245.850(d)).* Some additional specificity is needed concerning the testing of flowback water. It appears that the Department merely copied the list of chemicals required to be tested for in groundwater under Section 1-80 of the statute and applied them here, which does not make scientific sense. The list of groundwater chemicals to be tested for are specifically intended to be indicators of underground migration. Constituents that should be tested for in the flowback water include, at minimum, the following:

  - The Department should require testing for, in addition to the substances listed: BTEX, Al, As, Ba, Ca, Cd, Cl-, Co, Cr, Cu, F-, Fe, HCl, HCO3-, H2S, HF, K, Mg, Mn, Nitrate, Nitrite, Na, Ammonia, Ni, Pb, Se, SO4, Zn, Radionuclides: Alpha, Beta, Ra226, Ra228, and U.
  - The Department should specify that the test of flowback should take place near the end of the flowback period (in order to better reflect the composition of produced water from the well).

- *Testing for radioactivity (245.850(3)).* The rules should specify what should be done in response to a positive hit for radioactivity. Information concerning this testing should also be included in the completion report.
- *Fluid handling report (245.850(k)(2)).* This report should be posted on the Department's website.

**Section 245.900 Managing Natural Gas and Hydrocarbon Fluids During Production**

- *"Cost effective" (245.900(e)).* The term "cost effective" needs to be defined. In our August 21 comments, we recommended that the Department clarify that clarify that "cost effective" refers to cost efficiency (cost/ton of emission reduction); or at least that the Department in some way require evaluation of cost of emissions (*i.e.*, costs to health and environment), not just cost of capture equipment.

**Section 245.1110 Notice of Violation**

- *Specification of grounds for suspension (245.1110(b)(3)).* This section requires that the notice of violation specify the grounds for suspension, but does not reference all of the bases for suspension identified in Act section 1-60. It states that the notice must specify, "a factual explanation indicating a significant threat to the public health, aquatic life, wildlife, or the environment if the permit operation is allowed to continue," but this is only one of the 6 grounds listed for suspension or revocation in section 1-60(a).

**Section 245.1120 Director's Decision**

- *Criteria for consideration of violations (245.1120(a)(3)(A)).* A previous violation should not cease to be counted in the Director's evaluation of a notice of violation merely because it is more than 2 years old. There is no reason violations should "expire" in this manner. We would not object to giving earlier violations less weight in consideration, but do object to excluding them entirely. Additionally, it is important to sure that the Director considers violations by a permitee operating under a different LLC.
- *Fines (245.1120(c)).* These fines are miniscule, and will have no meaning at all for enormously profitable drilling operations.
- *Settlement agreements (245.1120(i)).* This section inappropriately limits the Director's possible actions to relaxing the terms of a prior decision. Among other things, this language would limit the Director's ability to impose more stringent terms as a tradeoff for the relaxation of other terms.

**Section 245.1130 Director's Decision Hearings**

- *Criteria for a stay of suspension (245.1130(d)(2)).* As with the criteria for suspension set forth in 245.1110(b)(3), this section identifies only one of the 6 grounds for permit suspension set forth in 1-60(a). It may be that the permit was suspended for reasons unrelated to 1-60(a)(6), the criterion identified here, and hence the suspension should not be stayed by a showing that the applicant is in compliance with only that criterion.

**DECK THE HOMES**

DECK THE HOMES WITH SOLAR PANELS.
FALALALALA LA LA LA LA
KEEPING WARM WITH EXTRA FLANNELS.
FALALALALA LA LA LA LA
DON WE NOW OUR BEST INTENTIONS.
FALALA LALALA LA LA LA
PICKET ENERGY CONVENTIONS.
FALALALALA LA LA LA LA

SMELL THE BLAZING WELLS BEFORE US.
FALALALALA LA LA LA LA
GAS EXTRACTION THIS ABHORS US.
FALALA LALALA LA LA LA
COMP(A)NIES PROMISE TO PAY ROYALTIES.
FALALALALA LA LA LA LA
TO THE FOLKS WITH FAVORABLE LOYALTIES.
FALALALALA LA LA LA LA

FAST AWAY THE OLD GAS PASSES.
FALALALALA LA LA LA LA
HAIL THE WRECKAGE ON THE MASSES.
FALALA LALALA LA LA LA
IT'S MUCH NICER TO SING CAROLS.
FALALALALA LA LA LA LA
WHILE NOT FEARING FRACKING'S PERILS.
FALALALALA LA LA LA LA

# THE TWELVE DAYS OF FRACKING

C Am G7 C
On the first day of Christmas, the Senate brought to me
C F C G7 C F C
1. A half-baked Safety Guarantee.
G Dm D7 G
2. 2,000 pages *(after 5 gold rings, it goes "Two turtle doves.")*
G Dm F
3. Three minutes to speak *(after 5 gold rings, it goes "Three French hens."*
G Dm C
4. Four public hearings (*after 5 gold rings, it goes "Four calling birds" therafter.)*
G D7 G
5. 596 toxic chemicals!
G Dm
6. 600 lousy leases
G Dm
7. Seven major blowouts
G Dm
8. 80, 000 truck trips
G Dm
9. Nine rowdy man-camps
G Dm
10. 10,000 miles of pipeline
G Dm
11. Eleven lying lobbyists
G Dm
12. Twelve flaming faucets

Dying in a Fracking Wasted Land

```
D
Frack wells drill, are you listenin'
A
toxic waste pits are spillin'
A7          Em7         A      A7
a horrible sight, we're cryin' tonight
Bm7          A              D
dying in a fracking wasted land

D
these regulations are a big turd
A
don't protect us, its absurd
A7              Em7              A            A7
we're singing our song, no we won't go along
Bm7          A              D
dying in a fracking wasted land
```

Bridge:

```
F#                         B              F#
In the forest they have built a frack well
F#                         B            F#
they pretend that it is safe and sound
A                      D                 A
don't ya worry, you'll get used to that smell
A7                     E              A
and the poisons spreading all around
```

```
D
the situation is dire
A
industry's full of liars
A7              Em7             A          A7
its time that we break the plans that they made
Bm7           A                D
dying in a fracking wasted land
```

Bridge 2 (same as first)

(same chord progression as other choruses)

There'll be jobs if you're willing
to take part in the killin'
steal our water away, cuz a few men get paid
Dying in a fracking wasted land

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**We Wish You a Frack-Free Christmas**
(Tune: "We Wish You A Merry Christmas")

We wish you a frack-free Christmas
We wish you a frack-free Christmas
We wish you a frack-free Christmas
And a healthy New Year!

Good tidings to you and all of your kin
Good tidings..Stop Fracking!
Have a healthy New Year.

Oh bring forth a ban on drilling
Oh bring forth a ban on drilling
Oh bring forth a ban on drilling
Our earth is too dear!

We won't go until you stop this
We won't go until you stop this
We won't go until you promise
Clean water and air!

**IPA is Coming to Town**
(Tune: Santa Claus is Coming to Town)

You better watch out,
You better not try
Fracking our farmland,
We're telling you why
IPA is coming to town

We're making a list
Checking it twice
And if you're naughty,
We won't be nice
IPA is coming to town

Don't take oil and gas money
You know that they're all crooks
And if you do, then you'll look bad,
In our children's history books

Chorus

**"The Twelve Days of Fracking"**
(Tune: "The Twelve Days of Christmas" )

On the 12th day of Christmas, Senate brought to me
A half-baked safety guarantee.

(Continue until 12th day...)

12 Flaming Faucets
11 Lying Lobbyists
10,000 miles of Pipeline
9 Rowdy Man Camps
80,000 Truck Trips
7 Major Blowouts
600 Lousy Leases
596 Toxic Chemicals!

4 Public Hearings
3 minutes to speak
2,000 pages
And a Half-Baked Safety Guarantee.

**"Fracking Wonderland"**
Sung to: "Winter Wonderland"

Fire bells ring, are you listening
In the lane, oil is glistening
A terrible sight,
the gas drills at night.
Walking in a fracked up wonderland.

Gone away is the bluebird,
they're all dead ain't no new birds
the pipes that they laid,
sent the wildlife away,
living in a fracked up wonderland.

In the meadow we can build a snowman,
Til Haliburton comes and knocks it down
they'll say: Are you leasing?
We'll say: No man,
there ain't no frickin frackin in this town!

Later on, we'll expire,
when our sink erupts in fire
To fight unafraid,
The plans that they've made,
living in a fracked up wonderland.

In the meadow we can build a snowman,
Til Haliburton comes and knocks it down
they'll say: Are you leasing?
We'll say: No man,
there ain't no frickin frackin in this town!

When they come and start to drilling,
it's not just us that they're killing
We'll frolic and play, when we run them away,
living in a fracked up wonderland.
living in a fracked up wonderland.
living in a fracked up wonderlaaaaaaand

**Santa Claus is Coming to Town**

You better watch out,
You better not try
Passing bad rules
We're telling you why
Santa Claus is coming to town

We're making a list
He's checking it twice
And if you're naughty,
We won't be nice
Santa Claus is coming to town

Don't take oil and gas money
You know that they're all crooks
And if you do, then you'll look bad,
In our children's history books

Chorus

**Santa Claus is Coming to Town**

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You better not try
Passing bad rules
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Chorus

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Chorus

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You better watch out,
You better not try
Passing bad rules
We're telling you why
Santa Claus is coming to town

We're making a list
He's checking it twice
And if you're naughty,
We won't be nice
Santa Claus is coming to town

Don't take oil and gas money
You know that they're all crooks
And if you do, then you'll look bad,
In our children's history books

Chorus

# FRACKING WONDERLAND

```
             C                                           Dm7          G7
Fire bells ring, are you listening?  In the lane, oil is glistening:
  G7                                                 D7           G7
C   G7
A terrible sight, the gas drills at night, walking in a fracked up
wonderland.
         C                                          Dm7            G7
Gone away is the bluebird; they're all dead, ain't no new birds
   G7                                              D7           G7
C
The pipes that they laid sent the wildlife away, walking in a f-up
wonderland.
      E                  B7               E
      In the meadow, we can build a snowman
           E              B7                   E
      Till Halliburton comes and knocks it down.
      G                    D7                     G
      They'll say, "Are you leasing?"  We'll say, "No, man.
              A7             D7               Dm7    G7
      There ain't no frickin' frackin' in this town!"
      C                               Dm7           G7
Later on, we'll expire when our sink erupts in fire

   G7        F          Em7             Dm7    D7            G7
C
To fight unafraid the plans that they've made, living in a frak'd up
wonderland.
      E                  B7               E
      In the meadow, we can build a snowman
           E              B7                   E
      Till Halliburton comes and knocks it down.
      G                    D7                     G
      They'll say, "Are you leasing?"  We'll say, "No, man.
              A7             D7               Dm7    G7
      There ain't no frickin' frackin' in this town!"

             C                                           Dm7          G7
When they come and start drilling,  's not just us they are killing?
     G7        F                Em7        Dm7
We'll frolic and play when we run them away,
D7          G7                       C  A7
Walking in a fracked up wonderland

D7          G7                       C  A7  D7            G7
C  G7  C
Walking in a fracked up wonderland.   Walking in a win-ter won-der-
land.
```

022483

# DYING IN A FRACKING, WASTED LAND

C Dm7 G7
Frack wells drill, are you listening? Toxic waste pits are spillin':
G7 D7 G7
C G7
A horrible sight, we're cryin; tonight, dying in a fracked up wonderland.

C Dm7 G7
These regulations are a big turd; don't protect us, it's absurd
G7 D7 G7
C
We're singing our song--no, we won't go along, dying in a fracking, wasted land.

E B7 E
In the forest, they have built a frack well.
E B7 E
They pretend that it is safe and sound.
G D7 G
Don't ya worry; you'll get used to that smell.
A7 D7 Dm7 G7
And the poisons that they're spreading all around
C Dm7 G7
The situation is dire; industry is full of liars!
G7 F Em7 Dm7 D7 G7
C
It's time that we break the plans that they made, dying in a fracking, wasted land.

E B7 E
In the forest, they have built a frack well.
E B7 E
They pretend that it is safe and sound.
G D7 G
Don't ya worry; you'll get used to that smell.
A7 D7 Dm7 G7
And the poisons that they're spreading all around
C Dm7 G7
When they come and start drilling, 's not just us they are killing?
G7 F Em7 Dm7
We'll frolic and play when we run them away,
D7 G7 C A7
Walking in a fracked up wonderland
D7 G7 C A7 D7 G7
C G7 C

Walking in a fracked up wonderland. Walking in a fracked up won-der-land.

022484

# FRACTIVISTS ARE COMING TO TOWN

```
     A              A7       D          Dm
You better watch out, you better not try,
     A          A7       D                Dm
Fracking our farmland; we're telling you why:
  A    Fm       Bm      E    A      Fm  Bm  E7
Fractivists are coming   to town.

     A          A7       D          Dm
We're making a list;   checking it twice,
A               A7       D              Dm
And if you are naughty, we won't be nice!
A    Fm       Bm      E    A
Fractivists are coming    to town.
      A7                        D                        A7                    D
      Don't take oil and gas money.  You know that they're all crooks!
          B7                       E                          B7                    E
E7
      And if you do, then you'll look bad in our children's history
books!

     A              A7       D          Dm
You better watch out, you better not try,
    A          A7       D                Dm
Fracking our farmland; we're telling you why:
  A    Fm       Bm      E    A      E  A
Fractivists are coming   to town.
```

# Fracking Industrialization & Induced Earthquakes

## The Mechanisms that Connect the Disposal of Fracking Wastewater into Deep-Injection Wells to a Significant Increase in Midcontinent Seismic Activity

by Brent Ritzel *[brent@siu.edu]*

### Introduction

This paper explores the recent significant increase in *felt earthquakes* in the midcontinent of the United States over the past decade in relation to fracking industrialization and its associated voluminous wastewater disposal needs. Studies and expert insight from geologists and seismologists from over the past fifty years will be utilized in order to render evidenced-based conclusions regarding these matters that have often remained at the opinion level of discourse in the public sphere.

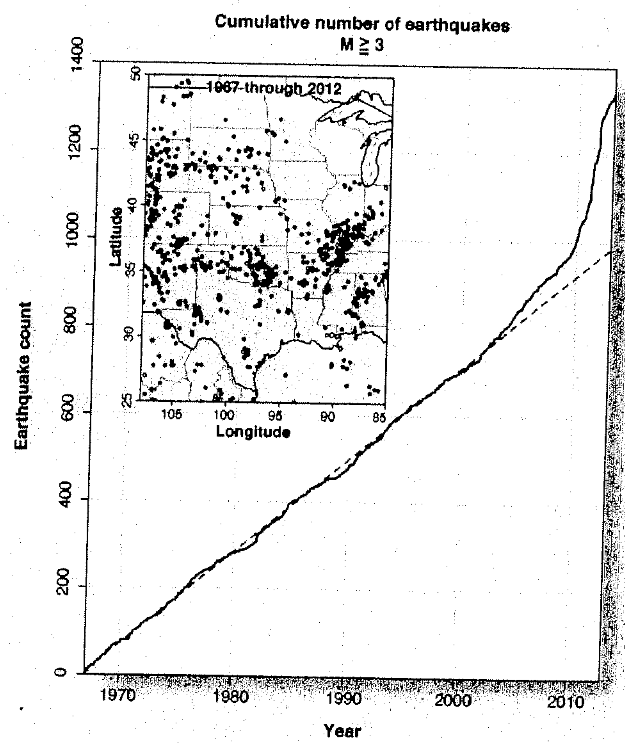
The current extent of U.S. fracking industrialization will be reviewed, including dissection of shale oil and gas production levels, the scale of proliferation of fracking wells, the volume of toxic and radioactive effluent, fracking flowback and produced wastewater disposal needs, and the impact of the exponential growth in deep-injection disposal well usage on the United States' current seismic reality. Two important limiting conditions, the *impervious* unknowns regarding subterranean geological formations *and* the fact that disposal wells will fail and leak, provide context for discussion of our obscured yet viable long term understanding of the mechanisms underlying the whole phenomenon of fracking wastewater disposal induced earthquakes.

### Historic Shift in Frequency of Midcontinent Earthquakes

Seismologists like the U.S. Geological Survey's William Ellsworth started noticing a historically unique trend about a dozen years ago, "that there were an unusual number of earthquakes in the middle of the country," in areas that have not been known for earthquakes (Rugh, 2013). The Guy-Greenbrier area of Arkansas, with total population of just over 5,000, was traditionally a quake-free area. Throughout all of 2007 the area had only one earthquake of magnitude 2.5 or greater, followed by only two such quakes in 2008. However, in 2009 there were 10, and in 2010 there were 54 earthquakes of magnitude 2.5 or greater (Kerr, 2012). On February 27, 2011, Guy experienced a magnitude 4.7 earthquake.

Neighboring state Oklahoma went through a similar pattern as a whole, experiencing just a few earthquakes per year from 1972 to 2007, 12 in 2008, 50 in 2009, and more than 1,000 in 2010, culminating with a magnitude 5.7 earthquake on November 6, 2011. While Oklahoma saw a more than hundred-fold increase in overall earthquakes, it also saw a twenty-fold increase in earthquakes with magnitude 3.0 or greater in those same three years from 2008 to 2010 (Ellsworth et al, 2012). Meanwhile, the Barnett Shale region of north central Texas has experienced "unprecedented levels of seismicity" since shale gas development began in late 1998, with "nine earthquakes of magnitude 3.0 or larger occurred, compared with none in the preceding 25 years." Overall, the states reporting unusually elevated levels of seismic activity include Arkansas, Colorado, New Mexico, Ohio, Oklahoma Texas, and Virginia (Ellsworth, 2013).

This pattern seen in both localized and statewide contexts is also reflected in data concerning the frequency of magnitude 3.0 or greater earthquakes in the entire U.S. midcontinent region, with the annual number of magnitude 3.0 or greater earthquakes having "increased almost tenfold in the past decade" (Lovett, 2013). The "middle part of the continent" went from a remarkably consistent average 21 per year from 1970 to 2000, to an average of 29 per year from 2001 to 2008, to 50 magnitude 3.0 or greater quakes in 2009, to 87 in 2010, to somewhere in the range of 134 to 188 in 2011




Cumulative count of earthquakes with magnitude $\geq 3.0$ in the central and eastern United States, 1967–2012. The dashed line corresponds to the long-term rate of 21.2 earthquakes/year.
*(Inset)* Distribution of epicenters in the United States midcontinent region.

(Demus, 2012; Ellsworth, 2013; Henry, 2012; Lovett, 2013). As William Ellsworth *et al* (2012) reported in their *Seismological Research Letters* study, "A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region" (Ellsworth et al, 2012). Especially in areas that have historically lacked earthquakes, like the Youngstown, Ohio area, as Columbia University's Lamont-Doherty Earth Observatory seismologist John Armbruster relates, "Having that many earthquakes [...] where there aren't a lot of earthquakes, was suspicious" (Fountain, 2012).

What all these different scenarios share is a common time frame for the onset of fracking industrialization, and an ever-expanding need for deep-injection disposal wells [DIDWs] to handle the massive volumes of associated fracking flowback and produced wastewater. A 2013 *Science* study (van der Elst et al, 2013) by a team of seismologists led by Nicholas van der Elst of Columbia University's Lamont-Doherty Earth Observatory found, "that at least half of the magnitude-4.5 or larger earthquakes that have struck the interior United States in the past decade have occurred near injection-well sites" (Lovett, 2013). A 2013 *Geology* study (Keranen et al., 2013) by a team of seismologists led by Katie Keranen

concluded while earthquakes with magnitude 5.0 or greater are a rarity east of the Rocky Mountains, "the number per year recorded in the midcontinent increased 11-fold between 2008 and 2011, compared to 1976–2007" (Keranen, 2013). When interviewed concerning colleague response to the study, Keranen indicated that, "Pretty much everybody who looks at our data accepts that these events were likely caused by injection" (Behar, 2013).

## Fracking Wastewater Deep-Injection Disposal Wells and Induced Earthquakes: The Jury's Verdict

While speculation and confusion dominate the lay population's conversation regarding the origins of this historic increase in midcontinent earthquakes, there is a strong consensus among geologists and seismologists that the recent uptick in earthquakes is primarily due to the recent increase in fracking industrialization and disposal of its associated wastewater.

William Ellsworth of the U.S. Geological Survey Earthquake Science Center concludes: "Clearly it is happening. Earthquakes have been happening in some unusual parts of the United States. At this point, we do not know if all or just some part of that increase is attributable to industrial activities like wastewater injection" (Vergano, 2013). These risks associated with deep-injection wells inducing earthquakes, which according to Scott Ausbrooks (geologist with the Arkansas Geological Survey) have "been known for decades," are especially heightened in known seismic zones, such as the Wabash and New Madrid Seismic Zones, as "what is clear... is that deep reservoirs in tectonically active zones carry a real risk of inducing damaging earthquakes" (Ellsworth, 2013).

For Cliff Frohlich, senior research scientist at the University of Texas at Austin's Institute for Geophysics, the problem is that faults are ubiquitous, they are most everywhere, and "most of them are stuck, because rock on rock is pretty sticky. But if you pump a fluid in there to reduce the friction, they can slip" (Behar, 2013). Frohlich continues regarding the recent uptick in seismic activity, "These earthquakes could have been anywhere. They weren't. Virtually all of them were near injection wells" (Behar, 2013).

*Popular Science* writer Francie Diep notes a strong consensus among those best equipped to comprehend the situation: "Since companies began doing [wastewater deep-injection] more often, U.S. Geological Survey and other scientists have noticed more earthquakes occurring in the Midwest, which isn't normally so seismically active. Three different geologists told me this, unprompted, when I was researching the Prague quakes earlier this year" (Diep, 2013). Those Prague, Oklahoma earthquakes included the strongest quake in Oklahoma history, a magnitude 5.7 that struck within a mile of three injection wells filled with fluid leftover from conventional oil dewatering operations (Behar, 2013; Holland & Keller, 2012). The quake destroyed 14 homes, injured two individuals, and was felt more than 600 miles away in Chicago (Choi, 2012; Ellsworth, 2013).

While a team of seismologists from Columbia University, University of Oklahoma and the U.S. Geological Survey concurred on the waste-injection origin of the series of quakes (Keranen et al., 2013), United Kingdom-based applied geophysicist James Verdon points out that, "the Oklahoma Geological Survey has subsequently released a rebuttal (Keller & Holland, 2013) stating that as far as it is concerned, there is not enough evidence to tie the quake to injection activities" (Verdon, 2013a).

## Fracking Wastewater DIDWs Are Primary Fracking-Related Seismic Hazard

A team of geologists and seismologists led by William Ellsworth posit in their 2012 study "Are seismicity rate changes in the midcontinent natural or manmade" that the slight increase in seismicity that began in 2001 was primarily due to a Raton Basin coal bed methane field west of Trinidad, Colorado along the Colorado-New Mexico border. They further conclude that the "acceleration in activity that began in 2009 appears to involve a combination of source regions of oil and gas production, including the Guy, Arkansas region, and in central and southern Oklahoma" (Ellsworth et al., 2012).

While some have raised concerned over seismicity related to the fracking event itself, the primary seismic hazard from fracking industrialization is its associated wastewater disposal into Class II deep-injection wells. Shale gas and oil extraction features four behaviors during the entire fracking industrialization life cycle that can induce some degree of seismicity or affect local geological stresses. These include the drilling of wells, the hydraulic fracturing of the shale, the removal of gas and fluids from the well during production, and deep-injection well wastewater disposal (Frohlich et al., 2010).

William Ellsworth points out that with nearly 100,000 wells having been fracked over the last twelve years, the largest induced earthquake from the hydraulic fracturing of the shale was magnitude 3.6, a barely felt earthquake that by itself poses no serious risk.

However, attitudes have shifted regarding wastewater injection induced seismology, as prior to 2011 the seismic event widely accepted by the scientific community as having been the largest wastewater injection induced earthquake in U.S. history was the magnitude 4.8 quake that took place on August 9, 1967 near Denver, Colorado (Ellsworth, 2013). Over the last decade, and especially since 2011, matters have literally shifted.

## Shutting Down of Wells that Induced Earthquakes

Geologists and seismologists are not the only engaged professionals raising concerns about fracking wastewater disposal related induced seismology. State oil and gas officials in both Arkansas and Ohio have shut down fracking wastewater disposal wells that have been connected with induced earthquakes. In the case of induced seismology in the Guy-Greenbrier area or Arkansas, the state's governor, Oil and Gas commission, and the general public all concurred to shut down the responsible injection-wells as, "nearly 1000 recorded quakes had struck the area since the wells had started up" (Kerr, 2012).

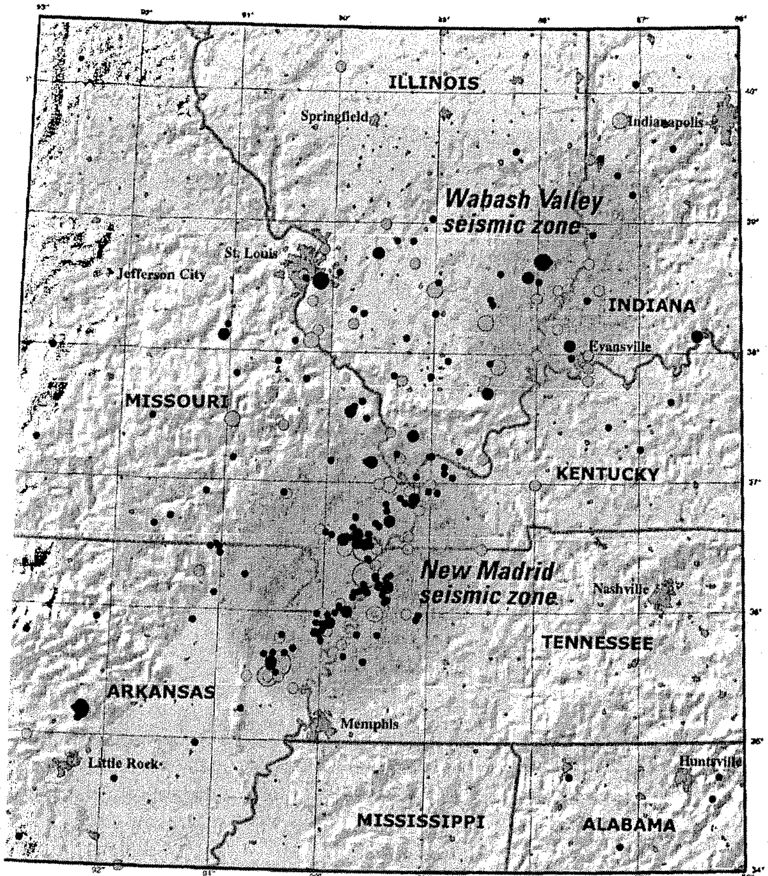
A moratorium was declared within a 1,150 square mile area around Guy-Greenbrier on deep-injection wastewater disposal activities, while seismic-risk studies of the entire Fayetteville shale play were also required. Additionally, "Affected residents filed a class-action lawsuit against Chesapeake Energy and BHP Billiton Petroleum—the first time anyone has sued oil and gas companies for causing an earthquake" (Behar, 2013). University of Memphis seismologist Stephen Horton related that once the wells were shut down the quakes tapered away and ultimately ceased (Kerr, 2012).

## The Youngstown, Ohio Fracking Wastewater Disposal Induced Earthquakes

When a magnitude 2.7 earthquake struck near Youngstown, Ohio on December 24, 2011, it was the tenth such earthquake in the 2.0 to 2.7 magnitude range since March of that year connected with fracking wastewater injection well Northstar 1 owned by D&L Energy Group. The well, which came online in December 2010 (just three months prior to start of seismic activity), received the vast majority of its wastewater from fracking projects in Pennsylvania (Fountain, 2012). Nearly 60% of all the fracking wastewater disposed of in Ohio injection-wells in 2012, 257 million gallons, originated in others states, marking a 19% one-year increase in out-of-state fracking wastewater injected into subterranean Ohio (Johanek, 2013). Prior to January 2011 Youngstown, Ohio had not experienced an earthquake dating back to 1776 when scientists first began recording their observations (Choi, 2013).

Upon analysis of the December 24, 2011 earthquake by the Ohio Department of Natural Resources it was determined that the quake originated less than 2,000 feet below the Northstar 1 well (Fountain, 2012). No sooner had the State of Ohio put an immediate cessation to injection at the well, when an earthquake with a 16 times greater magnitude of 3.9 struck the following week, on New Year's Eve, December 31, 2011. At that point state officials instituted a moratorium on the injection of fracking wastewater within a 5-mile radius of the D&L well until scientists had an opportunity to analyze the data from the string of quakes (Fountain, 2012).

By the time March 2012 rolled around, Youngstown, Ohio had recorded 109 earthquakes in the previous year (Choi, 2013), and "the indications were strong enough to prompt the state to order the




Dark circles — indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 located using modern instruments. *(University of Memphis)*

Light circles — indicate earthquakes that occurred prior to 1974. Larger earthquakes represented by larger circles. *(USGS Professional Paper 1527)*

shutdown of four injection wells in the area and issue strong new regulations" (Kerr, 2012). On July 12, 2012 Executive Order (2012-09K) was signed by Ohio Governor John Kasich, which required that operators conduct seismic studies prior to issuance of well permits (Kasich, 2012). Ohio now stands alone in requiring a seismic-risk assessment for all of its injection wells, as every other state, and the federal government, have yet to do (Behar, 2013).

Seismologist John Armbruster puts points out that within a year of the Northstar 1 well opening there were 109 total earthquakes, and "twelve felt earthquakes. After the well was shut down, the number decreased dramatically. You'd need Powerball odds for that to be a coincidence" (Behar, 2013).

## Proliferation of Shale Gas & Oil Extraction and Fracking Wells

Over the last decade the United States has seen an unprecedented increase in the proliferation of shale gas and oil extraction that has pushed domestic oil to its current place of highest level of production in 20 years, while bringing natural gas production to an all-time high (Weber, 2013). Shale gas from fracking specifically has gone from only 2% of U.S. natural gas production in 2000 to 23% of NG production in 2010 (US EIA, 2012). Because of fracking, the International Energy Agency projects that the U.S. will overtake Russia as the world's top producer of natural gas by 2015.

With this precipitous increase in shale oil and gas production, the U.S. has likewise seen an increase in the proliferation of fracking wells, with more than 82,000 drilled or permitted in 17 states between 2005 and 2012. At the time of this writing (November of 2013) there are likely in excess of 100,000 fracking wells permitted or drilled in the U.S. (Ellsworth, 2013). In 2012 alone there were 22,326 fracking wells drilled throughout the United States, with more than 60% of them (13,540) being drilled in Texas (Ridlington & Rumpler, 2013). During that year drilling inspectors identified more than 55,000 violations of Texas fracking laws by oil and gas companies (Soraghan, 2013a).

## Wastewater Associated with Fracking Industrialization

This dramatic increase in oil and gas production and associated fracking wells has in turn led to an increase in the need for fracking-related wastewater disposal. Each fracked well requires approximately 4 to 7 million gallons of water, fracking fluid and fracking sand to complete a hydraulic fracturing event. In the range of 20% to 80% of the fluid injected during the fracking event, an average of 2.75 million gallons of toxic and radioactive effluent per well ((Hammer & Van Briesen, 2012), returns to the surface as fracking flowback and wastewater (Miller, 2012; Moss, 2008).

The volume of wastewater to be disposed of during the fracking process is one factor that makes fracking industrialization different from anything other form of fossil fuel extraction that has been seen before, producing "50 to 100 times more" waste than conventional oil and gas wells (Cantarow, 2013). Multiply that level of industrialization in terms of number of wells, by that degree of waste management in terms of the volumes of toxic and radioactive effluent per fracked well, and the result is 280 billions gallons of total flowback and produced wastewater coming out of U.S. fracking wells each year (Ridlington & Rumpler, 2013). Unfortunately, these national numbers are woefully incomplete as wastewater produced by Texas alone represents nearly 93% of this total (260 billion gallons), and there was "no estimate" listed for seven of the seventeen fracking states included in the survey.

The shift over the last decade is undeniable, as an overwhelmed Marcellus Shale wastewater disposal infrastructure capacity can attest to, in that "developing the Marcellus shale has increased the total wastewater generated in the region by ~570%" between 2004 and 2012. This of course is a natural consequence of fracking industrialization, as toxic and radioactive wastewater "is an obligate byproduct of current methods and volumes will unavoidably increase with industry expansion" (Lutz et al, 2013).

## Various Methods for Disposing of Fracking Wastewater

While there are current alternatives to deep-well injection for disposing of fracking wastewater, scientists and regulators alike agree that the other options are generally far more expensive while embodying additional environmental risks (Lustgarten, 2013a). These alternatives, the first three of which have been utilized extensively in the Marcellus region due to lack of suitable geology for underground injection (MSAC, 2011), include: (1) Processing of wastewater at municipal wastewater treatment facility with final discharge into a local waterway; (2) Processing of wastewater at a private industrial wastewater facility, with either discharge into a local waterway or reuse of the treated effluent in fracking wells; (3) Recycling of wastewater and reuse of the partially treated effluent in fracking wells; (4) Burning of waste; (5) Disposal of waste by application on roadways and other surfaces (Lutz et al, 2013; Lustgarten, 2012a); and unfortunately, (6) "Fracking flowback is dumped into rivers, lakes and reservoirs" (Eco Watch, 2013).

Cliff Frohlich, senior research scientist at University of Texas at Austin's Institute for Geophysics, reminds us that "the people involved in this are going to do the cheapest way of doing things that is generally considered safe" (Henry, 2012a), and that is currently why more than 95% of fracking wastewater is injected into deep wells (Clark and Veil, 2009). Journalist Abrahm Lustgarten, however, reminds us that, "several key experts acknowledged that the idea that injection is safe rests on science that has not kept pace with reality, and on oversight that doesn't always work (Lustgarten, 2012a). It is not just the energy sector that is dependent on this form of waste elimination, as subterranean waste disposal is a cornerstone of the U.S. economy, with pharmaceutical, chemical and agricultural industries all being dependent upon deep-well injection for managing voluminous waste streams. Even carbon storage and sequestration that is the essential fossil fuel industry strategy for addressing climate change, as Lustgarten points out, "counts on pushing waste into rock

formations below the earth's surface" (Lustgarten, 2012a).

## Fracking Wastewater in Deep-Injection Disposal Wells

As there has been a monumental increase in total fracking-related wastewater produced over the last decade, there has likewise been a dramatic increase in total fracking wastewater injected into disposal wells, where 95% of the toxic effluent is managed. Of the more than 680,000 total injection wells in the United States, in excess of 150,000 fall into the energy industry-specific Class II category that includes both deep-disposal wells in addition to "wells in which fluids are injected to force out trapped oil and gas" (Lustgarten, 2012a). Approximately 30,000 to 40,000 of these Class II wells are deep-disposal wells that receive the volumes of fracking flowback and produced wastewater (Diep, 2013; Ellsworth, 2013; Soraghan, 2013). The states with the most Class II injection wells are Texas (52,016), California (29,505), Kansas (16,658), Oklahoma (10,629), and Illinois (7,843) (US EPA, 2010).

A study by the Argonne National Laboratory estimated that a total of 252 billion gallons of fracking wastewater is injected into Class II deep disposal wells in the United States per year (Clark and Veil, 2009; Clarke et al., 2012). In Texas the total amount of fracking wastewater being injected into deep disposal wells went from 46 million barrels (1.45 billion gallons) in 2005 to nearly 3.5 billion barrels (110.25 billion gallons) in 2011, representing a 76-fold increase in total fracking wastewater injection volume in a six-year period (Galbraith and Henry, 2013). The total amount injected into the more than 150,000 total Class II wells among 33 states is at least 10 trillion gallons of wastewater (Lustgarten, 2012c), while over the last several decades all U.S. industries combined have injected in excess of 30 trillion gallons of toxic liquid into all classes of injection wells, "using broad expanses of the nation's geology as an invisible dumping ground" (Lustgarten, 2012a).

## Wastewater Injection Induced Earthquakes – Factors That Increase Risk

As fracking wastewater injection has dramatically increased over the last decade, so have induced earthquakes, as elucidated by Cliff Frohlich: "The earthquakes are occurring more frequently now because there's so much more fluid injection due to the fracking and the development of unconventional gas. [...] So what's happened is that we have a lot more injection going on in a lot more places, where we're producing more gas and earthquakes" (Henry, 2012a). While most of the United States' 40,000 wastewater injection wells will never cause felt seismic activity, some have and will induce earthquakes in excess of 3.0, and so far, as great as 5.7 (Diep, 2013; Ellsworth, 2013).

The USGS's Williams Ellsworth identifies a number of factors that could enhance the probability of a given injection-well inducing earthquakes in his 2013 *Science* study. They include, "the magnitude of the perturbation, its spatial extent, ambient stress condition close to the failure condition, and the presence of faults well oriented for failure in the tectonic stress field. Hydraulic connection between the injection zone and faults in the basement may also favor inducing earthquakes, as the tectonic shear stress increases with depth in the brittle crust" (Ellsworth, 2013).

Frohlich likewise stresses that it is absolutely essential to "understand why some injection wells trigger seismic activity and others do not," especially when they seemingly have similar mechanical and geological characteristics. He hypothesizes that "injection only triggers earthquakes if injected fluids reach and relieve friction on a suitably oriented, nearby fault that is experiencing regional tectonic stress" (Frohlich, 2012), such that "the materials must be pre-stressed to a substantial fraction of their breaking strength in order for seismicity to be induced" (Kisslinger, 1976). The specific mechanisms involved in fluid-relieved friction on a locked fault will be explored in greater detail below.

## Limiting Condition 1: We Don't Exactly Know What Is Going On Down There

In light of these risk factors identified by Ellsworth and Frohlich, there are two major *limiting conditions* that can significantly contribute to fault rupture and earthquake inducement from fracking wastewater's injection into deep disposal wells. The first is that we do not necessarily know where the injected wastewater is going, and what subterranean pathways it might be following, especially in relation to pre-existing faults both known and unknown. The second is that wells can, and do, fail and leak.

Class II injection wells in practice do not have detailed geologic reviews performed, so there is not particularly any understanding regarding what the well opens up to as much as two and a half miles beneath the surface, including the location of possible faults (Clarke et al., 2012). ProPublica investigative reporter Abrahm Lustgarten captures this reality of disposal well structure: "Tubes of concrete and steel extend anywhere from a few hundred feet to two miles into the earth. At the bottom, the well opens into a natural rock formation. There is no container. Waste simply seeps out, filling tiny spaces left between the grains in the rock like the gaps between stacked marbles" (Lustgarten, 2012a).

The high wellhead pressures applied to inject millions of gallons of fracking wastewater into these deep recesses are sometimes in excess of 50 MPa (493 atmospheres or 7,250 psi) (Hsieh, 1979; Zhang et al, 2013). Injection pressures that high "may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers" (Lustgarten, 2012b). As Scott Ausbrooks, a geologist with the Arkansas Geological Survey, points out, water will eventually find a way out: "Water does not like to be squeezed. Just like a room of people. The more you put in, the more crowded it gets, and at some point, people are going to start being pushed out the doors" (Behar, 2013). Cliff Frohlich describes the wastewater as being forced "downward and outward" from excessive injection, adding that fracking's toxic effluent "can meander for months, creeping into unknown faults and prying the rock apart just enough to release pent-up energy" (Behar, 2013).

## Limiting Condition 2: Deep-Injection Disposal Wells Will Fail and Leak

While scientists and federal regulators generally acknowledge they do not know how many of the Class II injection well sites receiving fracking wastewater are leaking, a ProPublica analysis of EPA data and case histories from October 2007 to October 2010 regarding more than 220,000 well inspections shows that 3.2% of the wells failed and "showed signs that their walls were leaking" (Lustgarten, 2012a). ProPublica*'s* Abrahm Lustgarten further related, "records also show wells are frequently operated in violation of safety regulations and under conditions that greatly increase the risk of fluid leakage and the threat of water contamination."

According to federal water protection regulation descriptions more than 7,500 well test failures from those three years studied involved *fluid migration* and *significant leaks*, with most of those failures being due to cracks or holes that have damaged the well structure itself (Lustgarten, 2012a). Williams Ellsworth notes that while the current wastewater deep-injection disposal well regulatory framework was designed to protect aquifers and groundwater sources from contamination, the regulations fail to address seismic safety (Ellsworth, 2013).

Because of the *limiting conditions* that we do not necessarily know where the injected wastewater is going and that deep-injection wells fail and leak at an estimated rate of 3.2%, wastewater migrates not only to areas unknown, but also to regions where we specifically do not want it to go: fault zones. These fault zones tend to be located deep beneath the surface in the region of the lithosphere known as the Precambrian Crystalline Basement.

## Fracking Wastewater Injection and Induced Seismology

William Ellsworth noted in his 2013 *Science* study that, "There has been a growing realization that the principal seismic hazard from injection-induced earthquakes comes from those associated with disposal of wastewater into deep strata or basement formations" (Ellsworth, 2013). The operative notion is that in order for seismic activity to be induced, not only does that fault have to be pre-stressed, but it also must be reachable where they are located in the Precambrian crystalline basement by the meandering injected wastewater and its associated fluid pressure. Cliff Frohlich



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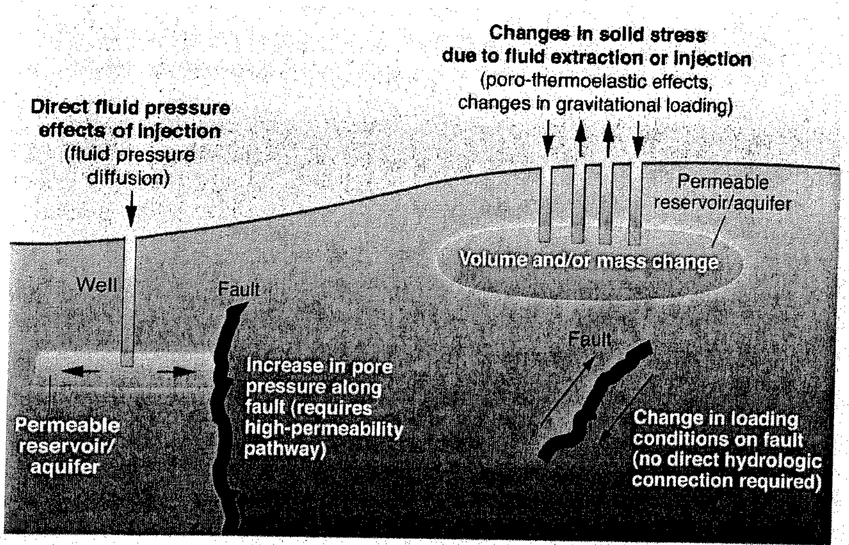


reiterates this point during a 2012 interview, suggesting "fluid injection may trigger earthquakes only if fluids reach and relieve friction on a nearby fault" (Choi, 2012).

A consensus among geologists support the understanding that a vast majority of the fracking wastewater DIDW induced earthquakes did not originate within the sedimentary reservoirs into which the toxic and radioactive fluid was directly injected. Rather this seismicity originated within the generally impermeable metamorphic and igneous crystalline basement that lies 1 to 6 kilometers deeper beneath the sedimentary platform (Horton, 2012; Hsieh and Bredehoeft, 1981; Nicholson and Wesson, 1990; Seeber et al., 2004; Zhang et al., 2013).

Zhang et al., in their 2013 *Groundwater* study, stated that the ever-increasing midcontinent earthquakes "probably occurred along faults that were likely critically stressed within the crystalline basement." More specifically, they found that induced seismic activity was a result of the fracking wastewater either, 1) being injected into a basal sedimentary reservoir that lacks a confining unit underneath the injection reservoir horizon, thus allowing for migration into Precambrian layers, or 2) being injected "directly into the underlying crystalline basement complex" (Zhang et al, 2013).

## Migrating Fluid and Precambrian Crystalline Basements

An essential practical conclusion from the *Groundwater* study (Zhang et al, 2013) is the factor that has the single largest impact in preventing seismic induction within the underlying crystalline basement is the presence of a confining unit barrier between the sedimentary reservoir and the lower Precambrian layer. William Ellsworth describes those injection wells that "dispose of very large volumes of water and/or communicate pressure perturbations directly into basement faults" (Ellsworth, 2013) as problematic disposal wells. Geophysicist Barry Raleigh, whose 1976 *Science* study "An experiment in earthquake control at Rangely, Colorado" demonstrated how earthquakes could be turned on and off by utilizing manipulation of fluid pressure, elucidates that the deep, low-permeability, brittle igneous and metamorphic rock of the crystalline basement "doesn't have a lot of capacity for taking any of these fluids. As a storage medium, they're pretty crappy" (Kerr, 2012).

Readily *felt earthquakes* larger than magnitude 4.0 that have been induced by injection of fracking wastewater into deep disposal wells additionally point to a deeper subterranean origin to these larger earthquakes. "Burdened by far more overlying rock, the deep rock is already carrying stress that," when combined with "the added pressure of the injection trigger," manifests conditions ripe for fault rupture and potentially destructive seismic activity (Kerr, 2012). Zhang et al. (2013) hypothesize that "elevated pore pressures could propagate downward along distributed fracture networks or along conductive fault zones in Precambrian crystalline rocks" (Zhang et al, 2013), meaning that the pressure from fluids can be potentially transmitted to hidden fractures at great depths, given the right conditions. In fact, David M. Evans, in his seminal 1966 *Geotimes* study, relates that even "if the Precambrian fracture system extends to a depth of 12 miles, then fluid pressure could [still] be transmitted to that depth by moderate surface injection pressure as long as the fracture system is open for transmission of that pressure" (Evans, 1966).

## The Long Understood Relationship Between Subterranean Fluid Disposal & Induced Seismology

Some may point to 77 CE Rome for the origins of the human demonstration of the relationship between elevated fluid pressure and induced geological failure, a well-documented case in which Romans utilized the technique to "undermine and instantly remove vast quantities of mountainside to extract gold from the buried mother lode at Las Médulas in northwest Spain" (Goodway, 2012). Others might claim that we have shared this understanding for almost a century, such as members of the Committee on Induced Seismicity Potential in Energy Technologies, who claim that "induced seismic activity has been documented since at least the 1920s" (Clarke et al., 2012), referencing a 1926 study that ran in the *Bulletin of the Seismological Society of America* regarding "Local subsidence of the Goose Creek oil field (Texas)" (Pratt and Johnson, 1926).

While these obscure examples add clarity to this generally familiar yet elusive phenomenon, it is David M. Evans' 1966 *Geotimes* study "Man-made earthquakes in Denver" that is popularly credited with establishing the connection between injection of waste fluids and induced earthquakes (Choi, 2012; Ellsworth, 2013; Frohlich, 2012; Henry, 2012; Kerr, 2012; Soraghan, 2013), such that "since 1966, scientists have generally agreed that injection may induce earthquakes in tectonically favorable situations" (Davis and Frohlich, 1993). Keep in mind that Plate Tectonic Theory did not come into general acceptance until just one-year prior, in 1965, to the verification of this form of human induced earthquake phenomena.

## The Mechanisms Underlying Earthquakes Induced by Fracking Wastewater DIDWs

In regards to the fracking wastewater disposal-induced earthquakes that have been escalating in frequency in the United States' midcontinent over the last decade, U.S. Geological Survey's William Ellsworth concludes that the mechanism responsible for inducing this seismic activity is the "well-understood process of weakening a preexisting fault by elevating the fluid pressure" (Ellsworth, 2013). Ellsworth clarifies that the three specific events that can trigger the nucleation of an earthquake by bringing the fault to failure are, 1) reducing the effective normal stress on a locked fault, 2) increasing the shear stress along a fracture plane, and 3) elevating the pore pressure of the fluid in the rock. Nucleation is the process that marks the beginning of an earthquake with an initial rupture that propagates along the fault surface. Fault failure or slippage can trigger this process, and in turn, generate an earthquake (Ellsworth, 2013).

## Effective Normal Stress and Induced Seismology

If the effective normal stress, the frictional forces that hold a fault a place, is lowered, it can result in fault slippage and trigger earthquake nucleation. Increased fluid pressure relieves enough of squeeze on the fault to release it and induce an earthquake (Kerr, 2012). Injecting fluids that act as a pressurized cushion to relieve the effective normal stress that keeps a fault locked over-pressures a fault (Sheppard et al, 2013). Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory, relates that, "When you over-pressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen" (Earth Institute, 2013).

Effective normal stress is equal to the difference between the applied normal stress and pore pressure (Ellsworth, 2013). Applied normal stress is the total stress on a rock (Hsieh, 1979), or the weight of a given block (Evans, 1966), and pore pressure is the pressure of fluid in the rock's pores and fractures (Ellsworth, 2013), such that

increased pore pressure causes a decrease in frictional force, the effective normal stress (Warpinski, 2012).

## Shear Stress and Induced Seismology

Raising or increasing the shear stress along a fracture plane can also result in induced seismology, such that once the shear stress overcomes the effective normal stress (multiplied by the coefficient of friction and added to cohesion) in a geological system, the fault will slip, fail, and result in an earthquake (Warpinski, 2012). Faults are locked due to frictional forces, which are the result of in situ stresses pressing vertically on the fault plane. Raising the shearing stress to the point of overcoming effective normal stress such that the fault slips is also known as the Mohr-Coulomb failure criterion. Paul Hsieh, recently named 2011 United States Federal Employee of the Year for his role in bringing to a close the BP oil spill in the Gulf of Mexico, remarks in his pivotal 1979 master's thesis that, "Shearing stresses will remain the same no matter how pore pressure varies. This results from the fact that fluid cannot support any shearing stress" (Hsieh, 1979).

Raleigh and others clarify this direct impact that injecting wastewater has on stressed fractures given its inability to support any shearing stress:

> "The pressurized fluid enters a fracture and supports a part of the normal stress equivalent to the pressure of the fluid. As the fluid has no shear strength, the effective normal stress and the frictional resistance to sliding are lowered. If the fracture is subject to shear stress greater than the product of this effective normal stress and the coefficient of friction, the rocks will slip and generate an earthquake" (Raleigh et al., 1976).

## Pore Pressure and Induced Seismology

Finally, elevating the pore pressure of the fluid in the rock can readily lead to seismic events given the proper conditions, like a stressed fault in contact with pressurized, migrating liquid. As the measure of the pressure of the fluid in the rock's pores and fractures, pore pressure is equal to the difference between applied normal stress and effective normal stress (Ellsworth, 2013). Thus as pore pressure increases, the effective normal stress will decrease. This effective normal stress can also be understood as the frictional resistance against the shearing stress along the fracture plane (Hsieh, 1979). If there is a sufficient enough increase in fluid pressure such that the shearing stress overcomes frictional resistance, the fault will slip and result in an earthquake. This is known as the Hubbert-Rubey mechanism, named after the findings in their seminal 1959 *Geological Society of America Bulletin* study "Role of fluid pressure in mechanics of overthrust faulting," as elucidated by Paul Hsieh:

> "The original work of Hubbert and Rubey (1959) actually concerns the role of pore pressure in the mechanics of overthrust faulting. They introduced the concept of rock movements caused by a Mohr-Coulomb-type failure in a fluid-filled rock environment. This concept was first cited by Evans (1966) in his paper on injection–earthquake relationship and subsequently gained wide acceptance as the mechanism through which injection has caused the earthquakes." (Hsieh, 1979)

In his "A review of theories of mechanisms of induced seismicity" that was published in *Engineering Geology*, Kisslinger relates that fluid injection induced earthquakes "are adequately explained" by a combination of the concept of effective pressure in a water-filled porous mechanism and the Coulomb-Mohr failure criterion, which embodies the three factors and their interrelationship that determines whether or not a particular fracking wastewater injection well will induce earthquakes (Kisslinger, 1976). Kisslinger further concludes that reservoir-related earthquakes, like those caused by fluid injection in bore holes, are induced by the same mechanisms, but in light of the lower injection pressures, "additional physical or chemical effects of the water on the materials may play an important role, [such as] a weakening of the materials in old fault zones by the introduction of water or static fatigue in silicate rocks due to stress corrosion (Kisslinger, 1976).

## How to Turn On and Turn Off Earthquakes: The Parameters of Induced Seismology

Now that it has been clarified what events have to transpire in subterranean realms for earthquakes to be induced by fracking wastewater disposal, the question then becomes *how do these mechanisms relate to specific surface behaviors*? The things that we do above ground that directly impact what happens not only 13,000 feet below the surface, but beneath those sedimentary layers in the Precambrian crystalline basements where faults lie within impervious rock formations.

Davis and Frohlich, in their 1993 *Seismological Research Letters* study "Did (or will) fluid injection cause earthquakes? Criteria for a rational assessment," provide us with a starting point by establishing criteria through which one can determine whether or not a given earthquake was induced by wastewater disposal (Davis & Frohlich, 1993). These criteria "include proximity to injection wells, a change from background seismicity, and a correlation with wastewater injection parameters" (Keranen et al., 2013). These parameters related to wastewater injection referred to by Keranen and others, all of which are ultimately controlled by decisions made and actions taken by the deep-well injection companies on the surface, include fluid pressure, total fluid volume, and rate of fluid injection. As noted by William Ellsworth, "the physical connection between operational parameters such as injected volume" and fluid pressure can be complex (Ellsworth, 2013).

## Fluid Pressure: Inducing Seismology By Exceeding Critical Value

The discovery by David Evans published in his 1966 *Geotimes* study, which led to speculations that earthquakes might be controllable, was that the subterranean high-pressure injection of fluid was responsible for the triggering of earthquakes at the Rocky Mountain Arsenal near Denver, Colorado in the early to mid 1960s. While earthquakes were being induced by the injection of pressurized wastewater into stressed rock formations, the reduction in fluid pressure caused a sharp decrease in frequency of seismic activity (Raleigh et al., 1976). A 1972 *Tectonophysics* study by Healy and others entitled "Prospects for earthquake prediction and control" more explicitly expressed this understanding and laid further groundwork for experimentally testing this hypothesis that, "Changes in fluid pressure may control timing of seismic activity and make it possible to control natural earthquakes by controlling variations in fluid pressure in fault zones" (Healy, et al., 1972).

Raleigh, Healy and Bredehoeft's landmark 1976 *Science* study "An Experiment in Earthquake Control at Rangely, Colorado" did demonstrate the capacity to turn on and turn off earthquakes and "established the correlation between fluid pressure and earthquakes beyond reasonable doubt," that they concluded the "control of the San Andreas fault could ultimately prove to be feasible." However, despite these earth-shattering revelations, perhaps the most important takeaway from these experiments was that, "successful prediction of the approximate pore pressure required for triggering of earthquakes according to the Hubbert-Rubey theory was possible" (Raleigh et al., 1976), as demonstrated by experimental verification of theoretical projections.

## Predicting Earthquake Behavior, Controlling Earthquakes By Manipulating Fluid Pressure

Utilizing the Mohr-Coulomb failure criterion in applying the Hubbert-Rubey theory, Raleigh and colleagues projected that 257 bars (25.7 MPa) would be the Rangely site's critical fluid pressure. The critical fluid pressure, the pressure required to trigger an earthquake, is governed by the equation:

$\tau_{crit} = \mu(S_n - P_c)$, with

$\tau_{crit}$ = shear stress at failure point,
$\mu$ = coefficient of static friction of the rocks,
$S_n$ = effective normal stress, and
$P_c$ = critical fluid pressure that induces seismicity.

"The fluid pressure required to trigger earthquakes on preexisting fractures" was experimentally tested against the theoretical



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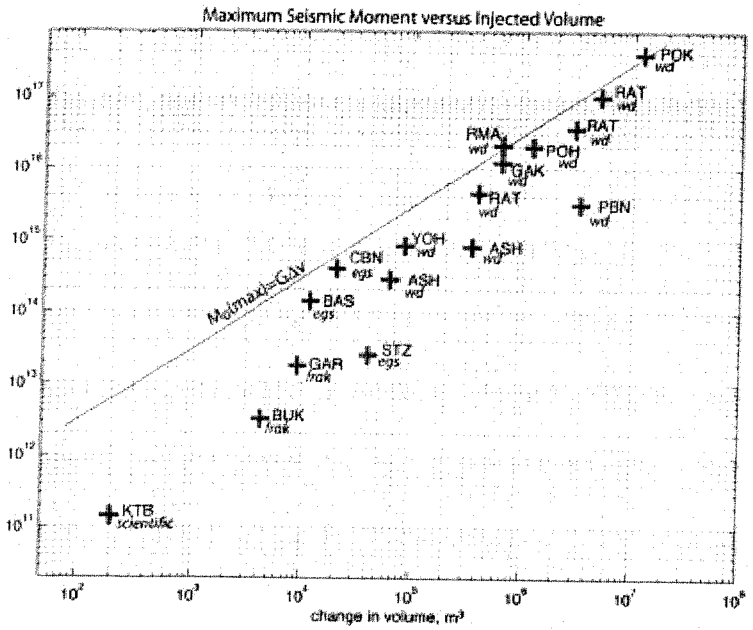



projections through use of "laboratory measurements of the frictional properties of the reservoir rocks and an in situ stress measurement made near the earthquake zone" (Raleigh et al., 1976).

Experimental results, which were obtained by varying fluid pressure through the process of "alternately injecting and recovering water from wells that penetrated the seismic zone" (Raleigh et al., 1976), demonstrated that when the injection wells were subjected to fluid pressures above 257 bars the earthquake frequency increased, and when the fluid pressure was less than 257 bars the earthquakes subsided. The idea is that for any given injection well and pre-existing fault situation a critical fluid pressure can be determined, such that "we may ultimately be able to control the timing and the size of major earthquakes [...] wherever we can control the fluid pressure in a fault zone" in relation to that critical fluid pressure (Raleigh et al., 1976).

Hsieh and Bredehoeft (1981), in an expansion of Hsieh's 1979 master's thesis (Hsieh, 1979), analyzed the Rocky Mountain Arsenal injection wells and earthquakes in similar fashion, utilizing Hubbert-Rubey theory to identify the fluid pressure critical value, "the pressure build-up above which earthquakes occur" (Hsieh, 1979). Their conclusion was that, "At the Rocky Mountain Arsenal near Denver, earthquakes occurred within the crystalline basement when the fluid pressures were raised over 320 m above hydrostatic conditions [32 bars, 3.2 MPa] between a depth of about 0.7–7 km (Hsieh and Bredehoeft, 1981; Zhang et al, 2013). Another way to frame this is that the earthquakes were confined strictly to those parts of the reservoir where the pressure build-up exceeded 32 bars (Hsieh, 1979). According to Davis and Frohlich (1993), Hsieh and Bredehoeft's breakthrough was that they were "able to explain the spatial and temporal extent of seismic activity in Denver in terms of the flow of fluids along a permeable semi-infinite rectangular region which approximately contained the activity."

## Total Injected Fluid Volume and Maximum Earthquake Magnitude

The relationship between total fluid volume injected and induced seismology has been noted by many, whether it is the "qualitative correlation between earthquake rates and the injected volume" that has served as a tool for investigating the triggered earthquake phenomena (Oprsal and Eisner, 2013), or the case history-driven evidence suggesting a connection between the total volume of injected wastewater and the maximum induced earthquake magnitude (Hayes, 2012). The U.S. Geological Survey's Art McGarr has compiled the data from these case histories and reports from fracking, waste disposal and geothermal induced seismic events, and has graphed Total Injected Volume vs. Maximum Earthquake Magnitude for 17 different cases of demonstrated fluid disposal triggered earthquakes (Holland and Keller, 2012; Verdon, 2013a; Verdon, 2013b):

| Total Gal. Injected (thousands) | Magnitude Richter Scale | Location |
|---|---|---|
| 53 | 1.4 | Bavaria Germany (KTB) |
| 1,057 | 2.3 | Blackpool, England (BUK) |
| 2,325 | 2.8 | Garvin County, Oklahoma (GAR) |
| 3,170 | 3.4 | Basel, Switzerland (BAS) |
| 9,774 | 3.7 | geothermal at CBN |
| 10,567 | 2.9 | Soultz, France (STZ) |
| 15,850 | 3.6 | Ashtabula, OH (ASH) |
| 21,134 | 3.9 | Youngstown, Ohio (YOH) |
| 89,818 | 3.8 | Ashtabula, OH (ASH) |
| 103,026 | 4.4 | Raton Basin, Colorado (RAT) |
| 158,502 | 4.6 | Guy, Arkansas (GAK) |
| 158,502 | 4.7 | Rocky Mountain Arsenal (RMA) |
| 766,093 | 5.0 | Raton Basin, Colorado (RAT) |
| 845,344 | 4.3 | Paradox Basin, Colorado (PBN) |
| 1,320,850 | 5.3 | Raton Basin, Colorado (RAT) |
| 3,170,040 | 5.7 | Prague, Oklahoma (POK) |

While "McGarr found a relationship between the maximum magnitude of induced earthquakes and the total volume of fluid injected into a site" (Balcerak, 2013), James Verdon reminds us that the McGarr model "is only empirical, there is no real physics behind it" (Verdon, 2013a). McGarr's model does, however, create an interesting framework for further theoretical and experimental work, while also leading to the derivation of the McGarr equation for injection-induced seismicity:

$M_0(max) = G\Delta v$, with

$M_0(max)$ = magnitude of largest seismic moment,

$G$ = shear modulus of rock (ratio of shear stress to shear strain), and

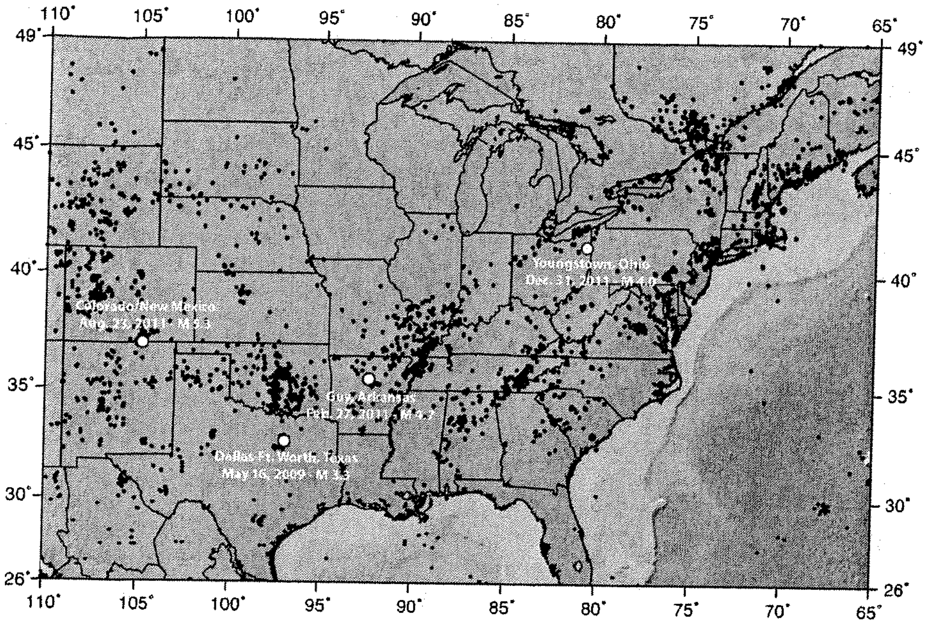
$\Delta v$ = total volume of fluid injected.

Despite potential shortcomings, Verdon does admit that, "In the meantime, we are left with the empirical McGarr equation as our main guide" (Verdon, 2013a). He also makes certain to clarify: "It should of course be remembered that the McGarr equation does not tell you the maximum magnitude you will get in an operation. [...] The McGarr line tells you the maximum magnitude you could get if you are very unlucky" (Verdon, 2013a). While McGarr continues to clarify the undeniable connection between the total injected fluid volume and the potential maximum magnitude of induced earthquakes, he does not find the rate of fluid injection to impact the magnitude of triggered earthquakes, but rather he found "that the rate of injection of fluid influences the frequency of induced earthquakes" (Balcerak, 2013).

## Rate of Fluid Injection and the Work of Cliff Frohlich

A third surface-controlled parameter that can impact fracking wastewater disposal induced seismicity is that of rate of fluid injection. While the rate of fluid injection and withdrawal played role in the Rangely, Colorado earthquake control experiments (Healy, et al., 1972), few scientists outside of Cliff Frohlich are investigating what he has observed to be a relationship between high rates of fluid injection and induced seismicity. From varies studies of the Barnett Shale play in Texas, Frohlich has found that injection wells nearest induced earthquake groups consistently reported maximum monthly injection rates in excess of 6.34 million gallons (24,000 cubic meters) of fluid, "and generally these injection rates had been maintained for a year or more prior to the onset of earthquake activity" (Frohlich, 2012).

While Frohlich has indicated in interviews that he is very much interested in pursuing this line of inquiry in other fracking wastewater injection regions (Choi, 2012), his own studies have already indicated that other faulted areas demonstrate different maximum monthly injection rates required to induce earthquakes, such as a fluid injection rate of 9.5 to 12.7 million gallons (32,000 to 48,000 cubic meters) per month in the case of Paradox Valley, Colorado (Frohlich et al, 2010). While there is still a lot of research and experimentation required to clarify the precise role of the three surface parameters of fluid pressure, total fluid volume, and rate of




fluid injection in triggering earthquakes, William Ellsworth concurs that experimental results distinctly suggest that these factors all "may be a predictor of seismic potential" (Ellsworth, 2013).

## Conclusion

The mechanisms that underlie fracking wastewater disposal induced earthquakes have been clarified and verified since 1966, making the Hubbert-Rubey theory just a year younger than the theory of plate tectonics and its general acceptance. By capturing the interrelationships between primary earthquake inducement factors that include effective normal stress, shear stress and pore pressure, they set the stage for a couple of decades worth of rich experimentation. All of which became nearly forgotten until fracking industrialization's rude awakening, a literal shaking the foundations of where we work, where we shop and where we live. Luckily, "after a decades long lull in triggered quake studies, researchers are playing catch-up with the latest round of temblors" (Kerr, 2012). And so, in the spirit of existential philosopher Martin Heidegger's conception of truth, we find ourselves in the process of *revealing that which had been concealed.*

One of the great concerns of many of the seismologists and geologists working on this issue is the reality of the earthquake domino effect that have been observed as a result of wastewater injection-induced seismicity. University of Oklahoma seismologist Katie Keranen relates this as the operative scenario in the Prague, Oklahoma magnitude 5.7 earthquake that struck on November 6, 2011: "We had one fault-plane go, a second one, and then a third one. They ruptured in sequence" (Behar, 2013). Lamont-Doherty Earth Observatory seismologist Geoffrey Abers elucidates, "the amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock" (The Earth Institute, 2013).

This is also of great concern to those potentially impacted individuals who live in Southern Illinois, existing between two active seismic zones, the New Madrid and the Wabash. With Southern Illinois facing the promise of mass fracking industrialization and its associated toxic and radioactive wastewater in need of disposal in deep-injection wells, it is not lost on many experts the danger that even small earthquakes can pose in this active seismic region. Geoffrey Abers acknowledges that, "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought (The Earth Institute, 2013). A study conducted by the University of Illinois Mid-America Earthquake Center in 2008 projected that if an earthquake the magnitude of the quakes that hit near New Madrid during 1811-1812 were to strike today, "there would be 3,500 fatalities, 2.6 million people without electricity and $300 billion in direct economic losses. Bridges, docks, highways and water infrastructure would be in shambles" (IEMA, 2013).

If mass fracking industrialization is to take hold of Southern Illinois, a land amidst two active seismic zones, then higher intelligence must be allowed to govern this process, its regulations, and their application. Stanford University geophysicist Mark Zoback answers this call by providing an empirically derived practical framework for reducing the probability of induced seismicity, with five straightforward steps:

(1) It is important to avoid injection into active faults and faults in brittle rock.

(2) Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.

(3) Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.

(4) Protocols should be established in advance to define how operations will be modified if seismicity is triggered.

(5) Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard (Zoback, 2012).

These five steps provide both the state (in form of regulators) and industry (in the form of operating companies) with a structure for reducing the risks involved in fracking wastewater disposal via deep-injection wells and the induced earthquakes that can accompany their utilization.



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*Brent Ritzel received his BA in Philosophy from Northwestern University in 1990 and is currently working on his master's thesis* PROJECTED TOTAL COSTS OF ROADWAY DEGRADATION DUE TO PROPOSED FRACKING INDUSTRIALIZATION OF SOUTHERN ILLINOIS *for a Master of Public Administration degree at Southern Illinois University Carbondale, expected completion May 2014.*

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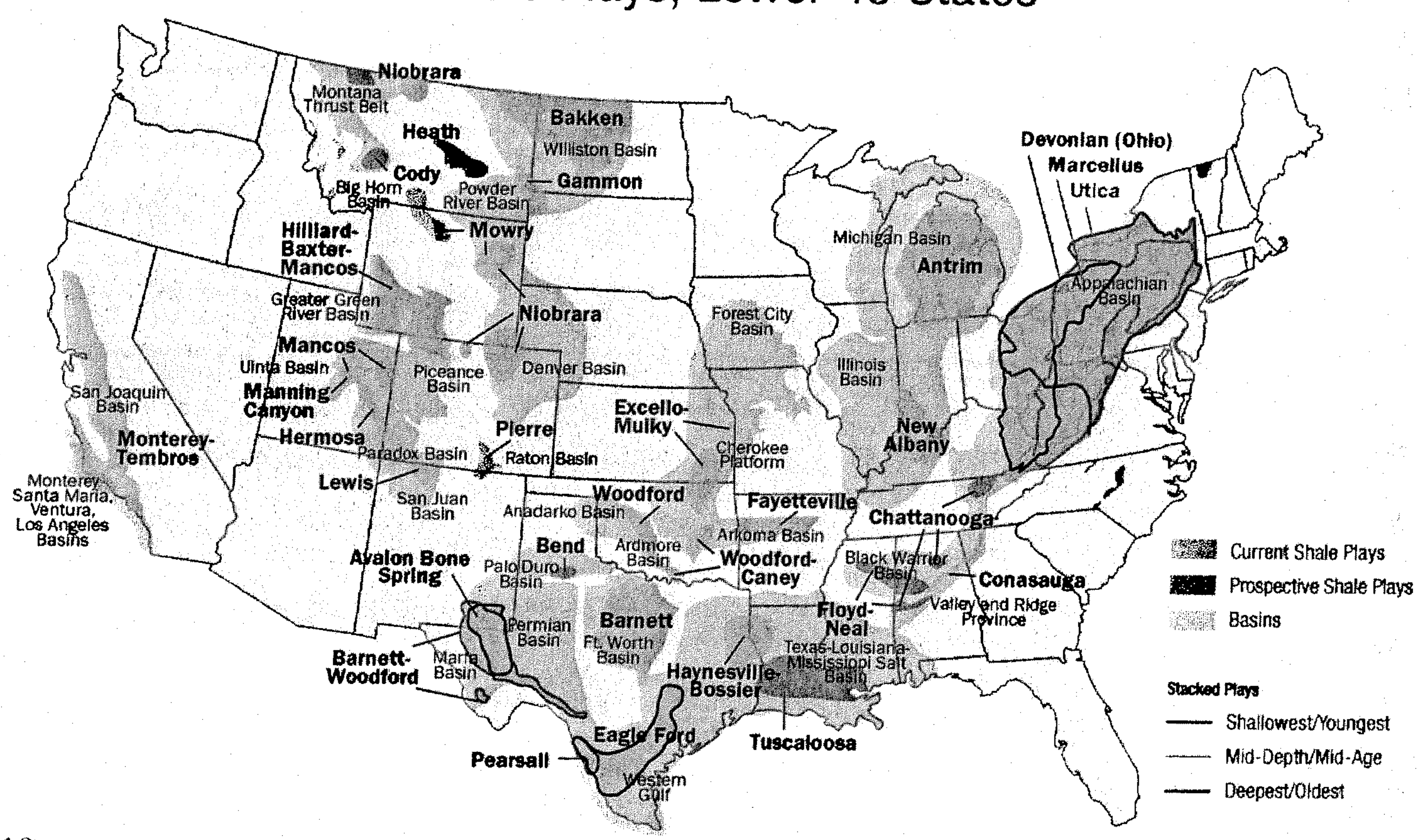
## Shale Plays, Lower 48 States



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# Fracking Industrialization & Induced Earthquakes

## The Mechanisms that Connect the Disposal of Fracking Wastewater into Deep-Injection Wells to a Significant Increase in Midcontinent Seismic Activity

by Brent Ritzel *[brent@siu.edu]*

### Introduction

This paper explores the recent significant increase in *felt earthquakes* in the midcontinent of the United States over the past decade in relation to fracking industrialization and its associated voluminous wastewater disposal needs. Studies and expert insight from geologists and seismologists from over the past fifty years will be utilized in order to render evidenced-based conclusions regarding these matters that have often remained at the opinion level of discourse in the public sphere.

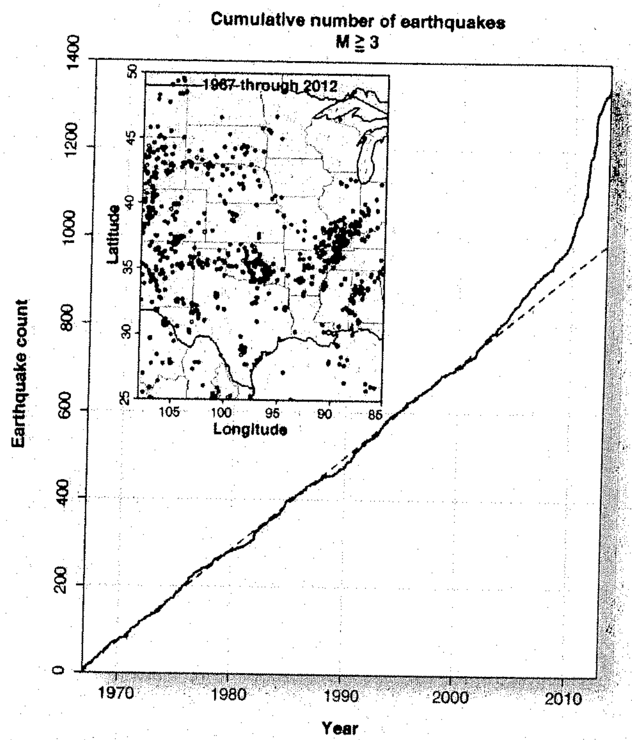
The current extent of U.S. fracking industrialization will be reviewed, including dissection of shale oil and gas production levels, the scale of proliferation of fracking wells, the volume of toxic and radioactive effluent, fracking flowback and produced wastewater disposal needs, and the impact of the exponential growth in deep-injection disposal well usage on the United States' current seismic reality. Two important limiting conditions, the *impervious* unknowns regarding subterranean geological formations *and* the fact that disposal wells will fail and leak, provide context for discussion of our obscured yet viable long term understanding of the mechanisms underlying the whole phenomenon of fracking wastewater disposal induced earthquakes.

### Historic Shift in Frequency of Midcontinent Earthquakes

Seismologists like the U.S. Geological Survey's William Ellsworth started noticing a historically unique trend about a dozen years ago, "that there were an unusual number of earthquakes in the middle of the country," in areas that have not been known for earthquakes (Rugh, 2013). The Guy-Greenbrier area of Arkansas, with total population of just over 5,000, was traditionally a quake-free area. Throughout all of 2007 the area had only one earthquake of magnitude 2.5 or greater, followed by only two such quakes in 2008. However, in 2009 there were 10, and in 2010 there were 54 earthquakes of magnitude 2.5 or greater (Kerr, 2012). On February 27, 2011, Guy experienced a magnitude 4.7 earthquake.

Neighboring state Oklahoma went through a similar pattern as a whole, experiencing just a few earthquakes per year from 1972 to 2007, 12 in 2008, 50 in 2009, and more than 1,000 in 2010, culminating with a magnitude 5.7 earthquake on November 6, 2011. While Oklahoma saw a more than hundred-fold increase in overall earthquakes, it also saw a twenty-fold increase in earthquakes with magnitude 3.0 or greater in those same three years from 2008 to 2010 (Ellsworth et al, 2012). Meanwhile, the Barnett Shale region of north central Texas has experienced "unprecedented levels of seismicity" since shale gas development began in late 1998, with "nine earthquakes of magnitude 3.0 or larger occurred, compared with none in the preceding 25 years." Overall, the states reporting unusually elevated levels of seismic activity include Arkansas, Colorado, New Mexico, Ohio, Oklahoma Texas, and Virginia (Ellsworth, 2013).

This pattern seen in both localized and statewide contexts is also reflected in data concerning the frequency of magnitude 3.0 or greater earthquakes in the entire U.S. midcontinent region, with the annual number of magnitude 3.0 or greater earthquakes having "increased almost tenfold in the past decade" (Lovett, 2013). The "middle part of the continent" went from a remarkably consistent average 21 per year from 1970 to 2000, to an average of 29 per year from 2001 to 2008, to 50 magnitude 3.0 or greater quakes in 2009, to 87 in 2010, to somewhere in the range of 134 to 188 in 2011




Cumulative count of earthquakes with magnitude ≥ 3.0 in the central and eastern United States, 1967–2012. The dashed line corresponds to the long-term rate of 21.2 earthquakes/year.
*(Inset)* Distribution of epicenters in the United States midcontinent region.

(Demus, 2012; Ellsworth, 2013; Henry, 2012; Lovett, 2013). As William Ellsworth *et al* (2012) reported in their *Seismological Research Letters* study, "A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region" (Ellsworth et al, 2012). Especially in areas that have historically lacked earthquakes, like the Youngstown, Ohio area, as Columbia University's Lamont-Doherty Earth Observatory seismologist John Armbruster relates, "Having that many earthquakes [...] where there aren't a lot of earthquakes, was suspicious" (Fountain, 2012).

What all these different scenarios share is a common time frame for the onset of fracking industrialization, and an ever-expanding need for deep-injection disposal wells [DIDWs] to handle the massive volumes of associated fracking flowback and produced wastewater. A 2013 *Science* study (van der Elst et al, 2013) by a team of seismologists led by Nicholas van der Elst of Columbia University's Lamont-Doherty Earth Observatory found, "that at least half of the magnitude-4.5 or larger earthquakes that have struck the interior United States in the past decade have occurred near injection-well sites" (Lovett, 2013). A 2013 *Geology* study (Keranen et al., 2013) by a team of seismologists led by Katie Keranen

concluded while earthquakes with magnitude 5.0 or greater are a rarity east of the Rocky Mountains, "the number per year recorded in the midcontinent increased 11-fold between 2008 and 2011, compared to 1976–2007" (Keranen, 2013). When interviewed concerning colleague response to the study, Keranen indicated that, "Pretty much everybody who looks at our data accepts that these events were likely caused by injection" (Behar, 2013).

## Fracking Wastewater Deep-Injection Disposal Wells and Induced Earthquakes: The Jury's Verdict

While speculation and confusion dominate the lay population's conversation regarding the origins of this historic increase in midcontinent earthquakes, there is a strong consensus among geologists and seismologists that the recent uptick in earthquakes is primarily due to the recent increase in fracking industrialization and disposal of its associated wastewater.

William Ellsworth of the U.S. Geological Survey Earthquake Science Center concludes: "Clearly it is happening. Earthquakes have been happening in some unusual parts of the United States. At this point, we do not know if all or just some part of that increase is attributable to industrial activities like wastewater injection" (Vergano, 2013). These risks associated with deep-injection wells inducing earthquakes, which according to Scott Ausbrooks (geologist with the Arkansas Geological Survey) have "been known for decades," are especially heightened in known seismic zones, such as the Wabash and New Madrid Seismic Zones, as "what is clear... is that deep reservoirs in tectonically active zones carry a real risk of inducing damaging earthquakes" (Ellsworth, 2013).

For Cliff Frohlich, senior research scientist at the University of Texas at Austin's Institute for Geophysics, the problem is that faults are ubiquitous, they are most everywhere, and "most of them are stuck, because rock on rock is pretty sticky. But if you pump a fluid in there to reduce the friction, they can slip" (Behar, 2013). Frohlich continues regarding the recent uptick in seismic activity, "These earthquakes could have been anywhere. They weren't. Virtually all of them were near injection wells" (Behar, 2013).

*Popular Science* writer Francie Diep notes a strong consensus among those best equipped to comprehend the situation: "Since companies began doing [wastewater deep-injection] more often, U.S. Geological Survey and other scientists have noticed more earthquakes occurring in the Midwest, which isn't normally so seismically active. Three different geologists told me this, unprompted, when I was researching the Prague quakes earlier this year" (Diep, 2013). Those Prague, Oklahoma earthquakes included the strongest quake in Oklahoma history, a magnitude 5.7 that struck within a mile of three injection wells filled with fluid leftover from conventional oil dewatering operations (Behar, 2013; Holland & Keller, 2012). The quake destroyed 14 homes, injured two individuals, and was felt more than 600 miles away in Chicago (Choi, 2012; Ellsworth, 2013).

While a team of seismologists from Columbia University, University of Oklahoma and the U.S. Geological Survey concurred on the waste-injection origin of the series of quakes (Keranen et al., 2013), United Kingdom-based applied geophysicist James Verdon points out that, "the Oklahoma Geological Survey has subsequently released a rebuttal (Keller & Holland, 2013) stating that as far as it is concerned, there is not enough evidence to tie the quake to injection activities" (Verdon, 2013a).

## Fracking Wastewater DIDWs Are Primary Fracking-Related Seismic Hazard

A team of geologists and seismologists led by William Ellsworth posit in their 2012 study "Are seismicity rate changes in the midcontinent natural or manmade" that the slight increase in seismicity that began in 2001 was primarily due to a Raton Basin coal bed methane field west of Trinidad, Colorado along the Colorado-New Mexico border. They further conclude that the "acceleration in activity that began in 2009 appears to involve a combination of source regions of oil and gas production, including the Guy, Arkansas region, and in central and southern Oklahoma" (Ellsworth et al., 2012).

While some have raised concerned over seismicity related to the fracking event itself, the primary seismic hazard from fracking industrialization is its associated wastewater disposal into Class II deep-injection wells. Shale gas and oil extraction features four behaviors during the entire fracking industrialization life cycle that can induce some degree of seismicity or affect local geological stresses. These include the drilling of wells, the hydraulic fracturing of the shale, the removal of gas and fluids from the well during production, and deep-injection well wastewater disposal (Frohlich et al., 2010).

William Ellsworth points out that with nearly 100,000 wells having been fracked over the last twelve years, the largest induced earthquake from the hydraulic fracturing of the shale was magnitude 3.6, a barely felt earthquake that by itself poses no serious risk. However, attitudes have shifted regarding wastewater injection induced seismology, as prior to 2011 the seismic event widely accepted by the scientific community as having been the largest wastewater injection induced earthquake in U.S. history was the magnitude 4.8 quake that took place on August 9, 1967 near Denver, Colorado (Ellsworth, 2013). Over the last decade, and especially since 2011, matters have literally shifted.

## Shutting Down of Wells that Induced Earthquakes

Geologists and seismologists are not the only engaged professionals raising concerns about fracking wastewater disposal related induced seismology. State oil and gas officials in both Arkansas and Ohio have shut down fracking wastewater disposal wells that have been connected with induced earthquakes. In the case of induced seismology in the Guy-Greenbrier area or Arkansas, the state's governor, Oil and Gas commission, and the general public all concurred to shut down the responsible injection-wells as, "nearly 1000 recorded quakes had struck the area since the wells had started up" (Kerr, 2012).

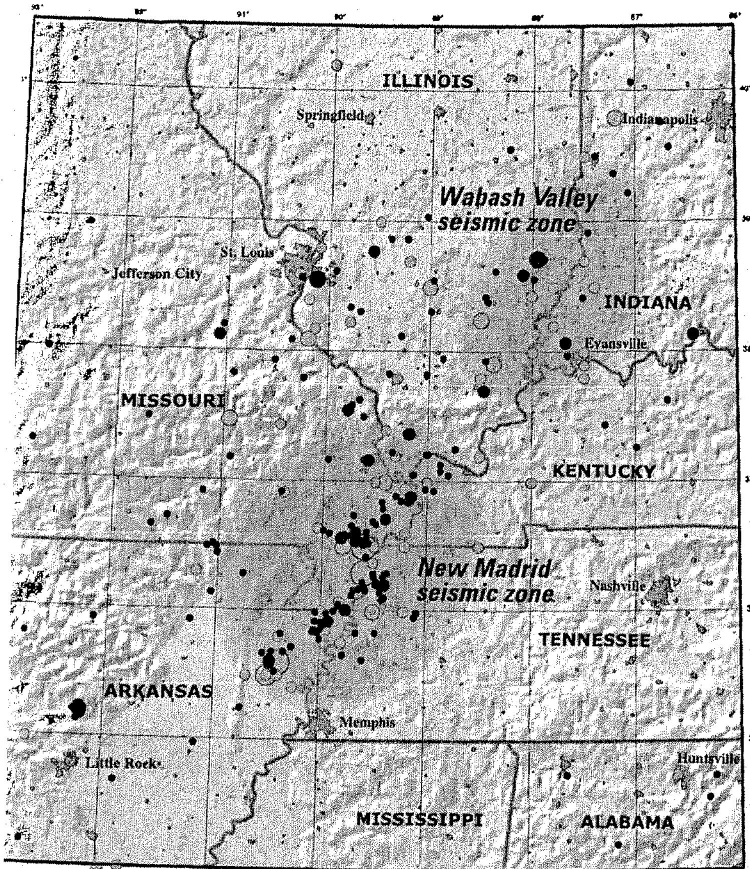
A moratorium was declared within a 1,150 square mile area around Guy-Greenbrier on deep-injection wastewater disposal activities, while seismic-risk studies of the entire Fayetteville shale play were also required. Additionally, "Affected residents filed a class-action lawsuit against Chesapeake Energy and BHP Billiton Petroleum—the first time anyone has sued oil and gas companies for causing an earthquake" (Behar, 2013). University of Memphis seismologist Stephen Horton related that once the wells were shut down the quakes tapered away and ultimately ceased (Kerr, 2012).

## The Youngstown, Ohio Fracking Wastewater Disposal Induced Earthquakes

When a magnitude 2.7 earthquake struck near Youngstown, Ohio on December 24, 2011, it was the tenth such earthquake in the 2.0 to 2.7 magnitude range since March of that year connected with fracking wastewater injection well Northstar 1 owned by D&L Energy Group. The well, which came online in December 2010 (just three months prior to start of seismic activity), received the vast majority of its wastewater from fracking projects in Pennsylvania (Fountain, 2012). Nearly 60% of all the fracking wastewater disposed of in Ohio injection-wells in 2012, 257 million gallons, originated in others states, marking a 19% one-year increase in out-of-state fracking wastewater injected into subterranean Ohio (Johanek, 2013). Prior to January 2011 Youngstown, Ohio had not experienced an earthquake dating back to 1776 when scientists first began recording their observations (Choi, 2013).

Upon analysis of the December 24, 2011 earthquake by the Ohio Department of Natural Resources it was determined that the quake originated less than 2,000 feet below the Northstar 1 well (Fountain, 2012). No sooner had the State of Ohio put an immediate cessation to injection at the well, when an earthquake with a 16 times greater magnitude of 3.9 struck the following week, on New Year's Eve, December 31, 2011. At that point state officials instituted a moratorium on the injection of fracking wastewater within a 5-mile radius of the D&L well until scientists had an opportunity to analyze the data from the string of quakes (Fountain, 2012).

By the time March 2012 rolled around, Youngstown, Ohio had recorded 109 earthquakes in the previous year (Choi, 2013), and "the indications were strong enough to prompt the state to order the




Dark circles — indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 located using modern instruments. *(University of Memphis)*

Light circles — indicate earthquakes that occurred prior to 1974. Larger earthquakes represented by larger circles. *(USGS Professional Paper 1527)*

shutdown of four injection wells in the area and issue strong new regulations" (Kerr, 2012). On July 12, 2012 Executive Order (2012-09K) was signed by Ohio Governor John Kasich, which required that operators conduct seismic studies prior to issuance of well permits (Kasich, 2012). Ohio now stands alone in requiring a seismic-risk assessment for all of its injection wells, as every other state, and the federal government, have yet to do (Behar, 2013).

Seismologist John Armbruster puts points out that within a year of the Northstar 1 well opening there were 109 total earthquakes, and "twelve felt earthquakes. After the well was shut down, the number decreased dramatically. You'd need Powerball odds for that to be a coincidence" (Behar, 2013).

## Proliferation of Shale Gas & Oil Extraction and Fracking Wells

Over the last decade the United States has seen an unprecedented increase in the proliferation of shale gas and oil extraction that has pushed domestic oil to its current place of highest level of production in 20 years, while bringing natural gas production to an all-time high (Weber, 2013). Shale gas from fracking specifically has gone from only 2% of U.S. natural gas production in 2000 to 23% of NG production in 2010 (US EIA, 2012). Because of fracking, the International Energy Agency projects that the U.S. will overtake Russia as the world's top producer of natural gas by 2015.

With this precipitous increase in shale oil and gas production, the U.S. has likewise seen an increase in the proliferation of fracking wells, with more than 82,000 drilled or permitted in 17 states between 2005 and 2012. At the time of this writing (November of 2013) there are likely in excess of 100,000 fracking wells permitted or drilled in the U.S. (Ellsworth, 2013). In 2012 alone there were 22,326 fracking wells drilled throughout the United States, with more than 60% of them (13,540) being drilled in Texas (Ridlington & Rumpler, 2013). During that year drilling inspectors identified more than 55,000 violations of Texas fracking laws by oil and gas companies (Soraghan, 2013a).

## Wastewater Associated with Fracking Industrialization

This dramatic increase in oil and gas production and associated fracking wells has in turn led to an increase in the need for fracking-related wastewater disposal. Each fracked well requires approximately 4 to 7 million gallons of water, fracking fluid and fracking sand to complete a hydraulic fracturing event. In the range of 20% to 80% of the fluid injected during the fracking event, an average of 2.75 million gallons of toxic and radioactive effluent per well ((Hammer & Van Briesen, 2012), returns to the surface as fracking flowback and wastewater (Miller, 2012; Moss, 2008).

The volume of wastewater to be disposed of during the fracking process is one factor that makes fracking industrialization different from anything other form of fossil fuel extraction that has been seen before, producing "50 to 100 times more" waste than conventional oil and gas wells (Cantarow, 2013). Multiply that level of industrialization in terms of number of wells, by that degree of waste management in terms of the volumes of toxic and radioactive effluent per fracked well, and the result is 280 billions gallons of total flowback and produced wastewater coming out of U.S. fracking wells each year (Ridlington & Rumpler, 2013). Unfortunately, these national numbers are woefully incomplete as wastewater produced by Texas alone represents nearly 93% of this total (260 billion gallons), and there was "no estimate" listed for seven of the seventeen fracking states included in the survey.

The shift over the last decade is undeniable, as an overwhelmed Marcellus Shale wastewater disposal infrastructure capacity can attest to, in that "developing the Marcellus shale has increased the total wastewater generated in the region by ~570%" between 2004 and 2012. This of course is a natural consequence of fracking industrialization, as toxic and radioactive wastewater "is an obligate byproduct of current methods and volumes will unavoidably increase with industry expansion" (Lutz et al, 2013).

## Various Methods for Disposing of Fracking Wastewater

While there are current alternatives to deep-well injection for disposing of fracking wastewater, scientists and regulators alike agree that the other options are generally far more expensive while embodying additional environmental risks (Lustgarten, 2013a). These alternatives, the first three of which have been utilized extensively in the Marcellus region due to lack of suitable geology for underground injection (MSAC, 2011), include: (1) Processing of wastewater at municipal wastewater treatment facility with final discharge into a local waterway; (2) Processing of wastewater at a private industrial wastewater facility, with either discharge into a local waterway or reuse of the treated effluent in fracking wells; (3) Recycling of wastewater and reuse of the partially treated effluent in fracking wells; (4) Burning of waste; (5) Disposal of waste by application on roadways and other surfaces (Lutz et al, 2013; Lustgarten, 2012a); and unfortunately, (6) "Fracking flowback is dumped into rivers, lakes and reservoirs" (Eco Watch, 2013).

Cliff Frohlich, senior research scientist at University of Texas at Austin's Institute for Geophysics, reminds us that "the people involved in this are going to do the cheapest way of doing things that is generally considered safe" (Henry, 2012a), and that is currently why more than 95% of fracking wastewater is injected into deep wells (Clark and Veil, 2009). Journalist Abrahm Lustgarten, however, reminds us that, "several key experts acknowledged that the idea that injection is safe rests on science that has not kept pace with reality, and on oversight that doesn't always work (Lustgarten, 2012a). It is not just the energy sector that is dependent on this form of waste elimination, as subterranean waste disposal is a cornerstone of the U.S. economy, with pharmaceutical, chemical and agricultural industries all being dependent upon deep-well injection for managing voluminous waste streams. Even carbon storage and sequestration that is the essential fossil fuel industry strategy for addressing climate change, as Lustgarten points out, "counts on pushing waste into rock

formations below the earth's surface" (Lustgarten, 2012a).

## Fracking Wastewater in Deep-Injection Disposal Wells

As there has been a monumental increase in total fracking-related wastewater produced over the last decade, there has likewise been a dramatic increase in total fracking wastewater injected into disposal wells, where 95% of the toxic effluent is managed. Of the more than 680,000 total injection wells in the United States, in excess of 150,000 fall into the energy industry-specific Class II category that includes both deep-disposal wells in addition to "wells in which fluids are injected to force out trapped oil and gas" (Lustgarten, 2012a). Approximately 30,000 to 40,000 of these Class II wells are deep-disposal wells that receive the volumes of fracking flowback and produced wastewater (Diep, 2013; Ellsworth, 2013; Soraghan, 2013). The states with the most Class II injection wells are Texas (52,016), California (29,505), Kansas (16,658), Oklahoma (10,629), and Illinois (7,843) (US EPA, 2010).

A study by the Argonne National Laboratory estimated that a total of 252 billion gallons of fracking wastewater is injected into Class II deep disposal wells in the United States per year (Clark and Veil, 2009; Clarke et al., 2012). In Texas the total amount of fracking wastewater being injected into deep disposal wells went from 46 million barrels (1.45 billion gallons) in 2005 to nearly 3.5 billion barrels (110.25 billion gallons) in 2011, representing a 76-fold increase in total fracking wastewater injection volume in a six-year period (Galbraith and Henry, 2013). The total amount injected into the more than 150,000 total Class II wells among 33 states is at least 10 trillion gallons of wastewater (Lustgarten, 2012c), while over the last several decades all U.S. industries combined have injected in excess of 30 trillion gallons of toxic liquid into all classes of injection wells, "using broad expanses of the nation's geology as an invisible dumping ground" (Lustgarten, 2012a).

## Wastewater Injection Induced Earthquakes – Factors That Increase Risk

As fracking wastewater injection has dramatically increased over the last decade, so have induced earthquakes, as elucidated by Cliff Frohlich: "The earthquakes are occurring more frequently now because there's so much more fluid injection due to the fracking and the development of unconventional gas. [...] So what's happened is that we have a lot more injection going on in a lot more places, where we're producing more gas and earthquakes" (Henry, 2012a). While most of the United States' 40,000 wastewater injection wells will never cause felt seismic activity, some have and will induce earthquakes in excess of 3.0, and so far, as great as 5.7 (Diep, 2013; Ellsworth, 2013).

The USGS's Williams Ellsworth identifies a number of factors that could enhance the probability of a given injection-well inducing earthquakes in his 2013 *Science* study. They include, "the magnitude of the perturbation, its spatial extent, ambient stress condition close to the failure condition, and the presence of faults well oriented for failure in the tectonic stress field. Hydraulic connection between the injection zone and faults in the basement may also favor inducing earthquakes, as the tectonic shear stress increases with depth in the brittle crust" (Ellsworth, 2013).

Frohlich likewise stresses that it is absolutely essential to "understand why some injection wells trigger seismic activity and others do not," especially when they seemingly have similar mechanical and geological characteristics. He hypothesizes that "injection only triggers earthquakes if injected fluids reach and relieve friction on a suitably oriented, nearby fault that is experiencing regional tectonic stress" (Frohlich, 2012), such that "the materials must be pre-stressed to a substantial fraction of their breaking strength in order for seismicity to be induced" (Kisslinger, 1976). The specific mechanisms involved in fluid-relieved friction on a locked fault will be explored in greater detail below.

## Limiting Condition 1: We Don't Exactly Know What Is Going On Down There

In light of these risk factors identified by Ellsworth and Frohlich, there are two major *limiting conditions* that can significantly contribute to fault rupture and earthquake inducement from fracking wastewater's injection into deep disposal wells. The first is that we do not necessarily know where the injected wastewater is going, and what subterranean pathways it might be following, especially in relation to pre-existing faults both known and unknown. The second is that wells can, and do, fail and leak.

Class II injection wells in practice do not have detailed geologic reviews performed, so there is not particularly any understanding regarding what the well opens up to as much as two and a half miles beneath the surface, including the location of possible faults (Clarke et al., 2012). ProPublica investigative reporter Abrahm Lustgarten captures this reality of disposal well structure: "Tubes of concrete and steel extend anywhere from a few hundred feet to two miles into the earth. At the bottom, the well opens into a natural rock formation. There is no container. Waste simply seeps out, filling tiny spaces left between the grains in the rock like the gaps between stacked marbles" (Lustgarten, 2012a).

The high wellhead pressures applied to inject millions of gallons of fracking wastewater into these deep recesses are sometimes in excess of 50 MPa (493 atmospheres or 7,250 psi) (Hsieh, 1979; Zhang et al, 2013). Injection pressures that high "may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers" (Lustgarten, 2012b). As Scott Ausbrooks, a geologist with the Arkansas Geological Survey, points out, water will eventually find a way out: "Water does not like to be squeezed. Just like a room of people. The more you put in, the more crowded it gets, and at some point, people are going to start being pushed out the doors" (Behar, 2013). Cliff Frohlich describes the wastewater as being forced "downward and outward" from excessive injection, adding that fracking's toxic effluent "can meander for months, creeping into unknown faults and prying the rock apart just enough to release pent-up energy" (Behar, 2013).

## Limiting Condition 2: Deep-Injection Disposal Wells Will Fail and Leak

While scientists and federal regulators generally acknowledge they do not know how many of the Class II injection well sites receiving fracking wastewater are leaking, a ProPublica analysis of EPA data and case histories from October 2007 to October 2010 regarding more than 220,000 well inspections shows that 3.2% of the wells failed and "showed signs that their walls were leaking" (Lustgarten, 2012a). ProPublica's Abrahm Lustgarten further related, "records also show wells are frequently operated in violation of safety regulations and under conditions that greatly increase the risk of fluid leakage and the threat of water contamination."

According to federal water protection regulation descriptions more than 7,500 well test failures from those three years studied involved *fluid migration* and *significant leaks*, with most of those failures being due to cracks or holes that have damaged the well structure itself (Lustgarten, 2012a). Williams Ellsworth notes that while the current wastewater deep-injection disposal well regulatory framework was designed to protect aquifers and groundwater sources from contamination, the regulations fail to address seismic safety (Ellsworth, 2013).

Because of the *limiting conditions* that we do not necessarily know where the injected wastewater is going and that deep-injection wells fail and leak at an estimated rate of 3.2%, wastewater migrates not only to areas unknown, but also to regions where we specifically do not want it to go: fault zones. These fault zones tend to be located deep beneath the surface in the region of the lithosphere known as the Precambrian Crystalline Basement.

## Fracking Wastewater Injection and Induced Seismology

William Ellsworth noted in his 2013 *Science* study that, "There has been a growing realization that the principal seismic hazard from injection-induced earthquakes comes from those associated with disposal of wastewater into deep strata or basement formations" (Ellsworth, 2013). The operative notion is that in order for seismic activity to be induced, not only does that fault have to be pre-stressed, but it also must be reachable where they are located in the Precambrian crystalline basement by the meandering injected wastewater and its associated fluid pressure. Cliff Frohlich



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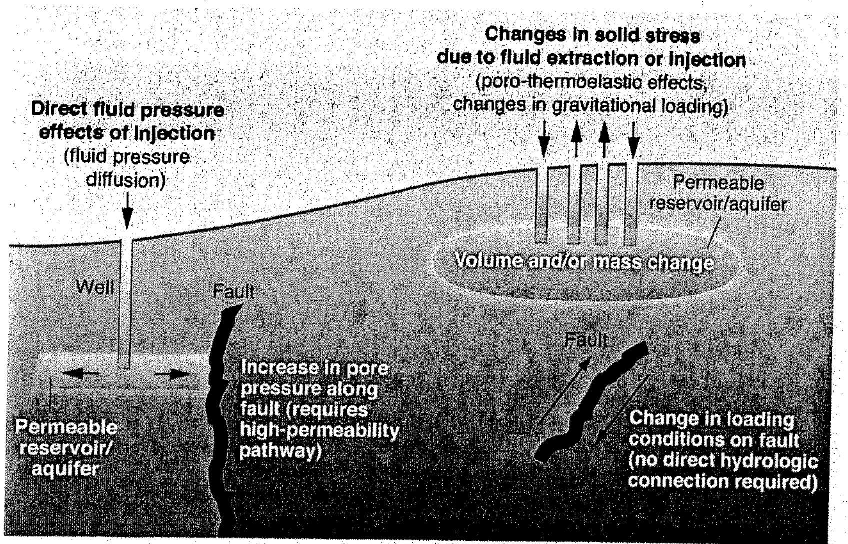


reiterates this point during a 2012 interview, suggesting "fluid injection may trigger earthquakes only if fluids reach and relieve friction on a nearby fault" (Choi, 2012).

A consensus among geologists support the understanding that a vast majority of the fracking wastewater DIDW induced earthquakes did not originate within the sedimentary reservoirs into which the toxic and radioactive fluid was directly injected. Rather this seismicity originated within the generally impermeable metamorphic and igneous crystalline basement that lies 1 to 6 kilometers deeper beneath the sedimentary platform (Horton, 2012; Hsieh and Bredehoeft, 1981; Nicholson and Wesson, 1990; Seeber et al., 2004; Zhang et al., 2013).

Zhang et al., in their 2013 *Groundwater* study, stated that the ever-increasing midcontinent earthquakes "probably occurred along faults that were likely critically stressed within the crystalline basement." More specifically, they found that induced seismic activity was a result of the fracking wastewater either, 1) being injected into a basal sedimentary reservoir that lacks a confining unit underneath the injection reservoir horizon, thus allowing for migration into Precambrian layers, or 2) being injected "directly into the underlying crystalline basement complex" (Zhang et al, 2013).

## Migrating Fluid and Precambrian Crystalline Basements

An essential practical conclusion from the *Groundwater* study (Zhang et al, 2013) is the factor that has the single largest impact in preventing seismic induction within the underlying crystalline basement is the presence of a confining unit barrier between the sedimentary reservoir and the lower Precambrian layer. William Ellsworth describes those injection wells that "dispose of very large volumes of water and/or communicate pressure perturbations directly into basement faults" (Ellsworth, 2013) as problematic disposal wells. Geophysicist Barry Raleigh, whose 1976 *Science* study "An experiment in earthquake control at Rangely, Colorado" demonstrated how earthquakes could be turned on and off by utilizing manipulation of fluid pressure, elucidates that the deep, low-permeability, brittle igneous and metamorphic rock of the crystalline basement "doesn't have a lot of capacity for taking any of these fluids. As a storage medium, they're pretty crappy" (Kerr, 2012).

Readily *felt earthquakes* larger than magnitude 4.0 that have been induced by injection of fracking wastewater into deep disposal wells additionally point to a deeper subterranean origin to these larger earthquakes. "Burdened by far more overlying rock, the deep rock is already carrying stress that," when combined with "the added pressure of the injection trigger," manifests conditions ripe for fault rupture and potentially destructive seismic activity (Kerr, 2012). Zhang et al. (2013) hypothesize that "elevated pore pressures could propagate downward along distributed fracture networks or along conductive fault zones in Precambrian crystalline rocks" (Zhang et al, 2013), meaning that the pressure from fluids can be potentially transmitted to hidden fractures at great depths, given the right conditions. In fact, David M. Evans, in his seminal 1966 *Geotimes* study, relates that even "if the Precambrian fracture system extends to a depth of 12 miles, then fluid pressure could [still] be transmitted to that depth by moderate surface injection pressure as long as the fracture system is open for transmission of that pressure" (Evans, 1966).

## The Long Understood Relationship Between Subterranean Fluid Disposal & Induced Seismology

Some may point to 77 CE Rome for the origins of the human demonstration of the relationship between elevated fluid pressure and induced geological failure, a well-documented case in which Romans utilized the technique to "undermine and instantly remove vast quantities of mountainside to extract gold from the buried mother lode at Las Médulas in northwest Spain" (Goodway, 2012). Others might claim that we have shared this understanding for almost a century, such as members of the Committee on Induced Seismicity Potential in Energy Technologies, who claim that "induced seismic activity has been documented since at least the 1920s" (Clarke et al., 2012), referencing a 1926 study that ran in the *Bulletin of the Seismological Society of America* regarding "Local subsidence of the Goose Creek oil field (Texas)" (Pratt and Johnson, 1926).

While these obscure examples add clarity to this generally familiar yet elusive phenomenon, it is David M. Evans' 1966 *Geotimes* study "Man-made earthquakes in Denver" that is popularly credited with establishing the connection between injection of waste fluids and induced earthquakes (Choi, 2012; Ellsworth, 2013; Frohlich, 2012; Henry, 2012; Kerr, 2012; Soraghan, 2013), such that "since 1966, scientists have generally agreed that injection may induce earthquakes in tectonically favorable situations" (Davis and Frohlich, 1993). Keep in mind that Plate Tectonic Theory did not come into general acceptance until just one-year prior, in 1965, to the verification of this form of human induced earthquake phenomena.

## The Mechanisms Underlying Earthquakes Induced by Fracking Wastewater DIDWs

In regards to the fracking wastewater disposal-induced earthquakes that have been escalating in frequency in the United States' midcontinent over the last decade, U.S. Geological Survey's William Ellsworth concludes that the mechanism responsible for inducing this seismic activity is the "well-understood process of weakening a preexisting fault by elevating the fluid pressure" (Ellsworth, 2013). Ellsworth clarifies that the three specific events that can trigger the nucleation of an earthquake by bringing the fault to failure are, 1) reducing the effective normal stress on a locked fault, 2) increasing the shear stress along a fracture plane, and 3) elevating the pore pressure of the fluid in the rock. Nucleation is the process that marks the beginning of an earthquake with an initial rupture that propagates along the fault surface. Fault failure or slippage can trigger this process, and in turn, generate an earthquake (Ellsworth, 2013).

## Effective Normal Stress and Induced Seismology

If the effective normal stress, the frictional forces that hold a fault a place, is lowered, it can result in fault slippage and trigger earthquake nucleation. Increased fluid pressure relieves enough of squeeze on the fault to release it and induce an earthquake (Kerr, 2012). Injecting fluids that act as a pressurized cushion to relieve the effective normal stress that keeps a fault locked over-pressures a fault (Sheppard et al, 2013). Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory, relates that, "When you over-pressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen" (Earth Institute, 2013).

Effective normal stress is equal to the difference between the applied normal stress and pore pressure (Ellsworth, 2013). Applied normal stress is the total stress on a rock (Hsieh, 1979), or the weight of a given block (Evans, 1966), and pore pressure is the pressure of fluid in the rock's pores and fractures (Ellsworth, 2013), such that

increased pore pressure causes a decrease in frictional force, the effective normal stress (Warpinski, 2012).

## Shear Stress and Induced Seismology

Raising or increasing the shear stress along a fracture plane can also result in induced seismology, such that once the shear stress overcomes the effective normal stress (multiplied by the coefficient of friction and added to cohesion) in a geological system, the fault will slip, fail, and result in an earthquake (Warpinski, 2012). Faults are locked due to frictional forces, which are the result of in situ stresses pressing vertically on the fault plane. Raising the shearing stress to the point of overcoming effective normal stress such that the fault slips is also known as the Mohr-Coulomb failure criterion. Paul Hsieh, recently named 2011 United States Federal Employee of the Year for his role in bringing to a close the BP oil spill in the Gulf of Mexico, remarks in his pivotal 1979 master's thesis that, "Shearing stresses will remain the same no matter how pore pressure varies. This results from the fact that fluid cannot support any shearing stress" (Hsieh, 1979).

Raleigh and others clarify this direct impact that injecting wastewater has on stressed fractures given its inability to support any shearing stress:

> "The pressurized fluid enters a fracture and supports a part of the normal stress equivalent to the pressure of the fluid. As the fluid has no shear strength, the effective normal stress and the frictional resistance to sliding are lowered. If the fracture is subject to shear stress greater than the product of this effective normal stress and the coefficient of friction, the rocks will slip and generate an earthquake" (Raleigh et al., 1976).

## Pore Pressure and Induced Seismology

Finally, elevating the pore pressure of the fluid in the rock can readily lead to seismic events given the proper conditions, like a stressed fault in contact with pressurized, migrating liquid. As the measure of the pressure of the fluid in the rock's pores and fractures, pore pressure is equal to the difference between applied normal stress and effective normal stress (Ellsworth, 2013). Thus as pore pressure increases, the effective normal stress will decrease. This effective normal stress can also be understood as the frictional resistance against the shearing stress along the fracture plane (Hsieh, 1979). If there is a sufficient enough increase in fluid pressure such that the shearing stress overcomes frictional resistance, the fault will slip and result in an earthquake. This is known as the Hubbert-Rubey mechanism, named after the findings in their seminal 1959 *Geological Society of America Bulletin* study "Role of fluid pressure in mechanics of overthrust faulting," as elucidated by Paul Hsieh:

> "The original work of Hubbert and Rubey (1959) actually concerns the role of pore pressure in the mechanics of overthrust faulting. They introduced the concept of rock movements caused by a Mohr-Coulomb-type failure in a fluid-filled rock environment. This concept was first cited by Evans (1966) in his paper on injection–earthquake relationship and subsequently gained wide acceptance as the mechanism through which injection has caused the earthquakes." (Hsieh, 1979)

In his "A review of theories of mechanisms of induced seismicity" that was published in *Engineering Geology*, Kisslinger relates that fluid injection induced earthquakes "are adequately explained" by a combination of the concept of effective pressure in a water-filled porous mechanism and the Coulomb-Mohr failure criterion, which embodies the three factors and their interrelationship that determines whether or not a particular fracking wastewater injection well will induce earthquakes (Kisslinger, 1976). Kisslinger further concludes that reservoir-related earthquakes, like those caused by fluid injection in bore holes, are induced by the same mechanisms, but in light of the lower injection pressures, "additional physical or chemical effects of the water on the materials may play an important role, [such as] a weakening of the materials in old fault zones by the introduction of water or static fatigue in silicate rocks due to stress corrosion (Kisslinger, 1976).

## How to Turn On and Turn Off Earthquakes: The Parameters of Induced Seismology

Now that it has been clarified what events have to transpire in subterranean realms for earthquakes to be induced by fracking wastewater disposal, the question then becomes *how do these mechanisms relate to specific surface behaviors*? The things that we do above ground that directly impact what happens not only 13,000 feet below the surface, but beneath those sedimentary layers in the Precambrian crystalline basements where faults lie within impervious rock formations.

Davis and Frohlich, in their 1993 *Seismological Research Letters* study "Did (or will) fluid injection cause earthquakes? Criteria for a rational assessment," provide us with a starting point by establishing criteria through which one can determine whether or not a given earthquake was induced by wastewater disposal (Davis & Frohlich, 1993). These criteria "include proximity to injection wells, a change from background seismicity, and a correlation with wastewater injection parameters" (Keranen et al., 2013). These parameters related to wastewater injection referred to by Keranen and others, all of which are ultimately controlled by decisions made and actions taken by the deep-well injection companies on the surface, include fluid pressure, total fluid volume, and rate of fluid injection. As noted by William Ellsworth, "the physical connection between operational parameters such as injected volume" and fluid pressure can be complex (Ellsworth, 2013).

## Fluid Pressure: Inducing Seismology By Exceeding Critical Value

The discovery by David Evans published in his 1966 *Geotimes* study, which led to speculations that earthquakes might be controllable, was that the subterranean high-pressure injection of fluid was responsible for the triggering of earthquakes at the Rocky Mountain Arsenal near Denver, Colorado in the early to mid 1960s. While earthquakes were being induced by the injection of pressurized wastewater into stressed rock formations, the reduction in fluid pressure caused a sharp decrease in frequency of seismic activity (Raleigh et al., 1976). A 1972 *Tectonophysics* study by Healy and others entitled "Prospects for earthquake prediction and control" more explicitly expressed this understanding and laid further groundwork for experimentally testing this hypothesis that, "Changes in fluid pressure may control timing of seismic activity and make it possible to control natural earthquakes by controlling variations in fluid pressure in fault zones" (Healy, et al., 1972).

Raleigh, Healy and Bredehoeft's landmark 1976 *Science* study "An Experiment in Earthquake Control at Rangely, Colorado" did demonstrate the capacity to turn on and turn off earthquakes and "established the correlation between fluid pressure and earthquakes beyond reasonable doubt," that they concluded the "control of the San Andreas fault could ultimately prove to be feasible." However, despite these earth-shattering revelations, perhaps the most important takeaway from these experiments was that, "successful prediction of the approximate pore pressure required for triggering of earthquakes according to the Hubbert-Rubey theory was possible" (Raleigh et al., 1976), as demonstrated by experimental verification of theoretical projections.

## Predicting Earthquake Behavior, Controlling Earthquakes By Manipulating Fluid Pressure

Utilizing the Mohr-Coulomb failure criterion in applying the Hubbert-Rubey theory, Raleigh and colleagues projected that 257 bars (25.7 MPa) would be the Rangely site's critical fluid pressure. The critical fluid pressure, the pressure required to trigger an earthquake, is governed by the equation:

$\tau_{crit} = \mu(S_n - P_c)$, with

$\tau_{crit}$ = shear stress at failure point,
$\mu$ = coefficient of static friction of the rocks,
$S_n$ = effective normal stress, and
$P_c$ = critical fluid pressure that induces seismicity.

"The fluid pressure required to trigger earthquakes on preexisting fractures" was experimentally tested against the theoretical



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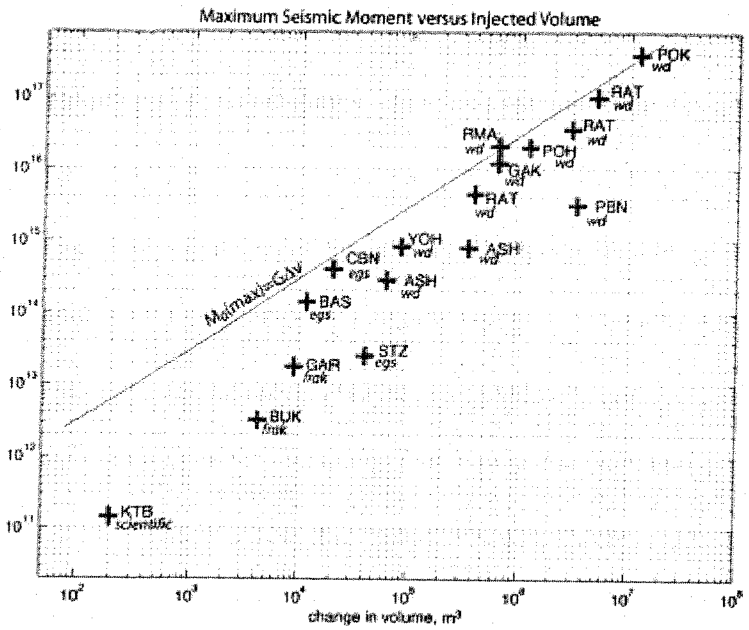



projections through use of "laboratory measurements of the frictional properties of the reservoir rocks and an in situ stress measurement made near the earthquake zone" (Raleigh et al., 1976).

Experimental results, which were obtained by varying fluid pressure through the process of "alternately injecting and recovering water from wells that penetrated the seismic zone" (Raleigh et al., 1976), demonstrated that when the injection wells were subjected to fluid pressures above 257 bars the earthquake frequency increased, and when the fluid pressure was less than 257 bars the earthquakes subsided. The idea is that for any given injection well and pre-existing fault situation a critical fluid pressure can be determined, such that "we may ultimately be able to control the timing and the size of major earthquakes [...] wherever we can control the fluid pressure in a fault zone" in relation to that critical fluid pressure (Raleigh et al., 1976).

Hsieh and Bredehoeft (1981), in an expansion of Hsieh's 1979 master's thesis (Hsieh, 1979), analyzed the Rocky Mountain Arsenal injection wells and earthquakes in similar fashion, utilizing Hubbert-Rubey theory to identify the fluid pressure critical value, "the pressure build-up above which earthquakes occur" (Hsieh, 1979). Their conclusion was that, "At the Rocky Mountain Arsenal near Denver, earthquakes occurred within the crystalline basement when the fluid pressures were raised over 320 m above hydrostatic conditions [32 bars, 3.2 MPa] between a depth of about 0.7–7 km (Hsieh and Bredehoeft, 1981; Zhang et al, 2013). Another way to frame this is that the earthquakes were confined strictly to those parts of the reservoir where the pressure build-up exceeded 32 bars (Hsieh, 1979). According to Davis and Frohlich (1993), Hsieh and Bredehoeft's breakthrough was that they were "able to explain the spatial and temporal extent of seismic activity in Denver in terms of the flow of fluids along a permeable semi-infinite rectangular region which approximately contained the activity."

## Total Injected Fluid Volume and Maximum Earthquake Magnitude

The relationship between total fluid volume injected and induced seismology has been noted by many, whether it is the "qualitative correlation between earthquake rates and the injected volume" that has served as a tool for investigating the triggered earthquake phenomena (Oprsal and Eisner, 2013), or the case history-driven evidence suggesting a connection between the total volume of injected wastewater and the maximum induced earthquake magnitude (Hayes, 2012). The U.S. Geological Survey's Art McGarr has compiled the data from these case histories and reports from fracking, waste disposal and geothermal induced seismic events, and has graphed Total Injected Volume vs. Maximum Earthquake Magnitude for 17 different cases of demonstrated fluid disposal triggered earthquakes (Holland and Keller, 2012; Verdon, 2013a; Verdon, 2013b):

| Total Gal. Injected (thousands) | Magnitude Richter Scale | Location |
|---|---|---|
| 53 | 1.4 | Bavaria Germany (KTB) |
| 1,057 | 2.3 | Blackpool, England (BUK) |
| 2,325 | 2.8 | Garvin County, Oklahoma (GAR) |
| 3,170 | 3.4 | Basel, Switzerland (BAS) |
| 9,774 | 3.7 | geothermal at CBN |
| 10,567 | 2.9 | Soultz, France (STZ) |
| 15,850 | 3.6 | Ashtabula, OH (ASH) |
| 21,134 | 3.9 | Youngstown, Ohio (YOH) |
| 89,818 | 3.8 | Ashtabula, OH (ASH) |
| 103,026 | 4.4 | Raton Basin, Colorado (RAT) |
| 158,502 | 4.6 | Guy, Arkansas (GAK) |
| 158,502 | 4.7 | Rocky Mountain Arsenal (RMA) |
| 766,093 | 5.0 | Raton Basin, Colorado (RAT) |
| 845,344 | 4.3 | Paradox Basin, Colorado (PBN) |
| 1,320,850 | 5.3 | Raton Basin, Colorado (RAT) |
| 3,170,040 | 5.7 | Prague, Oklahoma (POK) |

While "McGarr found a relationship between the maximum magnitude of induced earthquakes and the total volume of fluid injected into a site" (Balcerak, 2013), James Verdon reminds us that the McGarr model "is only empirical, there is no real physics behind it" (Verdon, 2013a). McGarr's model does, however, create an interesting framework for further theoretical and experimental work, while also leading to the derivation of the McGarr equation for injection-induced seismicity:

$M_0(max) = G\Delta v$, with

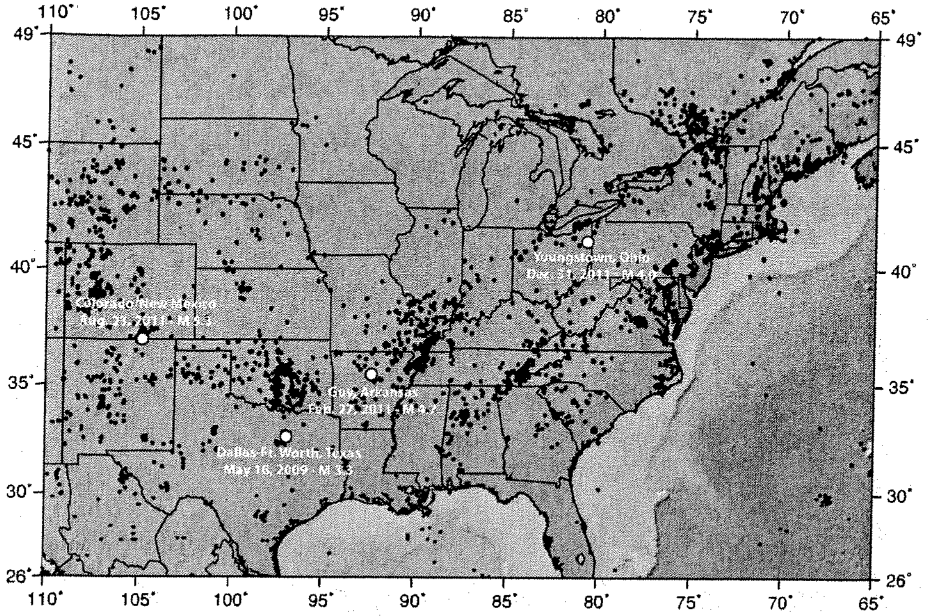
$M_0(max)$ = magnitude of largest seismic moment,
G = shear modulus of rock
(ratio of shear stress to shear strain), and
$\Delta v$ = total volume of fluid injected.

Despite potential shortcomings, Verdon does admit that, "In the meantime, we are left with the empirical McGarr equation as our main guide" (Verdon, 2013a). He also makes certain to clarify: "It should of course be remembered that the McGarr equation does not tell you the maximum magnitude you will get in an operation. [...] The McGarr line tells you the maximum magnitude you could get if you are very unlucky" (Verdon, 2013a). While McGarr continues to clarify the undeniable connection between the total injected fluid volume and the potential maximum magnitude of induced earthquakes, he does not find the rate of fluid injection to impact the magnitude of triggered earthquakes, but rather he found "that the rate of injection of fluid influences the frequency of induced earthquakes" (Balcerak, 2013).

## Rate of Fluid Injection and the Work of Cliff Frohlich

A third surface-controlled parameter that can impact fracking wastewater disposal induced seismicity is that of rate of fluid injection. While the rate of fluid injection and withdrawal played role in the Rangely, Colorado earthquake control experiments (Healy, et al., 1972), few scientists outside of Cliff Frohlich are investigating what he has observed to be a relationship between high rates of fluid injection and induced seismicity. From varies studies of the Barnett Shale play in Texas, Frohlich has found that injection wells nearest induced earthquake groups consistently reported maximum monthly injection rates in excess of 6.34 million gallons (24,000 cubic meters) of fluid, "and generally these injection rates had been maintained for a year or more prior to the onset of earthquake activity" (Frohlich, 2012).

While Frohlich has indicated in interviews that he is very much interested in pursuing this line of inquiry in other fracking wastewater injection regions (Choi, 2012), his own studies have already indicated that other faulted areas demonstrate different maximum monthly injection rates required to induce earthquakes, such as a fluid injection rate of 9.5 to 12.7 million gallons (32,000 to 48,000 cubic meters) per month in the case of Paradox Valley, Colorado (Frohlich et al, 2010). While there is still a lot of research and experimentation required to clarify the precise role of the three surface parameters of fluid pressure, total fluid volume, and rate of




fluid injection in triggering earthquakes, William Ellsworth concurs that experimental results distinctly suggest that these factors all "may be a predictor of seismic potential" (Ellsworth, 2013).

## Conclusion

The mechanisms that underlie fracking wastewater disposal induced earthquakes have been clarified and verified since 1966, making the Hubbert-Rubey theory just a year younger than the theory of plate tectonics and its general acceptance. By capturing the interrelationships between primary earthquake inducement factors that include effective normal stress, shear stress and pore pressure, they set the stage for a couple of decades worth of rich experimentation. All of which became nearly forgotten until fracking industrialization's rude awakening, a literal shaking the foundations of where we work, where we shop and where we live. Luckily, "after a decades long lull in triggered quake studies, researchers are playing catch-up with the latest round of temblors" (Kerr, 2012). And so, in the spirit of existential philosopher Martin Heidegger's conception of truth, we find ourselves in the process of *revealing that which had been concealed.*

One of the great concerns of many of the seismologists and geologists working on this issue is the reality of the earthquake domino effect that have been observed as a result of wastewater injection-induced seismicity. University of Oklahoma seismologist Katie Keranen relates this as the operative scenario in the Prague, Oklahoma magnitude 5.7 earthquake that struck on November 6, 2011: "We had one fault-plane go, a second one, and then a third one. They ruptured in sequence" (Behar, 2013). Lamont-Doherty Earth Observatory seismologist Geoffrey Abers elucidates, "the amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock" (The Earth Institute, 2013).

This is also of great concern to those potentially impacted individuals who live in Southern Illinois, existing between two active seismic zones, the New Madrid and the Wabash. With Southern Illinois facing the promise of mass fracking industrialization and its associated toxic and radioactive wastewater in need of disposal in deep-injection wells, it is not lost on many experts the danger that even small earthquakes can pose in this active seismic region. Geoffrey Abers acknowledges that, "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought (The Earth Institute, 2013). A study conducted by the University of Illinois Mid-America Earthquake Center in 2008 projected that if an earthquake the magnitude of the quakes that hit near New Madrid during 1811-1812 were to strike today, "there would be 3,500 fatalities, 2.6 million people without electricity and $300 billion in direct economic losses. Bridges, docks, highways and water infrastructure would be in shambles" (IEMA, 2013).

If mass fracking industrialization is to take hold of Southern Illinois, a land amidst two active seismic zones, then higher intelligence must be allowed to govern this process, its regulations, and their application. Stanford University geophysicist Mark Zoback answers this call by providing an empirically derived practical framework for reducing the probability of induced seismicity, with five straightforward steps:

(1) It is important to avoid injection into active faults and faults in brittle rock.

(2) Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.

(3) Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.

(4) Protocols should be established in advance to define how operations will be modified if seismicity is triggered.

(5) Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard (Zoback, 2012).

These five steps provide both the state (in form of regulators) and industry (in the form of operating companies) with a structure for reducing the risks involved in fracking wastewater disposal via deep-injection wells and the induced earthquakes that can accompany their utilization.



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*Brent Ritzel received his BA in Philosophy from Northwestern University in 1990 and is currently working on his master's thesis* PROJECTED TOTAL COSTS OF ROADWAY DEGRADATION DUE TO PROPOSED FRACKING INDUSTRIALIZATION OF SOUTHERN ILLINOIS *for a Master of Public Administration degree at Southern Illinois University Carbondale, expected completion May 2014.*

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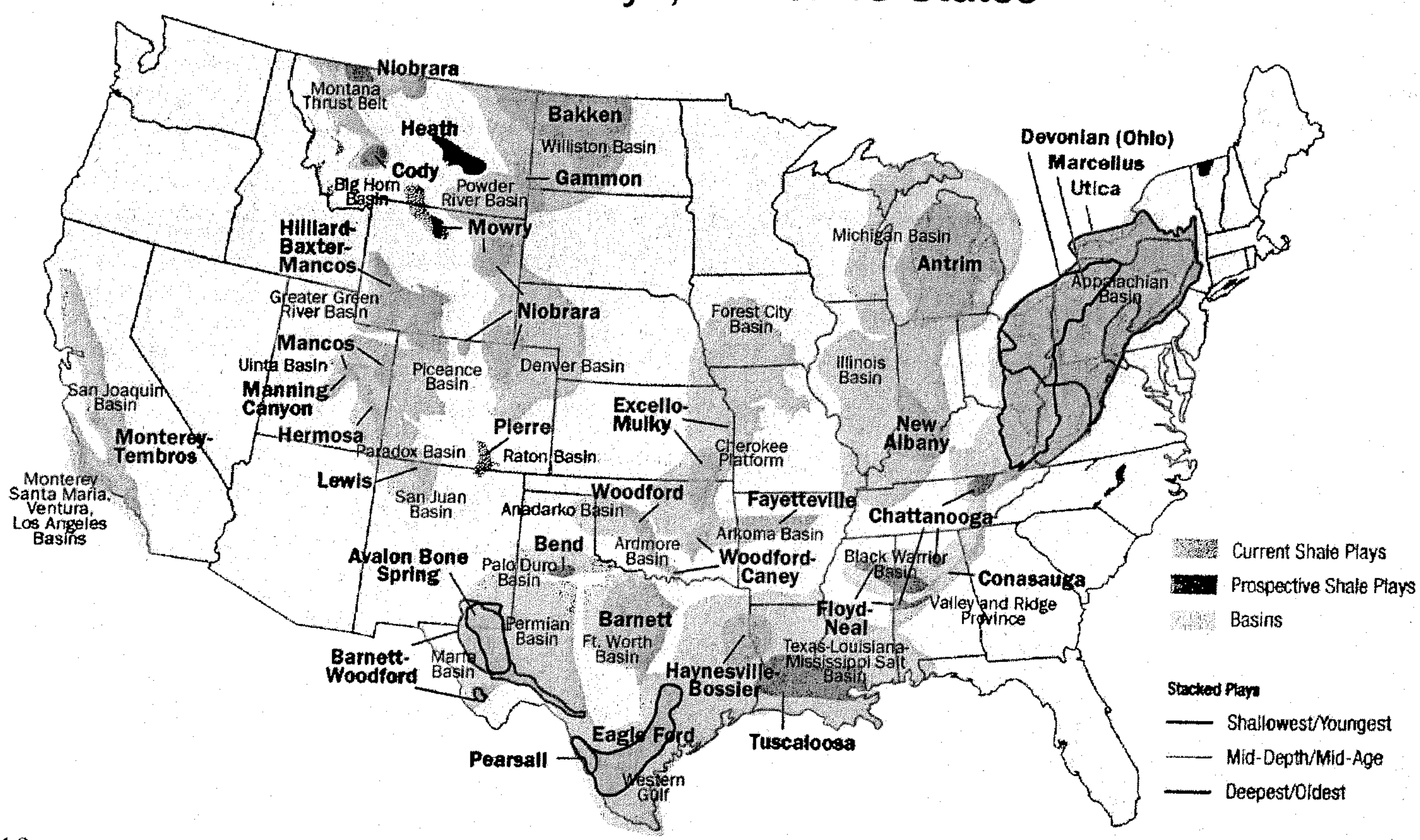
## Shale Plays, Lower 48 States



# Fracking Industrialization & Induced Earthquakes

## The Mechanisms that Connect the Disposal of Fracking Wastewater into Deep-Injection Wells to a Significant Increase in Midcontinent Seismic Activity

by Brent Ritzel *[brent@siu.edu]*

### Introduction

This paper explores the recent significant increase in *felt earthquakes* in the midcontinent of the United States over the past decade in relation to fracking industrialization and its associated voluminous wastewater disposal needs. Studies and expert insight from geologists and seismologists from over the past fifty years will be utilized in order to render evidenced-based conclusions regarding these matters that have often remained at the opinion level of discourse in the public sphere.

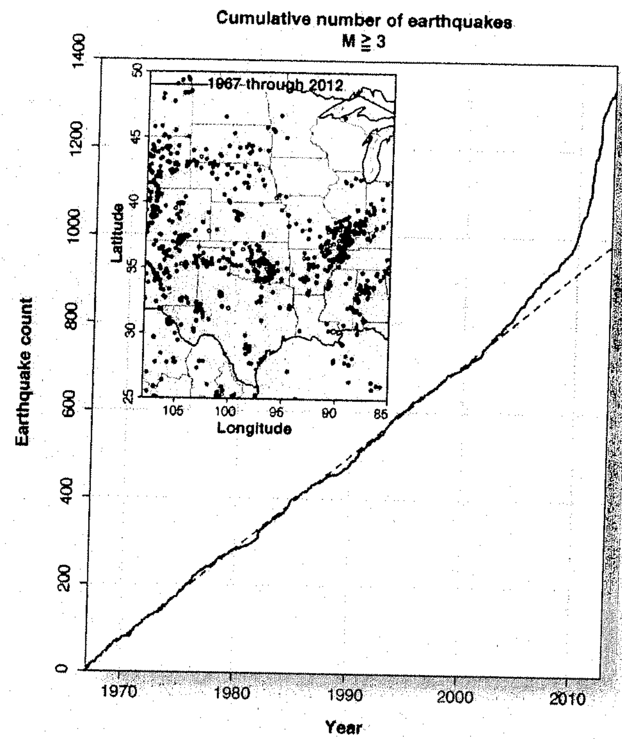
The current extent of U.S. fracking industrialization will be reviewed, including dissection of shale oil and gas production levels, the scale of proliferation of fracking wells, the volume of toxic and radioactive effluent, fracking flowback and produced wastewater disposal needs, and the impact of the exponential growth in deep-injection disposal well usage on the United States' current seismic reality. Two important limiting conditions, the *impervious* unknowns regarding subterranean geological formations *and* the fact that disposal wells will fail and leak, provide context for discussion of our obscured yet viable long term understanding of the mechanisms underlying the whole phenomenon of fracking wastewater disposal induced earthquakes.

### Historic Shift in Frequency of Midcontinent Earthquakes

Seismologists like the U.S. Geological Survey's William Ellsworth started noticing a historically unique trend about a dozen years ago, "that there were an unusual number of earthquakes in the middle of the country," in areas that have not been known for earthquakes (Rugh, 2013). The Guy-Greenbrier area of Arkansas, with total population of just over 5,000, was traditionally a quake-free area. Throughout all of 2007 the area had only one earthquake of magnitude 2.5 or greater, followed by only two such quakes in 2008. However, in 2009 there were 10, and in 2010 there were 54 earthquakes of magnitude 2.5 or greater (Kerr, 2012). On February 27, 2011, Guy experienced a magnitude 4.7 earthquake.

Neighboring state Oklahoma went through a similar pattern as a whole, experiencing just a few earthquakes per year from 1972 to 2007, 12 in 2008, 50 in 2009, and more than 1,000 in 2010, culminating with a magnitude 5.7 earthquake on November 6, 2011. While Oklahoma saw a more than hundred-fold increase in overall earthquakes, it also saw a twenty-fold increase in earthquakes with magnitude 3.0 or greater in those same three years from 2008 to 2010 (Ellsworth et al, 2012). Meanwhile, the Barnett Shale region of north central Texas has experienced "unprecedented levels of seismicity" since shale gas development began in late 1998, with "nine earthquakes of magnitude 3.0 or larger occurred, compared with none in the preceding 25 years." Overall, the states reporting unusually elevated levels of seismic activity include Arkansas, Colorado, New Mexico, Ohio, Oklahoma Texas, and Virginia (Ellsworth, 2013).

This pattern seen in both localized and statewide contexts is also reflected in data concerning the frequency of magnitude 3.0 or greater earthquakes in the entire U.S. midcontinent region, with the annual number of magnitude 3.0 or greater earthquakes having "increased almost tenfold in the past decade" (Lovett, 2013). The "middle part of the continent" went from a remarkably consistent average 21 per year from 1970 to 2000, to an average of 29 per year from 2001 to 2008, to 50 magnitude 3.0 or greater quakes in 2009, to 87 in 2010, to somewhere in the range of 134 to 188 in 2011




Cumulative count of earthquakes with magnitude ≥ 3.0 in the central and eastern United States, 1967–2012. The dashed line corresponds to the long-term rate of 21.2 earthquakes/year.
*(Inset)* Distribution of epicenters in the United States midcontinent region.

(Demus, 2012; Ellsworth, 2013; Henry, 2012; Lovett, 2013). As William Ellsworth *et al* (2012) reported in their *Seismological Research Letters* study, "A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region" (Ellsworth et al, 2012). Especially in areas that have historically lacked earthquakes, like the Youngstown, Ohio area, as Columbia University's Lamont-Doherty Earth Observatory seismologist John Armbruster relates, "Having that many earthquakes [...] where there aren't a lot of earthquakes, was suspicious" (Fountain, 2012).

What all these different scenarios share is a common time frame for the onset of fracking industrialization, and an ever-expanding need for deep-injection disposal wells [DIDWs] to handle the massive volumes of associated fracking flowback and produced wastewater. A 2013 *Science* study (van der Elst et al, 2013) by a team of seismologists led by Nicholas van der Elst of Columbia University's Lamont-Doherty Earth Observatory found, "that at least half of the magnitude-4.5 or larger earthquakes that have struck the interior United States in the past decade have occurred near injection-well sites" (Lovett, 2013). A 2013 *Geology* study (Keranen et al., 2013) by a team of seismologists led by Katie Keranen

concluded while earthquakes with magnitude 5.0 or greater are a rarity east of the Rocky Mountains, "the number per year recorded in the midcontinent increased 11-fold between 2008 and 2011, compared to 1976–2007" (Keranen, 2013). When interviewed concerning colleague response to the study, Keranen indicated that, "Pretty much everybody who looks at our data accepts that these events were likely caused by injection" (Behar, 2013).

## Fracking Wastewater Deep-Injection Disposal Wells and Induced Earthquakes: The Jury's Verdict

While speculation and confusion dominate the lay population's conversation regarding the origins of this historic increase in midcontinent earthquakes, there is a strong consensus among geologists and seismologists that the recent uptick in earthquakes is primarily due to the recent increase in fracking industrialization and disposal of its associated wastewater.

William Ellsworth of the U.S. Geological Survey Earthquake Science Center concludes: "Clearly it is happening. Earthquakes have been happening in some unusual parts of the United States. At this point, we do not know if all or just some part of that increase is attributable to industrial activities like wastewater injection" (Vergano, 2013). These risks associated with deep-injection wells inducing earthquakes, which according to Scott Ausbrooks (geologist with the Arkansas Geological Survey) have "been known for decades," are especially heightened in known seismic zones, such as the Wabash and New Madrid Seismic Zones, as "what is clear... is that deep reservoirs in tectonically active zones carry a real risk of inducing damaging earthquakes" (Ellsworth, 2013).

For Cliff Frohlich, senior research scientist at the University of Texas at Austin's Institute for Geophysics, the problem is that faults are ubiquitous, they are most everywhere, and "most of them are stuck, because rock on rock is pretty sticky. But if you pump a fluid in there to reduce the friction, they can slip" (Behar, 2013). Frohlich continues regarding the recent uptick in seismic activity, "These earthquakes could have been anywhere. They weren't. Virtually all of them were near injection wells" (Behar, 2013).

*Popular Science* writer Francie Diep notes a strong consensus among those best equipped to comprehend the situation: "Since companies began doing [wastewater deep-injection] more often, U.S. Geological Survey and other scientists have noticed more earthquakes occurring in the Midwest, which isn't normally so seismically active. Three different geologists told me this, unprompted, when I was researching the Prague quakes earlier this year" (Diep, 2013). Those Prague, Oklahoma earthquakes included the strongest quake in Oklahoma history, a magnitude 5.7 that struck within a mile of three injection wells filled with fluid leftover from conventional oil dewatering operations (Behar, 2013; Holland & Keller, 2012). The quake destroyed 14 homes, injured two individuals, and was felt more than 600 miles away in Chicago (Choi, 2012; Ellsworth, 2013).

While a team of seismologists from Columbia University, University of Oklahoma and the U.S. Geological Survey concurred on the waste-injection origin of the series of quakes (Keranen et al., 2013), United Kingdom-based applied geophysicist James Verdon points out that, "the Oklahoma Geological Survey has subsequently released a rebuttal (Keller & Holland, 2013) stating that as far as it is concerned, there is not enough evidence to tie the quake to injection activities" (Verdon, 2013a).

## Fracking Wastewater DIDWs Are Primary Fracking-Related Seismic Hazard

A team of geologists and seismologists led by William Ellsworth posit in their 2012 study "Are seismicity rate changes in the midcontinent natural or manmade" that the slight increase in seismicity that began in 2001 was primarily due to a Raton Basin coal bed methane field west of Trinidad, Colorado along the Colorado-New Mexico border. They further conclude that the "acceleration in activity that began in 2009 appears to involve a combination of source regions of oil and gas production, including the Guy, Arkansas region, and in central and southern Oklahoma" (Ellsworth et al., 2012).

While some have raised concerned over seismicity related to the fracking event itself, the primary seismic hazard from fracking industrialization is its associated wastewater disposal into Class II deep-injection wells. Shale gas and oil extraction features four behaviors during the entire fracking industrialization life cycle that can induce some degree of seismicity or affect local geological stresses. These include the drilling of wells, the hydraulic fracturing of the shale, the removal of gas and fluids from the well during production, and deep-injection well wastewater disposal (Frohlich et al., 2010).

William Ellsworth points out that with nearly 100,000 wells having been fracked over the last twelve years, the largest induced earthquake from the hydraulic fracturing of the shale was magnitude 3.6, a barely felt earthquake that by itself poses no serious risk.

However, attitudes have shifted regarding wastewater injection induced seismology, as prior to 2011 the seismic event widely accepted by the scientific community as having been the largest wastewater injection induced earthquake in U.S. history was the magnitude 4.8 quake that took place on August 9, 1967 near Denver, Colorado (Ellsworth, 2013). Over the last decade, and especially since 2011, matters have literally shifted.

## Shutting Down of Wells that Induced Earthquakes

Geologists and seismologists are not the only engaged professionals raising concerns about fracking wastewater disposal related induced seismology. State oil and gas officials in both Arkansas and Ohio have shut down fracking wastewater disposal wells that have been connected with induced earthquakes. In the case of induced seismology in the Guy-Greenbrier area or Arkansas, the state's governor, Oil and Gas commission, and the general public all concurred to shut down the responsible injection-wells as, "nearly 1000 recorded quakes had struck the area since the wells had started up" (Kerr, 2012).

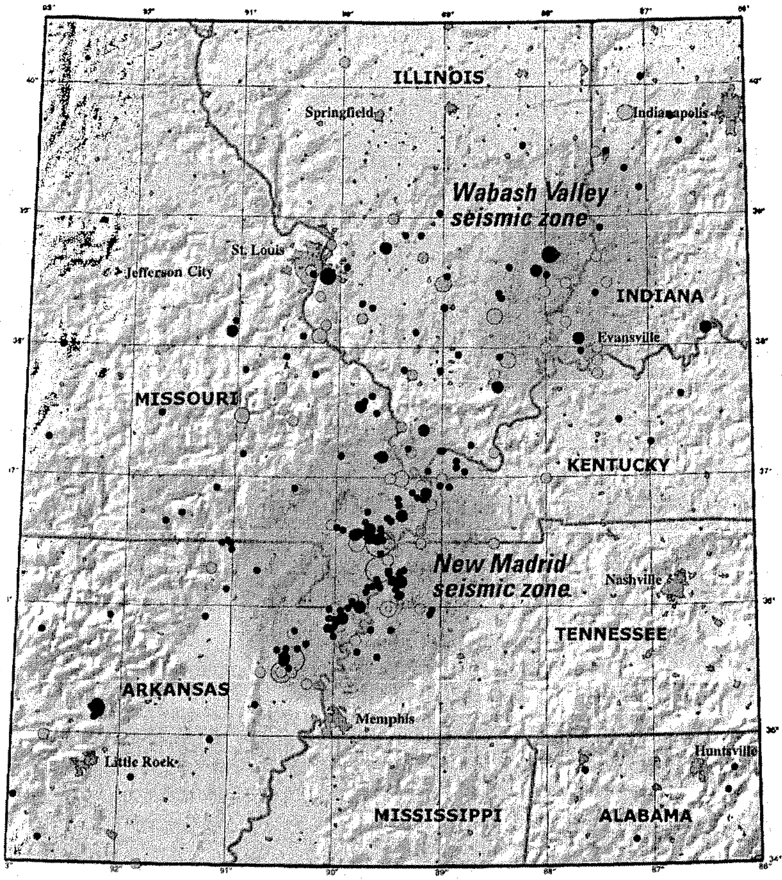
A moratorium was declared within a 1,150 square mile area around Guy-Greenbrier on deep-injection wastewater disposal activities, while seismic-risk studies of the entire Fayetteville shale play were also required. Additionally, "Affected residents filed a class-action lawsuit against Chesapeake Energy and BHP Billiton Petroleum—the first time anyone has sued oil and gas companies for causing an earthquake" (Behar, 2013). University of Memphis seismologist Stephen Horton related that once the wells were shut down the quakes tapered away and ultimately ceased (Kerr, 2012).

## The Youngstown, Ohio Fracking Wastewater Disposal Induced Earthquakes

When a magnitude 2.7 earthquake struck near Youngstown, Ohio on December 24, 2011, it was the tenth such earthquake in the 2.0 to 2.7 magnitude range since March of that year connected with fracking wastewater injection well Northstar 1 owned by D&L Energy Group. The well, which came online in December 2010 (just three months prior to start of seismic activity), received the vast majority of its wastewater from fracking projects in Pennsylvania (Fountain, 2012). Nearly 60% of all the fracking wastewater disposed of in Ohio injection-wells in 2012, 257 million gallons, originated in others states, marking a 19% one-year increase in out-of-state fracking wastewater injected into subterranean Ohio (Johanek, 2013). Prior to January 2011 Youngstown, Ohio had not experienced an earthquake dating back to 1776 when scientists first began recording their observations (Choi, 2013).

Upon analysis of the December 24, 2011 earthquake by the Ohio Department of Natural Resources it was determined that the quake originated less than 2,000 feet below the Northstar 1 well (Fountain, 2012). No sooner had the State of Ohio put an immediate cessation to injection at the well, when an earthquake with a 16 times greater magnitude of 3.9 struck the following week, on New Year's Eve, December 31, 2011. At that point state officials instituted a moratorium on the injection of fracking wastewater within a 5-mile radius of the D&L well until scientists had an opportunity to analyze the data from the string of quakes (Fountain, 2012).

By the time March 2012 rolled around, Youngstown, Ohio had recorded 109 earthquakes in the previous year (Choi, 2013), and "the indications were strong enough to prompt the state to order the




Dark circles — indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 located using modern instruments. *(University of Memphis)*

Light circles — indicate earthquakes that occurred prior to 1974. Larger earthquakes represented by larger circles. *(USGS Professional Paper 1527)*

shutdown of four injection wells in the area and issue strong new regulations" (Kerr, 2012). On July 12, 2012 Executive Order (2012-09K) was signed by Ohio Governor John Kasich, which required that operators conduct seismic studies prior to issuance of well permits (Kasich, 2012). Ohio now stands alone in requiring a seismic-risk assessment for all of its injection wells, as every other state, and the federal government, have yet to do (Behar, 2013).

Seismologist John Armbruster puts points out that within a year of the Northstar 1 well opening there were 109 total earthquakes, and "twelve felt earthquakes. After the well was shut down, the number decreased dramatically. You'd need Powerball odds for that to be a coincidence" (Behar, 2013).

## Proliferation of Shale Gas & Oil Extraction and Fracking Wells

Over the last decade the United States has seen an unprecedented increase in the proliferation of shale gas and oil extraction that has pushed domestic oil to its current place of highest level of production in 20 years, while bringing natural gas production to an all-time high (Weber, 2013). Shale gas from fracking specifically has gone from only 2% of U.S. natural gas production in 2000 to 23% of NG production in 2010 (US EIA, 2012). Because of fracking, the International Energy Agency projects that the U.S. will overtake Russia as the world's top producer of natural gas by 2015.

With this precipitous increase in shale oil and gas production, the U.S. has likewise seen an increase in the proliferation of fracking wells, with more than 82,000 drilled or permitted in 17 states between 2005 and 2012. At the time of this writing (November of 2013) there are likely in excess of 100,000 fracking wells permitted or drilled in the U.S. (Ellsworth, 2013). In 2012 alone there were 22,326 fracking wells drilled throughout the United States, with more than 60% of them (13,540) being drilled in Texas (Ridlington & Rumpler, 2013). During that year drilling inspectors identified more than 55,000 violations of Texas fracking laws by oil and gas companies (Soraghan, 2013a).

## Wastewater Associated with Fracking Industrialization

This dramatic increase in oil and gas production and associated fracking wells has in turn led to an increase in the need for fracking-related wastewater disposal. Each fracked well requires approximately 4 to 7 million gallons of water, fracking fluid and fracking sand to complete a hydraulic fracturing event. In the range of 20% to 80% of the fluid injected during the fracking event, an average of 2.75 million gallons of toxic and radioactive effluent per well ((Hammer & Van Briesen, 2012), returns to the surface as fracking flowback and wastewater (Miller, 2012; Moss, 2008).

The volume of wastewater to be disposed of during the fracking process is one factor that makes fracking industrialization different from anything other form of fossil fuel extraction that has been seen before, producing "50 to 100 times more" waste than conventional oil and gas wells (Cantarow, 2013). Multiply that level of industrialization in terms of number of wells, by that degree of waste management in terms of the volumes of toxic and radioactive effluent per fracked well, and the result is 280 billions gallons of total flowback and produced wastewater coming out of U.S. fracking wells each year (Ridlington & Rumpler, 2013). Unfortunately, these national numbers are woefully incomplete as wastewater produced by Texas alone represents nearly 93% of this total (260 billion gallons), and there was "no estimate" listed for seven of the seventeen fracking states included in the survey.

The shift over the last decade is undeniable, as an overwhelmed Marcellus Shale wastewater disposal infrastructure capacity can attest to, in that "developing the Marcellus shale has increased the total wastewater generated in the region by ~570%" between 2004 and 2012. This of course is a natural consequence of fracking industrialization, as toxic and radioactive wastewater "is an obligate byproduct of current methods and volumes will unavoidably increase with industry expansion" (Lutz et al, 2013).

## Various Methods for Disposing of Fracking Wastewater

While there are current alternatives to deep-well injection for disposing of fracking wastewater, scientists and regulators alike agree that the other options are generally far more expensive while embodying additional environmental risks (Lustgarten, 2013a). These alternatives, the first three of which have been utilized extensively in the Marcellus region due to lack of suitable geology for underground injection (MSAC, 2011), include: (1) Processing of wastewater at municipal wastewater treatment facility with final discharge into a local waterway; (2) Processing of wastewater at a private industrial wastewater facility, with either discharge into a local waterway or reuse of the treated effluent in fracking wells; (3) Recycling of wastewater and reuse of the partially treated effluent in fracking wells; (4) Burning of waste; (5) Disposal of waste by application on roadways and other surfaces (Lutz et al, 2013; Lustgarten, 2012a); and unfortunately, (6) "Fracking flowback is dumped into rivers, lakes and reservoirs" (Eco Watch, 2013).

Cliff Frohlich, senior research scientist at University of Texas at Austin's Institute for Geophysics, reminds us that "the people involved in this are going to do the cheapest way of doing things that is generally considered safe" (Henry, 2012a), and that is currently why more than 95% of fracking wastewater is injected into deep wells (Clark and Veil, 2009). Journalist Abrahm Lustgarten, however, reminds us that, "several key experts acknowledged that the idea that injection is safe rests on science that has not kept pace with reality, and on oversight that doesn't always work (Lustgarten, 2012a). It is not just the energy sector that is dependent on this form of waste elimination, as subterranean waste disposal is a cornerstone of the U.S. economy, with pharmaceutical, chemical and agricultural industries all being dependent upon deep-well injection for managing voluminous waste streams. Even carbon storage and sequestration that is the essential fossil fuel industry strategy for addressing climate change, as Lustgarten points out, "counts on pushing waste into rock

formations below the earth's surface" (Lustgarten, 2012a).

## Fracking Wastewater in Deep-Injection Disposal Wells

As there has been a monumental increase in total fracking-related wastewater produced over the last decade, there has likewise been a dramatic increase in total fracking wastewater injected into disposal wells, where 95% of the toxic effluent is managed. Of the more than 680,000 total injection wells in the United States, in excess of 150,000 fall into the energy industry-specific Class II category that includes both deep-disposal wells in addition to "wells in which fluids are injected to force out trapped oil and gas" (Lustgarten, 2012a). Approximately 30,000 to 40,000 of these Class II wells are deep-disposal wells that receive the volumes of fracking flowback and produced wastewater (Diep, 2013; Ellsworth, 2013; Soraghan, 2013). The states with the most Class II injection wells are Texas (52,016), California (29,505), Kansas (16,658), Oklahoma (10,629), and Illinois (7,843) (US EPA, 2010).

A study by the Argonne National Laboratory estimated that a total of 252 billion gallons of fracking wastewater is injected into Class II deep disposal wells in the United States per year (Clark and Veil, 2009; Clarke et al., 2012). In Texas the total amount of fracking wastewater being injected into deep disposal wells went from 46 million barrels (1.45 billion gallons) in 2005 to nearly 3.5 billion barrels (110.25 billion gallons) in 2011, representing a 76-fold increase in total fracking wastewater injection volume in a six-year period (Galbraith and Henry, 2013). The total amount injected into the more than 150,000 total Class II wells among 33 states is at least 10 trillion gallons of wastewater (Lustgarten, 2012c), while over the last several decades all U.S. industries combined have injected in excess of 30 trillion gallons of toxic liquid into all classes of injection wells, "using broad expanses of the nation's geology as an invisible dumping ground" (Lustgarten, 2012a).

## Wastewater Injection Induced Earthquakes – Factors That Increase Risk

As fracking wastewater injection has dramatically increased over the last decade, so have induced earthquakes, as elucidated by Cliff Frohlich: "The earthquakes are occurring more frequently now because there's so much more fluid injection due to the fracking and the development of unconventional gas. [...] So what's happened is that we have a lot more injection going on in a lot more places, where we're producing more gas and earthquakes" (Henry, 2012a). While most of the United States' 40,000 wastewater injection wells will never cause felt seismic activity, some have and will induce earthquakes in excess of 3.0, and so far, as great as 5.7 (Diep, 2013; Ellsworth, 2013).

The USGS's Williams Ellsworth identifies a number of factors that could enhance the probability of a given injection-well inducing earthquakes in his 2013 *Science* study. They include, "the magnitude of the perturbation, its spatial extent, ambient stress condition close to the failure condition, and the presence of faults well oriented for failure in the tectonic stress field. Hydraulic connection between the injection zone and faults in the basement may also favor inducing earthquakes, as the tectonic shear stress increases with depth in the brittle crust" (Ellsworth, 2013).

Frohlich likewise stresses that it is absolutely essential to "understand why some injection wells trigger seismic activity and others do not," especially when they seemingly have similar mechanical and geological characteristics. He hypothesizes that "injection only triggers earthquakes if injected fluids reach and relieve friction on a suitably oriented, nearby fault that is experiencing regional tectonic stress" (Frohlich, 2012), such that "the materials must be pre-stressed to a substantial fraction of their breaking strength in order for seismicity to be induced" (Kisslinger, 1976). The specific mechanisms involved in fluid-relieved friction on a locked fault will be explored in greater detail below.

## Limiting Condition 1: We Don't Exactly Know What Is Going On Down There

In light of these risk factors identified by Ellsworth and Frohlich, there are two major *limiting conditions* that can significantly contribute to fault rupture and earthquake inducement from fracking wastewater's injection into deep disposal wells. The first is that we do not necessarily know where the injected wastewater is going, and what subterranean pathways it might be following, especially in relation to pre-existing faults both known and unknown. The second is that wells can, and do, fail and leak.

Class II injection wells in practice do not have detailed geologic reviews performed, so there is not particularly any understanding regarding what the well opens up to as much as two and a half miles beneath the surface, including the location of possible faults (Clarke et al., 2012). ProPublica investigative reporter Abrahm Lustgarten captures this reality of disposal well structure: "Tubes of concrete and steel extend anywhere from a few hundred feet to two miles into the earth. At the bottom, the well opens into a natural rock formation. There is no container. Waste simply seeps out, filling tiny spaces left between the grains in the rock like the gaps between stacked marbles" (Lustgarten, 2012a).

The high wellhead pressures applied to inject millions of gallons of fracking wastewater into these deep recesses are sometimes in excess of 50 MPa (493 atmospheres or 7,250 psi) (Hsieh, 1979; Zhang et al, 2013). Injection pressures that high "may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers" (Lustgarten, 2012b). As Scott Ausbrooks, a geologist with the Arkansas Geological Survey, points out, water will eventually find a way out: "Water does not like to be squeezed. Just like a room of people. The more you put in, the more crowded it gets, and at some point, people are going to start being pushed out the doors" (Behar, 2013). Cliff Frohlich describes the wastewater as being forced "downward and outward" from excessive injection, adding that fracking's toxic effluent "can meander for months, creeping into unknown faults and prying the rock apart just enough to release pent-up energy" (Behar, 2013).

## Limiting Condition 2: Deep-Injection Disposal Wells Will Fail and Leak

While scientists and federal regulators generally acknowledge they do not know how many of the Class II injection well sites receiving fracking wastewater are leaking, a ProPublica analysis of EPA data and case histories from October 2007 to October 2010 regarding more than 220,000 well inspections shows that 3.2% of the wells failed and "showed signs that their walls were leaking" (Lustgarten, 2012a). ProPublica's Abrahm Lustgarten further related, "records also show wells are frequently operated in violation of safety regulations and under conditions that greatly increase the risk of fluid leakage and the threat of water contamination."

According to federal water protection regulation descriptions more than 7,500 well test failures from those three years studied involved *fluid migration* and *significant leaks*, with most of those failures being due to cracks or holes that have damaged the well structure itself (Lustgarten, 2012a). Williams Ellsworth notes that while the current wastewater deep-injection disposal well regulatory framework was designed to protect aquifers and groundwater sources from contamination, the regulations fail to address seismic safety (Ellsworth, 2013).

Because of the *limiting conditions* that we do not necessarily know where the injected wastewater is going and that deep-injection wells fail and leak at an estimated rate of 3.2%, wastewater migrates not only to areas unknown, but also to regions where we specifically do not want it to go: fault zones. These fault zones tend to be located deep beneath the surface in the region of the lithosphere known as the Precambrian Crystalline Basement.

## Fracking Wastewater Injection and Induced Seismology

William Ellsworth noted in his 2013 *Science* study that, "There has been a growing realization that the principal seismic hazard from injection-induced earthquakes comes from those associated with disposal of wastewater into deep strata or basement formations" (Ellsworth, 2013). The operative notion is that in order for seismic activity to be induced, not only does that fault have to be pre-stressed, but it also must be reachable where they are located in the Precambrian crystalline basement by the meandering injected wastewater and its associated fluid pressure. Cliff Frohlich



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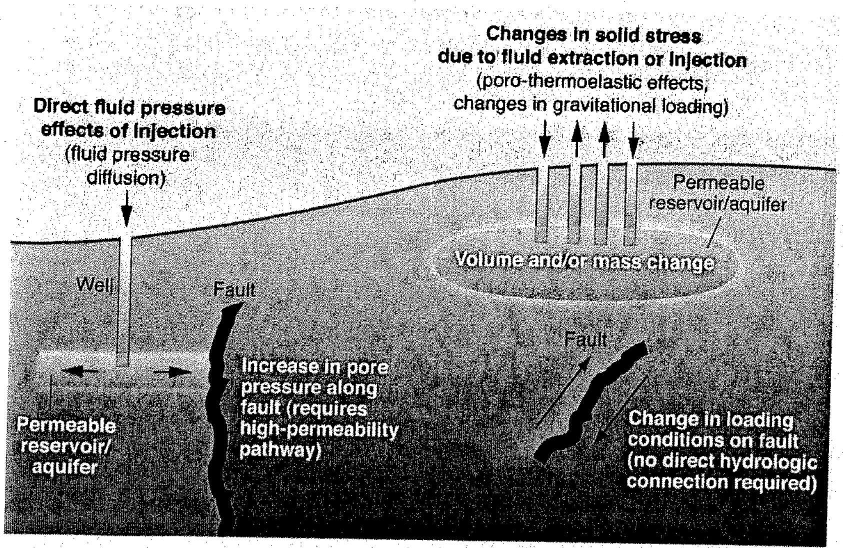



reiterates this point during a 2012 interview, suggesting "fluid injection may trigger earthquakes only if fluids reach and relieve friction on a nearby fault" (Choi, 2012).

A consensus among geologists support the understanding that a vast majority of the fracking wastewater DIDW induced earthquakes did not originate within the sedimentary reservoirs into which the toxic and radioactive fluid was directly injected. Rather this seismicity originated within the generally impermeable metamorphic and igneous crystalline basement that lies 1 to 6 kilometers deeper beneath the sedimentary platform (Horton, 2012; Hsieh and Bredehoeft, 1981; Nicholson and Wesson, 1990; Seeber et al., 2004; Zhang et al., 2013).

Zhang et al., in their 2013 *Groundwater* study, stated that the ever-increasing midcontinent earthquakes "probably occurred along faults that were likely critically stressed within the crystalline basement." More specifically, they found that induced seismic activity was a result of the fracking wastewater either, 1) being injected into a basal sedimentary reservoir that lacks a confining unit underneath the injection reservoir horizon, thus allowing for migration into Precambrian layers, or 2) being injected "directly into the underlying crystalline basement complex" (Zhang et al, 2013).

## Migrating Fluid and Precambrian Crystalline Basements

An essential practical conclusion from the *Groundwater* study (Zhang et al, 2013) is the factor that has the single largest impact in preventing seismic induction within the underlying crystalline basement is the presence of a confining unit barrier between the sedimentary reservoir and the lower Precambrian layer. William Ellsworth describes those injection wells that "dispose of very large volumes of water and/or communicate pressure perturbations directly into basement faults" (Ellsworth, 2013) as problematic disposal wells. Geophysicist Barry Raleigh, whose 1976 *Science* study "An experiment in earthquake control at Rangely, Colorado" demonstrated how earthquakes could be turned on and off by utilizing manipulation of fluid pressure, elucidates that the deep, low-permeability, brittle igneous and metamorphic rock of the crystalline basement "doesn't have a lot of capacity for taking any of these fluids. As a storage medium, they're pretty crappy" (Kerr, 2012).

Readily *felt earthquakes* larger than magnitude 4.0 that have been induced by injection of fracking wastewater into deep disposal wells additionally point to a deeper subterranean origin to these larger earthquakes. "Burdened by far more overlying rock, the deep rock is already carrying stress that," when combined with "the added pressure of the injection trigger," manifests conditions ripe for fault rupture and potentially destructive seismic activity (Kerr, 2012). Zhang et al. (2013) hypothesize that "elevated pore pressures could propagate downward along distributed fracture networks or along conductive fault zones in Precambrian crystalline rocks" (Zhang et al, 2013), meaning that the pressure from fluids can be potentially transmitted to hidden fractures at great depths, given the right conditions. In fact, David M. Evans, in his seminal 1966 *Geotimes* study, relates that even "if the Precambrian fracture system extends to a depth of 12 miles, then fluid pressure could [still] be transmitted to that depth by moderate surface injection pressure as long as the fracture system is open for transmission of that pressure" (Evans, 1966).

## The Long Understood Relationship Between Subterranean Fluid Disposal & Induced Seismology

Some may point to 77 CE Rome for the origins of the human demonstration of the relationship between elevated fluid pressure and induced geological failure, a well-documented case in which Romans utilized the technique to "undermine and instantly remove vast quantities of mountainside to extract gold from the buried mother lode at Las Médulas in northwest Spain" (Goodway, 2012). Others might claim that we have shared this understanding for almost a century, such as members of the Committee on Induced Seismicity Potential in Energy Technologies, who claim that "induced seismic activity has been documented since at least the 1920s" (Clarke et al., 2012), referencing a 1926 study that ran in the *Bulletin of the Seismological Society of America* regarding "Local subsidence of the Goose Creek oil field (Texas)" (Pratt and Johnson, 1926).

While these obscure examples add clarity to this generally familiar yet elusive phenomenon, it is David M. Evans' 1966 *Geotimes* study "Man-made earthquakes in Denver" that is popularly credited with establishing the connection between injection of waste fluids and induced earthquakes (Choi, 2012; Ellsworth, 2013; Frohlich, 2012; Henry, 2012; Kerr, 2012; Soraghan, 2013), such that "since 1966, scientists have generally agreed that injection may induce earthquakes in tectonically favorable situations" (Davis and Frohlich, 1993). Keep in mind that Plate Tectonic Theory did not come into general acceptance until just one-year prior, in 1965, to the verification of this form of human induced earthquake phenomena.

## The Mechanisms Underlying Earthquakes Induced by Fracking Wastewater DIDWs

In regards to the fracking wastewater disposal-induced earthquakes that have been escalating in frequency in the United States' midcontinent over the last decade, U.S. Geological Survey's William Ellsworth concludes that the mechanism responsible for inducing this seismic activity is the "well-understood process of weakening a preexisting fault by elevating the fluid pressure" (Ellsworth, 2013). Ellsworth clarifies that the three specific events that can trigger the nucleation of an earthquake by bringing the fault to failure are, 1) reducing the effective normal stress on a locked fault, 2) increasing the shear stress along a fracture plane, and 3) elevating the pore pressure of the fluid in the rock. Nucleation is the process that marks the beginning of an earthquake with an initial rupture that propagates along the fault surface. Fault failure or slippage can trigger this process, and in turn, generate an earthquake (Ellsworth, 2013).

## Effective Normal Stress and Induced Seismology

If the effective normal stress, the frictional forces that hold a fault a place, is lowered, it can result in fault slippage and trigger earthquake nucleation. Increased fluid pressure relieves enough of squeeze on the fault to release it and induce an earthquake (Kerr, 2012). Injecting fluids that act as a pressurized cushion to relieve the effective normal stress that keeps a fault locked over-pressures a fault (Sheppard et al, 2013). Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory, relates that, "When you over-pressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen" (Earth Institute, 2013).

Effective normal stress is equal to the difference between the applied normal stress and pore pressure (Ellsworth, 2013). Applied normal stress is the total stress on a rock (Hsieh, 1979), or the weight of a given block (Evans, 1966), and pore pressure is the pressure of fluid in the rock's pores and fractures (Ellsworth, 2013), such that

increased pore pressure causes a decrease in frictional force, the effective normal stress (Warpinski, 2012).

## Shear Stress and Induced Seismology

Raising or increasing the shear stress along a fracture plane can also result in induced seismology, such that once the shear stress overcomes the effective normal stress (multiplied by the coefficient of friction and added to cohesion) in a geological system, the fault will slip, fail, and result in an earthquake (Warpinski, 2012). Faults are locked due to frictional forces, which are the result of in situ stresses pressing vertically on the fault plane. Raising the shearing stress to the point of overcoming effective normal stress such that the fault slips is also known as the Mohr-Coulomb failure criterion. Paul Hsieh, recently named 2011 United States Federal Employee of the Year for his role in bringing to a close the BP oil spill in the Gulf of Mexico, remarks in his pivotal 1979 master's thesis that, "Shearing stresses will remain the same no matter how pore pressure varies. This results from the fact that fluid cannot support any shearing stress" (Hsieh, 1979).

Raleigh and others clarify this direct impact that injecting wastewater has on stressed fractures given its inability to support any shearing stress:

> "The pressurized fluid enters a fracture and supports a part of the normal stress equivalent to the pressure of the fluid. As the fluid has no shear strength, the effective normal stress and the frictional resistance to sliding are lowered. If the fracture is subject to shear stress greater than the product of this effective normal stress and the coefficient of friction, the rocks will slip and generate an earthquake" (Raleigh et al., 1976).

## Pore Pressure and Induced Seismology

Finally, elevating the pore pressure of the fluid in the rock can readily lead to seismic events given the proper conditions, like a stressed fault in contact with pressurized, migrating liquid. As the measure of the pressure of the fluid in the rock's pores and fractures, pore pressure is equal to the difference between applied normal stress and effective normal stress (Ellsworth, 2013). Thus as pore pressure increases, the effective normal stress will decrease. This effective normal stress can also be understood as the frictional resistance against the shearing stress along the fracture plane (Hsieh, 1979). If there is a sufficient enough increase in fluid pressure such that the shearing stress overcomes frictional resistance, the fault will slip and result in an earthquake. This is known as the Hubbert-Rubey mechanism, named after the findings in their seminal 1959 *Geological Society of America Bulletin* study "Role of fluid pressure in mechanics of overthrust faulting," as elucidated by Paul Hsieh:

> "The original work of Hubbert and Rubey (1959) actually concerns the role of pore pressure in the mechanics of overthrust faulting. They introduced the concept of rock movements caused by a Mohr-Coulomb-type failure in a fluid-filled rock environment. This concept was first cited by Evans (1966) in his paper on injection–earthquake relationship and subsequently gained wide acceptance as the mechanism through which injection has caused the earthquakes." (Hsieh, 1979)

In his "A review of theories of mechanisms of induced seismicity" that was published in *Engineering Geology*, Kisslinger relates that fluid injection induced earthquakes "are adequately explained" by a combination of the concept of effective pressure in a water-filled porous mechanism and the Coulomb-Mohr failure criterion, which embodies the three factors and their interrelationship that determines whether or not a particular fracking wastewater injection well will induce earthquakes (Kisslinger, 1976). Kisslinger further concludes that reservoir-related earthquakes, like those caused by fluid injection in bore holes, are induced by the same mechanisms, but in light of the lower injection pressures, "additional physical or chemical effects of the water on the materials may play an important role, [such as] a weakening of the materials in old fault zones by the introduction of water or static fatigue in silicate rocks due to stress corrosion (Kisslinger, 1976).

## How to Turn On and Turn Off Earthquakes: The Parameters of Induced Seismology

Now that it has been clarified what events have to transpire in subterranean realms for earthquakes to be induced by fracking wastewater disposal, the question then becomes *how do these mechanisms relate to specific surface behaviors*? The things that we do above ground that directly impact what happens not only 13,000 feet below the surface, but beneath those sedimentary layers in the Precambrian crystalline basements where faults lie within impervious rock formations.

Davis and Frohlich, in their 1993 *Seismological Research Letters* study "Did (or will) fluid injection cause earthquakes? Criteria for a rational assessment," provide us with a starting point by establishing criteria through which one can determine whether or not a given earthquake was induced by wastewater disposal (Davis & Frohlich, 1993). These criteria "include proximity to injection wells, a change from background seismicity, and a correlation with wastewater injection parameters" (Keranen et al., 2013). These parameters related to wastewater injection referred to by Keranen and others, all of which are ultimately controlled by decisions made and actions taken by the deep-well injection companies on the surface, include fluid pressure, total fluid volume, and rate of fluid injection. As noted by William Ellsworth, "the physical connection between operational parameters such as injected volume" and fluid pressure can be complex (Ellsworth, 2013).

## Fluid Pressure: Inducing Seismology By Exceeding Critical Value

The discovery by David Evans published in his 1966 *Geotimes* study, which led to speculations that earthquakes might be controllable, was that the subterranean high-pressure injection of fluid was responsible for the triggering of earthquakes at the Rocky Mountain Arsenal near Denver, Colorado in the early to mid 1960s. While earthquakes were being induced by the injection of pressurized wastewater into stressed rock formations, the reduction in fluid pressure caused a sharp decrease in frequency of seismic activity (Raleigh et al., 1976). A 1972 *Tectonophysics* study by Healy and others entitled "Prospects for earthquake prediction and control" more explicitly expressed this understanding and laid further groundwork for experimentally testing this hypothesis that, "Changes in fluid pressure may control timing of seismic activity and make it possible to control natural earthquakes by controlling variations in fluid pressure in fault zones" (Healy, et al., 1972).

Raleigh, Healy and Bredehoeft's landmark 1976 *Science* study "An Experiment in Earthquake Control at Rangely, Colorado" did demonstrate the capacity to turn on and turn off earthquakes and "established the correlation between fluid pressure and earthquakes beyond reasonable doubt," that they concluded the "control of the San Andreas fault could ultimately prove to be feasible." However, despite these earth-shattering revelations, perhaps the most important takeaway from these experiments was that, "successful prediction of the approximate pore pressure required for triggering of earthquakes according to the Hubbert-Rubey theory was possible" (Raleigh et al., 1976), as demonstrated by experimental verification of theoretical projections.

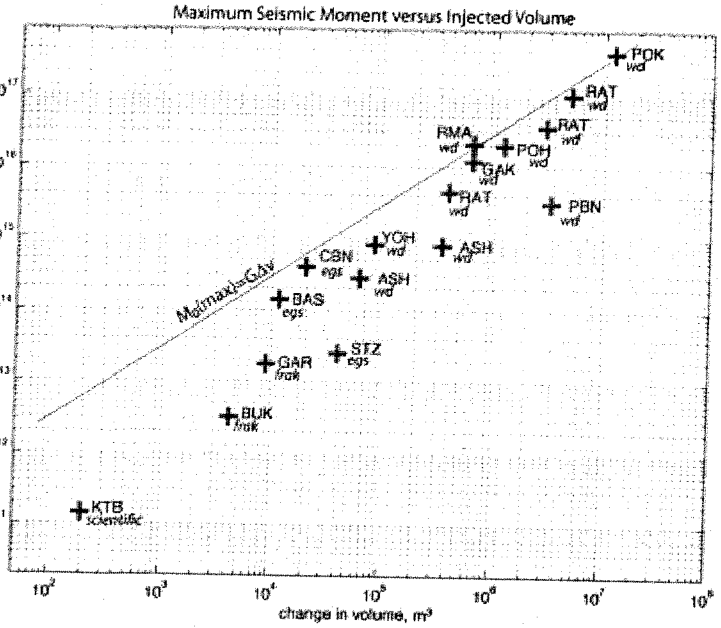
## Predicting Earthquake Behavior, Controlling Earthquakes By Manipulating Fluid Pressure

Utilizing the Mohr-Coulomb failure criterion in applying the Hubbert-Rubey theory, Raleigh and colleagues projected that 257 bars (25.7 MPa) would be the Rangely site's critical fluid pressure. The critical fluid pressure, the pressure required to trigger an earthquake, is governed by the equation:

$\tau_{crit} = \mu(S_n - P_c)$, with

$\tau_{crit}$ = shear stress at failure point,
$\mu$ = coefficient of static friction of the rocks,
$S_n$ = effective normal stress, and
$P_c$ = critical fluid pressure that induces seismicity.

"The fluid pressure required to trigger earthquakes on preexisting fractures" was experimentally tested against the theoretical




projections through use of "laboratory measurements of the frictional properties of the reservoir rocks and an in situ stress measurement made near the earthquake zone" (Raleigh et al., 1976).

Experimental results, which were obtained by varying fluid pressure through the process of "alternately injecting and recovering water from wells that penetrated the seismic zone" (Raleigh et al., 1976), demonstrated that when the injection wells were subjected to fluid pressures above 257 bars the earthquake frequency increased, and when the fluid pressure was less than 257 bars the earthquakes subsided. The idea is that for any given injection well and pre-existing fault situation a critical fluid pressure can be determined, such that "we may ultimately be able to control the timing and the size of major earthquakes [...] wherever we can control the fluid pressure in a fault zone" in relation to that critical fluid pressure (Raleigh et al., 1976).

Hsieh and Bredehoeft (1981), in an expansion of Hsieh's 1979 master's thesis (Hsieh, 1979), analyzed the Rocky Mountain Arsenal injection wells and earthquakes in similar fashion, utilizing Hubbert-Rubey theory to identify the fluid pressure critical value, "the pressure build-up above which earthquakes occur" (Hsieh, 1979). Their conclusion was that, "At the Rocky Mountain Arsenal near Denver, earthquakes occurred within the crystalline basement when the fluid pressures were raised over 320 m above hydrostatic conditions [32 bars, 3.2 MPa] between a depth of about 0.7–7 km (Hsieh and Bredehoeft, 1981; Zhang et al, 2013). Another way to frame this is that the earthquakes were confined strictly to those parts of the reservoir where the pressure build-up exceeded 32 bars (Hsieh, 1979). According to Davis and Frohlich (1993), Hsieh and Bredehoeft's breakthrough was that they were "able to explain the spatial and temporal extent of seismic activity in Denver in terms of the flow of fluids along a permeable semi-infinite rectangular region which approximately contained the activity."

## Total Injected Fluid Volume and Maximum Earthquake Magnitude

The relationship between total fluid volume injected and induced seismology has been noted by many, whether it is the "qualitative correlation between earthquake rates and the injected volume" that has served as a tool for investigating the triggered earthquake phenomena (Oprsal and Eisner, 2013), or the case history-driven evidence suggesting a connection between the total volume of injected wastewater and the maximum induced earthquake magnitude (Hayes, 2012). The U.S. Geological Survey's Art McGarr has compiled the data from these case histories and reports from fracking, waste disposal and geothermal induced seismic events, and has graphed Total Injected Volume vs. Maximum Earthquake Magnitude for 17 different cases of demonstrated fluid disposal triggered earthquakes (Holland and Keller, 2012; Verdon, 2013a; Verdon, 2013b):

| Total Gal. Injected (thousands) | Magnitude Richter Scale | Location |
|---|---|---|
| 53 | 1.4 | Bavaria Germany (KTB) |
| 1,057 | 2.3 | Blackpool, England (BUK) |
| 2,325 | 2.8 | Garvin County, Oklahoma (GAR) |
| 3,170 | 3.4 | Basel, Switzerland (BAS) |
| 9,774 | 3.7 | geothermal at CBN |
| 10,567 | 2.9 | Soultz, France (STZ) |
| 15,850 | 3.6 | Ashtabula, OH (ASH) |
| 21,134 | 3.9 | Youngstown, Ohio (YOH) |
| 89,818 | 3.8 | Ashtabula, OH (ASH) |
| 103,026 | 4.4 | Raton Basin, Colorado (RAT) |
| 158,502 | 4.6 | Guy, Arkansas (GAK) |
| 158,502 | 4.7 | Rocky Mountain Arsenal (RMA) |
| 766,093 | 5.0 | Raton Basin, Colorado (RAT) |
| 845,344 | 4.3 | Paradox Basin, Colorado (PBN) |
| 1,320,850 | 5.3 | Raton Basin, Colorado (RAT) |
| 3,170,040 | 5.7 | Prague, Oklahoma (POK) |

While "McGarr found a relationship between the maximum magnitude of induced earthquakes and the total volume of fluid injected into a site" (Balcerak, 2013), James Verdon reminds us that the McGarr model "is only empirical, there is no real physics behind it" (Verdon, 2013a). McGarr's model does, however, create an interesting framework for further theoretical and experimental work, while also leading to the derivation of the McGarr equation for injection-induced seismicity:

$M_0(max) = G\Delta v$, with

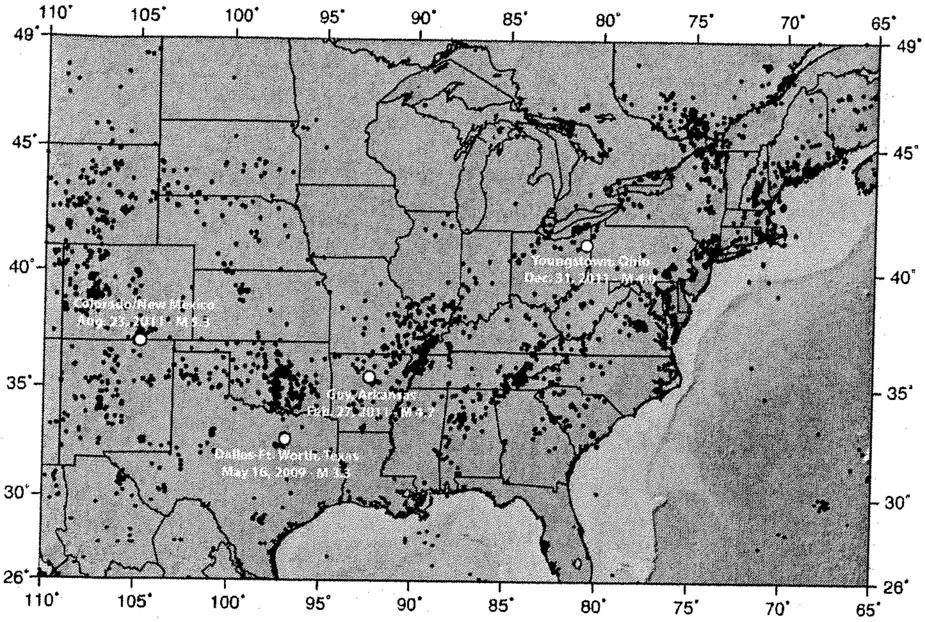
$M_0(max)$ = magnitude of largest seismic moment,
G = shear modulus of rock
(ratio of shear stress to shear strain), and
$\Delta v$ = total volume of fluid injected.

Despite potential shortcomings, Verdon does admit that, "In the meantime, we are left with the empirical McGarr equation as our main guide" (Verdon, 2013a). He also makes certain to clarify: "It should of course be remembered that the McGarr equation does not tell you the maximum magnitude you will get in an operation. [...] The McGarr line tells you the maximum magnitude you could get if you are very unlucky" (Verdon, 2013a). While McGarr continues to clarify the undeniable connection between the total injected fluid volume and the potential maximum magnitude of induced earthquakes, he does not find the rate of fluid injection to impact the magnitude of triggered earthquakes, but rather he found "that the rate of injection of fluid influences the frequency of induced earthquakes" (Balcerak, 2013).

## Rate of Fluid Injection and the Work of Cliff Frohlich

A third surface-controlled parameter that can impact fracking wastewater disposal induced seismicity is that of rate of fluid injection. While the rate of fluid injection and withdrawal played role in the Rangely, Colorado earthquake control experiments (Healy, et al., 1972), few scientists outside of Cliff Frohlich are investigating what he has observed to be a relationship between high rates of fluid injection and induced seismicity. From varies studies of the Barnett Shale play in Texas, Frohlich has found that injection wells nearest induced earthquake groups consistently reported maximum monthly injection rates in excess of 6.34 million gallons (24,000 cubic meters) of fluid, "and generally these injection rates had been maintained for a year or more prior to the onset of earthquake activity" (Frohlich, 2012).

While Frohlich has indicated in interviews that he is very much interested in pursuing this line of inquiry in other fracking wastewater injection regions (Choi, 2012), his own studies have already indicated that other faulted areas demonstrate different maximum monthly injection rates required to induce earthquakes, such as a fluid injection rate of 9.5 to 12.7 million gallons (32,000 to 48,000 cubic meters) per month in the case of Paradox Valley, Colorado (Frohlich et al, 2010). While there is still a lot of research and experimentation required to clarify the precise role of the three surface parameters of fluid pressure, total fluid volume, and rate of




fluid injection in triggering earthquakes, William Ellsworth concurs that experimental results distinctly suggest that these factors all "may be a predictor of seismic potential" (Ellsworth, 2013).

## Conclusion

The mechanisms that underlie fracking wastewater disposal induced earthquakes have been clarified and verified since 1966, making the Hubbert-Rubey theory just a year younger than the theory of plate tectonics and its general acceptance. By capturing the interrelationships between primary earthquake inducement factors that include effective normal stress, shear stress and pore pressure, they set the stage for a couple of decades worth of rich experimentation. All of which became nearly forgotten until fracking industrialization's rude awakening, a literal shaking the foundations of where we work, where we shop and where we live. Luckily, "after a decades long lull in triggered quake studies, researchers are playing catch-up with the latest round of temblors" (Kerr, 2012). And so, in the spirit of existential philosopher Martin Heidegger's conception of truth, we find ourselves in the process of *revealing that which had been concealed.*

One of the great concerns of many of the seismologists and geologists working on this issue is the reality of the earthquake domino effect that have been observed as a result of wastewater injection-induced seismicity. University of Oklahoma seismologist Katie Keranen relates this as the operative scenario in the Prague, Oklahoma magnitude 5.7 earthquake that struck on November 6, 2011: "We had one fault-plane go, a second one, and then a third one. They ruptured in sequence" (Behar, 2013). Lamont-Doherty Earth Observatory seismologist Geoffrey Abers elucidates, "the amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock" (The Earth Institute, 2013).

This is also of great concern to those potentially impacted individuals who live in Southern Illinois, existing between two active seismic zones, the New Madrid and the Wabash. With Southern Illinois facing the promise of mass fracking industrialization and its associated toxic and radioactive wastewater in need of disposal in deep-injection wells, it is not lost on many experts the danger that even small earthquakes can pose in this active seismic region. Geoffrey Abers acknowledges that, "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought (The Earth Institute, 2013). A study conducted by the University of Illinois Mid-America Earthquake Center in 2008 projected that if an earthquake the magnitude of the quakes that hit near New Madrid during 1811-1812 were to strike today, "there would be 3,500 fatalities, 2.6 million people without electricity and $300 billion in direct economic losses. Bridges, docks, highways and water infrastructure would be in shambles" (IEMA, 2013).

If mass fracking industrialization is to take hold of Southern Illinois, a land amidst two active seismic zones, then higher intelligence must be allowed to govern this process, its regulations, and their application. Stanford University geophysicist Mark Zoback answers this call by providing an empirically derived practical framework for reducing the probability of induced seismicity, with five straightforward steps:

(1) It is important to avoid injection into active faults and faults in brittle rock.

(2) Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.

(3) Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.

(4) Protocols should be established in advance to define how operations will be modified if seismicity is triggered.

(5) Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard (Zoback, 2012).

These five steps provide both the state (in form of regulators) and industry (in the form of operating companies) with a structure for reducing the risks involved in fracking wastewater disposal via deep-injection wells and the induced earthquakes that can accompany their utilization.



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*Brent Ritzel received his BA in Philosophy from Northwestern University in 1990 and is currently working on his master's thesis* PROJECTED TOTAL COSTS OF ROADWAY DEGRADATION DUE TO PROPOSED FRACKING INDUSTRIALIZATION OF SOUTHERN ILLINOIS *for a Master of Public Administration degree at Southern Illinois University Carbondale, expected completion May 2014.*

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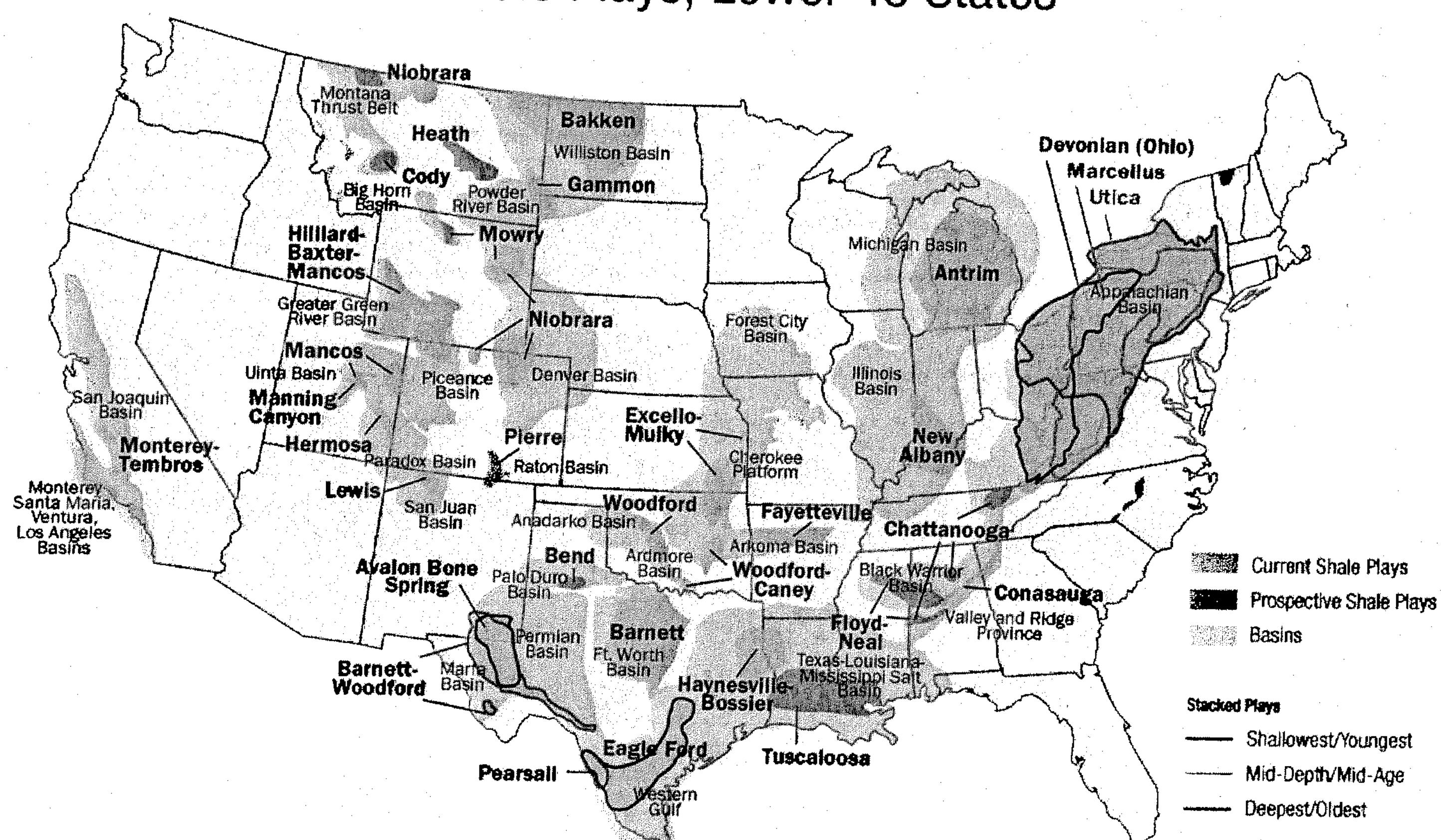
# Shale Plays, Lower 48 States



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# Fracking Industrialization & Induced Earthquakes

## The Mechanisms that Connect the Disposal of Fracking Wastewater into Deep-Injection Wells to a Significant Increase in Midcontinent Seismic Activity

by Brent Ritzel *[brent@siu.edu]*

### Introduction

This paper explores the recent significant increase in *felt earthquakes* in the midcontinent of the United States over the past decade in relation to fracking industrialization and its associated voluminous wastewater disposal needs. Studies and expert insight from geologists and seismologists from over the past fifty years will be utilized in order to render evidenced-based conclusions regarding these matters that have often remained at the opinion level of discourse in the public sphere.

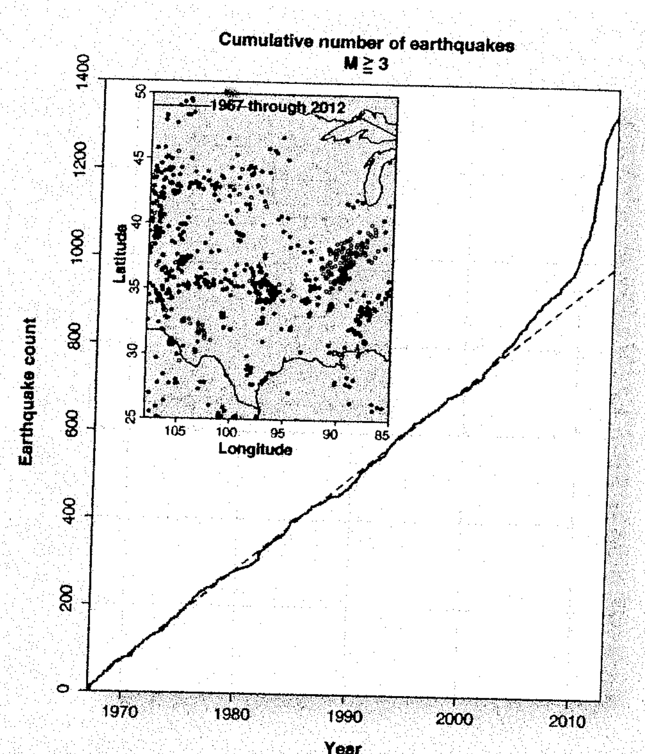
The current extent of U.S. fracking industrialization will be reviewed, including dissection of shale oil and gas production levels, the scale of proliferation of fracking wells, the volume of toxic and radioactive effluent, fracking flowback and produced wastewater disposal needs, and the impact of the exponential growth in deep-injection disposal well usage on the United States' current seismic reality. Two important limiting conditions, the *impervious* unknowns regarding subterranean geological formations *and* the fact that disposal wells will fail and leak, provide context for discussion of our obscured yet viable long term understanding of the mechanisms underlying the whole phenomena of fracking wastewater disposal induced earthquakes.

### Historic Shift in Frequency of Midcontinent Earthquakes

Seismologists like the U.S. Geological Survey's William Ellsworth started noticing a historically unique trend about a dozen years ago, "that there were an unusual number of earthquakes in the middle of the country," in areas that have not been known for earthquakes (Rugh, 2013). The Guy-Greenbrier area of Arkansas, with total population of just over 5,000, was traditionally a quake-free area. Throughout all of 2007 the area had only one earthquake of magnitude 2.5 or greater, followed by only two such quakes in 2008. However, in 2009 there were 10, and in 2010 there were 54 earthquakes of magnitude 2.5 or greater (Kerr, 2012). On February 27, 2011, Guy experienced a magnitude 4.7 earthquake.

Neighboring state Oklahoma went through a similar pattern as a whole, experiencing just a few earthquakes per year from 1972 to 2007, 12 in 2008, 50 in 2009, and more than 1,000 in 2010, culminating with a magnitude 5.7 earthquake on November 6, 2011. While Oklahoma saw a more than hundred-fold increase in overall earthquakes, it also saw a twenty-fold increase in earthquakes with magnitude 3.0 or greater in those same three years from 2008 to 2010 (Ellsworth et al, 2012). Meanwhile, the Barnett Shale region of north central Texas has experienced "unprecedented levels of seismicity" since shale gas development began in late 1998, with "nine earthquakes of magnitude 3.0 or larger occurred, compared with none in the preceding 25 years." Overall, the states reporting unusually elevated levels of seismic activity include Arkansas, Colorado, New Mexico, Ohio, Oklahoma Texas, and Virginia (Ellsworth, 2013).

This pattern seen in both localized and statewide contexts is also reflected in data concerning the frequency of magnitude 3.0 or greater earthquakes in the entire U.S. midcontinent region, with the annual number of magnitude 3.0 or greater earthquakes having "increased almost tenfold in the past decade" (Lovett, 2013). The "middle part of the continent" went from a remarkably consistent average 21 per year from 1970 to 2000, to an average of 29 per year from 2001 to 2008, to 50 magnitude 3.0 or greater quakes in 2009, to 87 in 2010, to somewhere in the range of 134 to 188 in 2011




Cumulative count of earthquakes with magnitude ≥ 3.0 in the central and eastern United States, 1967–2012. The dashed line corresponds to the long-term rate of 21.2 earthquakes/year.
*(Inset)* Distribution of epicenters in the United States midcontinent region.

(Demus, 2012; Ellsworth, 2013; Henry, 2012; Lovett, 2013). As William Ellsworth *et al* (2012) reported in their *Seismological Research Letters* study, "A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region" (Ellsworth et al, 2012). Especially in areas that have historically lacked earthquakes, like the Youngstown, Ohio area, as Columbia University's Lamont-Doherty Earth Observatory seismologist John Armbruster relates, "Having that many earthquakes [...] where there aren't a lot of earthquakes, was suspicious" (Fountain, 2012).

What all these different scenarios share is a common time frame for the onset of fracking industrialization, and an ever-expanding need for deep-injection disposal wells [DIDWs] to handle the massive volumes of associated fracking flowback and produced wastewater. A 2013 *Science* study (van der Elst et al, 2013) by a team of seismologists led by Nicholas van der Elst of Columbia University's Lamont-Doherty Earth Observatory found, "that at least half of the magnitude-4.5 or larger earthquakes that have struck the interior United States in the past decade have occurred near injection-well sites" (Lovett, 2013). A 2013 *Geology* study (Keranen et al., 2013) by a team of seismologists led by Katie Keranen

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concluded while earthquakes with magnitude 5.0 or greater are a rarity east of the Rocky Mountains, "the number per year recorded in the midcontinent increased 11-fold between 2008 and 2011, compared to 1976–2007" (Keranen, 2013). When interviewed concerning colleague response to the study, Keranen indicated that, "Pretty much everybody who looks at our data accepts that these events were likely caused by injection" (Behar, 2013).

## Fracking Wastewater Deep-Injection Disposal Wells and Induced Earthquakes: The Jury's Verdict

While speculation and confusion dominate the lay population's conversation regarding the origins of this historic increase in midcontinent earthquakes, there is a strong consensus among geologists and seismologists that the recent uptick in earthquakes is primarily due to the recent increase in fracking industrialization and disposal of its associated wastewater.

William Ellsworth of the U.S. Geological Survey Earthquake Science Center concludes: "Clearly it is happening. Earthquakes have been happening in some unusual parts of the United States. At this point, we do not know if all or just some part of that increase is attributable to industrial activities like wastewater injection" (Vergano, 2013). These risks associated with deep-injection wells inducing earthquakes, which according to Scott Ausbrooks (geologist with the Arkansas Geological Survey) have "been known for decades," are especially heightened in known seismic zones, such as the Wabash and New Madrid Seismic Zones, as "what is clear... is that deep reservoirs in tectonically active zones carry a real risk of inducing damaging earthquakes" (Ellsworth, 2013).

For Cliff Frohlich, senior research scientist at the University of Texas at Austin's Institute for Geophysics, the problem is that faults are ubiquitous, they are most everywhere, and "most of them are stuck, because rock on rock is pretty sticky. But if you pump a fluid in there to reduce the friction, they can slip" (Behar, 2013). Frohlich continues regarding the recent uptick in seismic activity, "These earthquakes could have been anywhere. They weren't. Virtually all of them were near injection wells" (Behar, 2013).

*Popular Science* writer Francie Diep notes a strong consensus among those best equipped to comprehend the situation: "Since companies began doing [wastewater deep-injection] more often, U.S. Geological Survey and other scientists have noticed more earthquakes occurring in the Midwest, which isn't normally so seismically active. Three different geologists told me this, unprompted, when I was researching the Prague quakes earlier this year" (Diep, 2013). Those Prague, Oklahoma earthquakes included the strongest quake in Oklahoma history, a magnitude 5.7 that struck within a mile of three injection wells filled with fluid leftover from conventional oil dewatering operations (Behar, 2013; Holland & Keller, 2012). The quake destroyed 14 homes, injured two individuals, and was felt more than 600 miles away in Chicago (Choi, 2012; Ellsworth, 2013).

While a team of seismologists from Columbia University, University of Oklahoma and the U.S. Geological Survey concurred on the waste-injection origin of the series of quakes (Keranen et al., 2013), United Kingdom-based applied geophysicist James Verdon points out that, "the Oklahoma Geological Survey has subsequently released a rebuttal (Keller & Holland, 2013) stating that as far as it is concerned, there is not enough evidence to tie the quake to injection activities" (Verdon, 2013a).

## Fracking Wastewater DIDWs Are Primary Fracking-Related Seismic Hazard

A team of geologists and seismologists led by William Ellsworth posit in their 2012 study "Are seismicity rate changes in the midcontinent natural or manmade" that the slight increase in seismicity that began in 2001 was primarily due to a Raton Basin coal bed methane field west of Trinidad, Colorado along the Colorado-New Mexico border. They further conclude that the "acceleration in activity that began in 2009 appears to involve a combination of source regions of oil and gas production, including the Guy, Arkansas region, and in central and southern Oklahoma" (Ellsworth et al., 2012).

While some have raised concerned over seismicity related to the fracking event itself, the primary seismic hazard from fracking industrialization is its associated wastewater disposal into Class II deep-injection wells. Shale gas and oil extraction features four behaviors during the entire fracking industrialization life cycle that can induce some degree of seismicity or affect local geological stresses. These include the drilling of wells, the hydraulic fracturing of the shale, the removal of gas and fluids from the well during production, and deep-injection well wastewater disposal (Frohlich et al., 2010).

William Ellsworth points out that with nearly 100,000 wells having been fracked over the last twelve years, the largest induced earthquake from the hydraulic fracturing of the shale was magnitude 3.6, a barely felt earthquake that by itself poses no serious risk. However, attitudes have shifted regarding wastewater injection induced seismology, as prior to 2011 the seismic event widely accepted by the scientific community as having been the largest wastewater injection induced earthquake in U.S. history was the magnitude 4.8 quake that took place on August 9, 1967 near Denver, Colorado (Ellsworth, 2013). Over the last decade, and especially since 2011, matters have literally shifted.

## Shutting Down of Wells that Induced Earthquakes

Geologists and seismologists are not the only engaged professionals raising concerns about fracking wastewater disposal related induced seismology. State oil and gas officials in both Arkansas and Ohio have shut down fracking wastewater disposal wells that have been connected with induced earthquakes. In the case of induced seismology in the Guy-Greenbrier area or Arkansas, the state's governor, Oil and Gas commission, and the general public all concurred to shut down the responsible injection-wells as, "nearly 1000 recorded quakes had struck the area since the wells had started up" (Kerr, 2012).

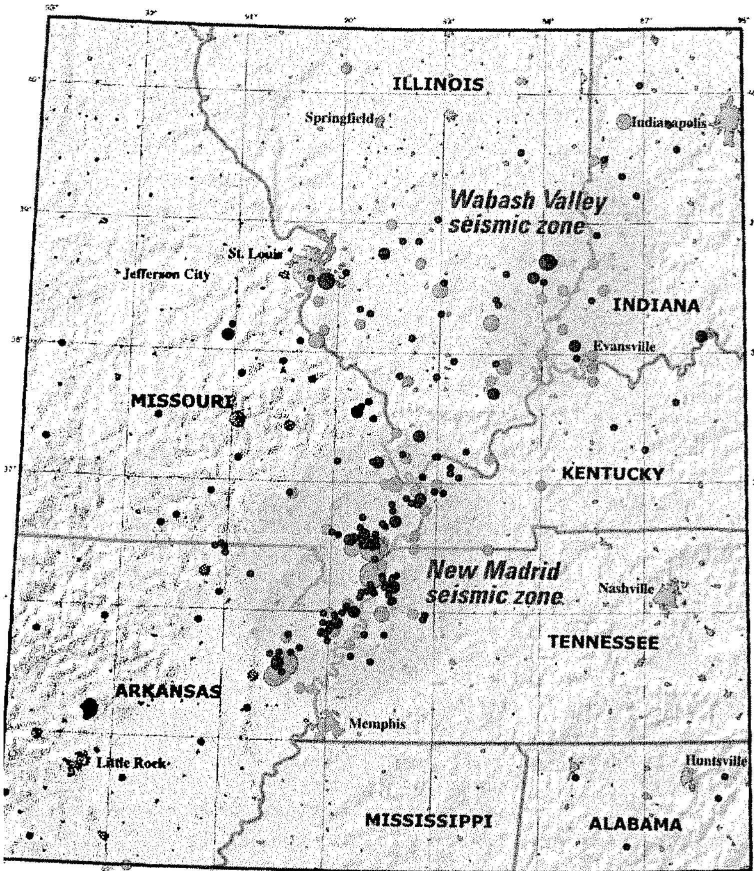
A moratorium was declared within a 1,150 square mile area around Guy-Greenbrier on deep-injection wastewater disposal activities, while seismic-risk studies of the entire Fayetteville shale play were also required. Additionally, "Affected residents filed a class-action lawsuit against Chesapeake Energy and BHP Billiton Petroleum—the first time anyone has sued oil and gas companies for causing an earthquake" (Behar, 2013). University of Memphis seismologist Stephen Horton related that once the wells were shut down the quakes tapered away and ultimately ceased (Kerr, 2012).

## The Youngstown, Ohio Fracking Wastewater Disposal Induced Earthquakes

When a magnitude 2.7 earthquake struck near Youngstown, Ohio on December 24, 2011, it was the tenth such earthquake in the 2.0 to 2.7 magnitude range since March of that year connected with fracking wastewater injection well Northstar 1 owned by D&L Energy Group. The well, which came online in December 2010 (just three months prior to start of seismic activity), received the vast majority of its wastewater from fracking projects in Pennsylvania (Fountain, 2012). Nearly 60% of all the fracking wastewater disposed of in Ohio injection-wells in 2012, 257 million gallons, originated in others states, marking a 19% one-year increase in out-of-state fracking wastewater injected into subterranean Ohio (Johanek, 2013). Prior to January 2011 Youngstown, Ohio had not experienced an earthquake dating back to 1776 when scientists first began recording their observations (Choi, 2013).

Upon analysis of the December 24, 2011 earthquake by the Ohio Department of Natural Resources it was determined that the quake originated less than 2,000 feet below the Northstar 1 well (Fountain, 2012). No sooner had the State of Ohio put an immediate cessation to injection at the well, when an earthquake with a 16 times greater magnitude of 3.9 struck the following week, on New Year's Eve, December 31, 2011. At that point state officials instituted a moratorium on the injection of fracking wastewater within a 5-mile radius of the D&L well until scientists had an opportunity to analyze the data from the string of quakes (Fountain, 2012).

By the time March 2012 rolled around, Youngstown, Ohio had recorded 109 earthquakes in the previous year (Choi, 2013), and "the indications were strong enough to prompt the state to order the




**Red circles** — indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 located using modern instruments. *(University of Memphis)*

**Green circles** — indicate earthquakes that occurred prior to 1974. Larger earthquakes represented by larger circles. *(USGS Professional Paper 1527)*

shutdown of four injection wells in the area and issue strong new regulations" (Kerr, 2012). On July 12, 2012 Executive Order (2012-09K) was signed by Ohio Governor John Kasich, which required that operators conduct seismic studies prior to issuance of well permits (Kasich, 2012). Ohio now stands alone in requiring a seismic-risk assessment for all of its injection wells, as every other state, and the federal government, have yet to do (Behar, 2013).

Seismologist John Armbruster puts points out that within a year of the Northstar 1 well opening there were 109 total earthquakes, and "twelve felt earthquakes. After the well was shut down, the number decreased dramatically. You'd need Powerball odds for that to be a coincidence" (Behar, 2013).

## Proliferation of Shale Gas & Oil Extraction and Fracking Wells

Over the last decade the United States has seen an unprecedented increase in the proliferation of shale gas and oil extraction that has pushed domestic oil to its current place of highest level of production in 20 years, while bringing natural gas production to an all-time high (Weber, 2013). Shale gas from fracking specifically has gone from only 2% of U.S. natural gas production in 2000 to 23% of NG production in 2010 (US EIA, 2012). Because of fracking, the International Energy Agency projects that the U.S. will overtake Russia as the world's top producer of natural gas by 2015.

With this precipitous increase in shale oil and gas production, the U.S. has likewise seen an increase in the proliferation of fracking wells, with more than 82,000 drilled or permitted in 17 states between 2005 and 2012. At the time of this writing (November of 2013) there are likely in excess of 100,000 fracking wells permitted or drilled in the U.S. (Ellsworth, 2013). In 2012 alone there were 22,326 fracking wells drilled throughout the United States, with more than 60% of them (13,540) being drilled in Texas (Ridlington & Rumpler, 2013). During that year drilling inspectors identified more than 55,000 violations of Texas fracking laws by oil and gas companies (Soraghan, 2013a).

## Wastewater Associated with Fracking Industrialization

This dramatic increase in oil and gas production and associated fracking wells has in turn led to an increase in the need for fracking-related wastewater disposal. Each fracked well requires approximately 4 to 7 million gallons of water, fracking fluid and fracking sand to complete a hydraulic fracturing event. In the range of 20% to 80% of the fluid injected during the fracking event, an average of 2.75 million gallons of toxic and radioactive effluent per well ((Hammer & Van Briesen, 2012), returns to the surface as fracking flowback and wastewater (Miller, 2012; Moss, 2008).

The volume of wastewater to be disposed of during the fracking process is one factor that makes fracking industrialization different from anything other form of fossil fuel extraction that has been seen before, producing "50 to 100 times more" waste than conventional oil and gas wells (Cantarow, 2013). Multiply that level of industrialization in terms of number of wells, by that degree of waste management in terms of the volumes of toxic and radioactive effluent per fracked well, and the result is 280 billions gallons of total flowback and produced wastewater coming out of U.S. fracking wells each year (Ridlington & Rumpler, 2013). Unfortunately, these national numbers are woefully incomplete as wastewater produced by Texas alone represents nearly 93% of this total (260 billion gallons), and there was "no estimate" listed for seven of the seventeen fracking states included in the survey.

The shift over the last decade is undeniable, as an overwhelmed Marcellus Shale wastewater disposal infrastructure capacity can attest to, in that "developing the Marcellus shale has increased the total wastewater generated in the region by ~570%" between 2004 and 2012. This of course is a natural consequence of fracking industrialization, as toxic and radioactive wastewater "is an obligate byproduct of current methods and volumes will unavoidably increase with industry expansion" (Lutz et al, 2013).

## Various Methods for Disposing of Fracking Wastewater

While there are current alternatives to deep-well injection for disposing of fracking wastewater, scientists and regulators alike agree that the other options are generally far more expensive while embodying additional environmental risks (Lustgarten, 2013a). These alternatives, the first three of which have been utilized extensively in the Marcellus region due to lack of suitable geology for underground injection (MSAC, 2011), include: (1) Processing of wastewater at municipal wastewater treatment facility with final discharge into a local waterway; (2) Processing of wastewater at a private industrial wastewater facility, with either discharge into a local waterway or reuse of the treated effluent in fracking wells; (3) Recycling of wastewater and reuse of the partially treated effluent in fracking wells; (4) Burning of waste; (5) Disposal of waste by application on roadways and other surfaces (Lutz et al, 2013; Lustgarten, 2012a); and unfortunately, (6) "Fracking flowback is dumped into rivers, lakes and reservoirs" (Eco Watch, 2013).

Cliff Frohlich, senior research scientist at University of Texas at Austin's Institute for Geophysics, reminds us that "the people involved in this are going to do the cheapest way of doing things that is generally considered safe" (Henry, 2012a), and that is currently why more than 95% of fracking wastewater is injected into deep wells (Clark and Veil, 2009). Journalist Abrahm Lustgarten, however, reminds us that, "several key experts acknowledged that the idea that injection is safe rests on science that has not kept pace with reality, and on oversight that doesn't always work (Lustgarten, 2012a). It is not just the energy sector that is dependent on this form of waste elimination, as subterranean waste disposal is a cornerstone of the U.S. economy, with pharmaceutical, chemical and agricultural industries all being dependent upon deep-well injection for managing voluminous waste streams. Even carbon storage and sequestration that is the essential fossil fuel industry strategy for addressing climate change, as Lustgarten points out, "counts on pushing waste into rock

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formations below the earth's surface" (Lustgarten, 2012a).

### Fracking Wastewater in Deep-Injection Disposal Wells

As there has been a monumental increase in total fracking-related wastewater produced over the last decade, there has likewise been a dramatic increase in total fracking wastewater injected into disposal wells, where 95% of the toxic effluent is managed. Of the more than 680,000 total injection wells in the United States, in excess of 150,000 fall into the energy industry-specific Class II category that includes both deep-disposal wells in addition to "wells in which fluids are injected to force out trapped oil and gas" (Lustgarten, 2012a). Approximately 30,000 to 40,000 of these Class II wells are deep-disposal wells that receive the volumes of fracking flowback and produced wastewater (Diep, 2013; Ellsworth, 2013; Soraghan, 2013). The states with the most Class II injection wells are Texas (52,016), California (29,505), Kansas (16,658), Oklahoma (10,629), and Illinois (7,843) (US EPA, 2010).

A study by the Argonne National Laboratory estimated that a total of 252 billion gallons of fracking wastewater is injected into Class II deep disposal wells in the United States per year (Clark and Veil, 2009; Clarke et al., 2012). In Texas the total amount of fracking wastewater being injected into deep disposal wells went from 46 million barrels (1.45 billion gallons) in 2005 to nearly 3.5 billion barrels (110.25 billion gallons) in 2011, representing a 76-fold increase in total fracking wastewater injection volume in a six-year period (Galbraith and Henry, 2013). The total amount injected into the more than 150,000 total Class II wells among 33 states is at least 10 trillion gallons of wastewater (Lustgarten, 2012c), while over the last several decades all U.S. industries combined have injected in excess of 30 trillion gallons of toxic liquid into all classes of injection wells, "using broad expanses of the nation's geology as an invisible dumping ground" (Lustgarten, 2012a).

### Wastewater Injection Induced Earthquakes – Factors That Increase Risk

As fracking wastewater injection has dramatically increased over the last decade, so have induced earthquakes, as elucidated by Cliff Frohlich: "The earthquakes are occurring more frequently now because there's so much more fluid injection due to the fracking and the development of unconventional gas. [...] So what's happened is that we have a lot more injection going on in a lot more places, where we're producing more gas and earthquakes" (Henry, 2012a). While most of the United States' 40,000 wastewater injection wells will never cause felt seismic activity, some have and will induce earthquakes in excess of 3.0, and so far, as great as 5.7 (Diep, 2013; Ellsworth, 2013).

The USGS's Williams Ellsworth identifies a number of factors that could enhance the probability of a given injection-well inducing earthquakes in his 2013 *Science* study. They include, "the magnitude of the perturbation, its spatial extent, ambient stress condition close to the failure condition, and the presence of faults well oriented for failure in the tectonic stress field. Hydraulic connection between the injection zone and faults in the basement may also favor inducing earthquakes, as the tectonic shear stress increases with depth in the brittle crust" (Ellsworth, 2013).

Frohlich likewise stresses that it is absolutely essential to "understand why some injection wells trigger seismic activity and others do not," especially when they seemingly have similar mechanical and geological characteristics. He hypothesizes that "injection only triggers earthquakes if injected fluids reach and relieve friction on a suitably oriented, nearby fault that is experiencing regional tectonic stress" (Frohlich, 2012), such that "the materials must be pre-stressed to a substantial fraction of their breaking strength in order for seismicity to be induced" (Kisslinger, 1976). The specific mechanisms involved in fluid-relieved friction on a locked fault will be explored in greater detail below.

### Limiting Condition 1: We Don't Exactly Know What Is Going On Down There

In light of these risk factors identified by Ellsworth and Frohlich, there are two major *limiting conditions* that can significantly contribute to fault rupture and earthquake inducement from fracking wastewater's injection into deep disposal wells. The first is that we do not necessarily know where the injected wastewater is going, and what subterranean pathways it might be following, especially in relation to pre-existing faults both known and unknown. The second is that wells can, and do, fail and leak.

Class II injection wells in practice do not have detailed geologic reviews performed, so there is not particularly any understanding regarding what the well opens up to as much as two and a half miles beneath the surface, including the location of possible faults (Clarke et al., 2012). ProPublica investigative reporter Abrahm Lustgarten captures this reality of disposal well structure: "Tubes of concrete and steel extend anywhere from a few hundred feet to two miles into the earth. At the bottom, the well opens into a natural rock formation. There is no container. Waste simply seeps out, filling tiny spaces left between the grains in the rock like the gaps between stacked marbles" (Lustgarten, 2012a).

The high wellhead pressures applied to inject millions of gallons of fracking wastewater into these deep recesses are sometimes in excess of 50 MPa (493 atmospheres or 7,250 psi) (Hsieh, 1979; Zhang et al, 2013). Injection pressures that high "may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers" (Lustgarten, 2012b). As Scott Ausbrooks, a geologist with the Arkansas Geological Survey, points out, water will eventually find a way out: "Water does not like to be squeezed. Just like a room of people. The more you put in, the more crowded it gets, and at some point, people are going to start being pushed out the doors" (Behar, 2013). Cliff Frohlich describes the wastewater as being forced "downward and outward" from excessive injection, adding that fracking's toxic effluent "can meander for months, creeping into unknown faults and prying the rock apart just enough to release pent-up energy" (Behar, 2013).

### Limiting Condition 2: Deep-Injection Disposal Wells Will Fail and Leak

While scientists and federal regulators generally acknowledge they do not know how many of the Class II injection well sites receiving fracking wastewater are leaking, a ProPublica analysis of EPA data and case histories from October 2007 to October 2010 regarding more than 220,000 well inspections shows that 3.2% of the wells failed and "showed signs that their walls were leaking" (Lustgarten, 2012a). ProPublica's Abrahm Lustgarten further related, "records also show wells are frequently operated in violation of safety regulations and under conditions that greatly increase the risk of fluid leakage and the threat of water contamination."

According to federal water protection regulation descriptions more than 7,500 well test failures from those three years studied involved *fluid migration* and *significant leaks*, with most of those failures being due to cracks or holes that have damaged the well structure itself (Lustgarten, 2012a). Williams Ellsworth notes that while the current wastewater deep-injection disposal well regulatory framework was designed to protect aquifers and groundwater sources from contamination, the regulations fail to address seismic safety (Ellsworth, 2013).

Because of the *limiting conditions* that we do not necessarily know where the injected wastewater is going and that deep-injection wells fail and leak at an estimated rate of 3.2%, wastewater migrates not only to areas unknown, but also to regions where we specifically do not want it to go: fault zones. These fault zones tend to be located deep beneath the surface in the region of the lithosphere known as the Precambrian Crystalline Basement.

### Fracking Wastewater Injection and Induced Seismology

William Ellsworth noted in his 2013 *Science* study that, "There has been a growing realization that the principal seismic hazard from injection-induced earthquakes comes from those associated with disposal of wastewater into deep strata or basement formations" (Ellsworth, 2013). The operative notion is that in order for seismic activity to be induced, not only does that fault have to be pre-stressed, but it also must be reachable where they are located in the Precambrian crystalline basement by the meandering injected wastewater and its associated fluid pressure. Cliff Frohlich



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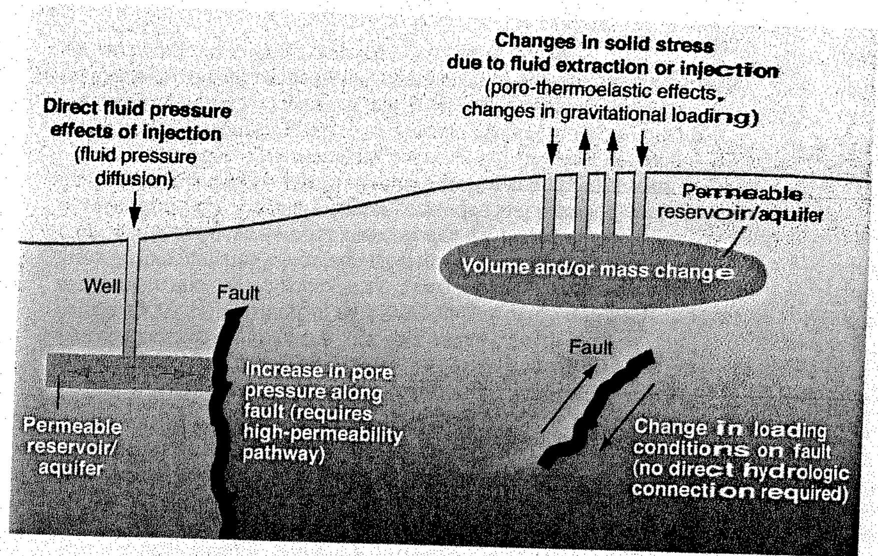


reiterates this point during a 2012 interview, suggesting "fluid injection may trigger earthquakes only if fluids reach and relieve friction on a nearby fault" (Choi, 2012).

A consensus among geologists support the understanding that a vast majority of the fracking wastewater DIDW induced earthquakes did not originate within the sedimentary reservoirs into which the toxic and radioactive fluid was directly injected. Rather this seismicity originated within the generally impermeable metamorphic and igneous crystalline basement that lies 1 to 6 kilometers deeper beneath the sedimentary platform (Horton, 2012; Hsieh and Bredehoeft, 1981; Nicholson and Wesson, 1990; Seeber et al., 2004; Zhang et al., 2013).

Zhang et al., in their 2013 *Groundwater* study, stated that the ever-increasing midcontinent earthquakes "probably occurred along faults that were likely critically stressed within the crystalline basement." More specifically, they found that induced seismic activity was a result of the fracking wastewater either, 1) being injected into a basal sedimentary reservoir that lacks a confining unit underneath the injection reservoir horizon, thus allowing for migration into Precambrian layers, or 2) being injected "directly into the underlying crystalline basement complex" (Zhang et al, 2013).

## Migrating Fluid and Precambrian Crystalline Basements

An essential practical conclusion from the *Groundwater* study (Zhang et al, 2013) is the factor that has the single largest impact in preventing seismic induction within the underlying crystalline basement is the presence of a confining unit barrier between the sedimentary reservoir and the lower Precambrian layer. William Ellsworth describes those injection wells that "dispose of very large volumes of water and/or communicate pressure perturbations directly into basement faults" (Ellsworth, 2013) as problematic disposal wells. Geophysicist Barry Raleigh, whose 1976 *Science* study "An experiment in earthquake control at Rangely, Colorado" demonstrated how earthquakes could be turned on and off by utilizing manipulation of fluid pressure, elucidates that the deep, low-permeability, brittle igneous and metamorphic rock of the crystalline basement "doesn't have a lot of capacity for taking any of these fluids. As a storage medium, they're pretty crappy" (Kerr, 2012).

Readily *felt earthquakes* larger than magnitude 4.0 that have been induced by injection of fracking wastewater into deep disposal wells additionally point to a deeper subterranean origin to these larger earthquakes. "Burdened by far more overlying rock, the deep rock is already carrying stress that," when combined with "the added pressure of the injection trigger," manifests conditions ripe for fault rupture and potentially destructive seismic activity (Kerr, 2012). Zhang et al. (2013) hypothesize that "elevated pore pressures could propagate downward along distributed fracture networks or along conductive fault zones in Precambrian crystalline rocks" (Zhang et al, 2013), meaning that the pressure from fluids can be potentially transmitted to hidden fractures at great depths, given the right conditions. In fact, David M. Evans, in his seminal 1966 *Geotimes* study, relates that even "if the Precambrian fracture system extends to a depth of 12 miles, then fluid pressure could [still] be transmitted to that depth by moderate surface injection pressure as long as the fracture system is open for transmission of that pressure" (Evans, 1966).

## The Long Understood Relationship Between Subterranean Fluid Disposal & Induced Seismology

Some may point to 77 CE Rome for the origins of the human demonstration of the relationship between elevated fluid pressure and induced geological failure, a well-documented case in which Romans utilized the technique to "undermine and instantly remove vast quantities of mountainside to extract gold from the buried mother lode at Las Médulas in northwest Spain" (Goodway, 2012). Others might claim that we have shared this understanding for almost a century, such as members of the Committee on Induced Seismicity Potential in Energy Technologies, who claim that "induced seismic activity has been documented since at least the 1920s" (Clarke et al., 2012), referencing a 1926 study that ran in the *Bulletin of the Seismological Society of America* regarding "Local subsidence of the Goose Creek oil field (Texas)" (Pratt and Johnson, 1926).

While these obscure examples add clarity to this generally familiar yet elusive phenomenon, it is David M. Evans' 1966 *Geotimes* study "Man-made earthquakes in Denver" that is popularly credited with establishing the connection between injection of waste fluids and induced earthquakes (Choi, 2012; Ellsworth, 2013; Frohlich, 2012; Henry, 2012; Kerr, 2012; Soraghan, 2013), such that "since 1966, scientists have generally agreed that injection may induce earthquakes in tectonically favorable situations" (Davis and Frohlich, 1993). Keep in mind that Plate Tectonic Theory did not come into general acceptance until just one-year prior, in 1965, to the verification of this form of human induced earthquake phenomena.

## The Mechanisms Underlying Earthquakes Induced by Fracking Wastewater DIDWs

In regards to the fracking wastewater disposal-induced earthquakes that have been escalating in frequency in the United States' midcontinent over the last decade, U.S. Geological Survey's William Ellsworth concludes that the mechanism responsible for inducing this seismic activity is the "well-understood process of weakening a preexisting fault by elevating the fluid pressure" (Ellsworth, 2013). Ellsworth clarifies that the three specific events that can trigger the nucleation of an earthquake by bringing the fault to failure are, 1) reducing the effective normal stress on a locked fault, 2) increasing the shear stress along a fracture plane, and 3) elevating the pore pressure of the fluid in the rock. Nucleation is the process that marks the beginning of an earthquake with an initial rupture that propagates along the fault surface. Fault failure or slippage can trigger this process, and in turn, generate an earthquake (Ellsworth, 2013).

## Effective Normal Stress and Induced Seismology

If the effective normal stress, the frictional forces that hold a fault a place, is lowered, it can result in fault slippage and trigger earthquake nucleation. Increased fluid pressure relieves enough of squeeze on the fault to release it and induce an earthquake (Kerr, 2012). Injecting fluids that act as a pressurized cushion to relieve the effective normal stress that keeps a fault locked over-pressures a fault (Sheppard et al, 2013). Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory, relates that, "When you over-pressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen" (Earth Institute, 2013).

Effective normal stress is equal to the difference between the applied normal stress and pore pressure (Ellsworth, 2013). Applied normal stress is the total stress on a rock (Hsieh, 1979), or the weight of a given block (Evans, 1966), and pore pressure is the pressure of fluid in the rock's pores and fractures (Ellsworth, 2013), such that

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increased pore pressure causes a decrease in frictional force, the effective normal stress (Warpinski, 2012).

## Shear Stress and Induced Seismology

Raising or increasing the shear stress along a fracture plane can also result in induced seismology, such that once the shear stress overcomes the effective normal stress (multiplied by the coefficient of friction and added to cohesion) in a geological system, the fault will slip, fail, and result in an earthquake (Warpinski, 2012). Faults are locked due to frictional forces, which are the result of in situ stresses pressing vertically on the fault plane. Raising the shearing stress to the point of overcoming effective normal stress such that the fault slips is also known as the Mohr-Coulomb failure criterion. Paul Hsieh, recently named 2011 United States Federal Employee of the Year for his role in bringing to a close the BP oil spill in the Gulf of Mexico, remarks in his pivotal 1979 master's thesis that, "Shearing stresses will remain the same no matter how pore pressure varies. This results from the fact that fluid cannot support any shearing stress" (Hsieh, 1979).

Raleigh and others clarify this direct impact that injecting wastewater has on stressed fractures given its inability to support any shearing stress:

> "The pressurized fluid enters a fracture and supports a part of the normal stress equivalent to the pressure of the fluid. As the fluid has no shear strength, the effective normal stress and the frictional resistance to sliding are lowered. If the fracture is subject to shear stress greater than the product of this effective normal stress and the coefficient of friction, the rocks will slip and generate an earthquake" (Raleigh et al., 1976).

## Pore Pressure and Induced Seismology

Finally, elevating the pore pressure of the fluid in the rock can readily lead to seismic events given the proper conditions, like a stressed fault in contact with pressurized, migrating liquid. As the measure of the pressure of the fluid in the rock's pores and fractures, pore pressure is equal to the difference between applied normal stress and effective normal stress (Ellsworth, 2013). Thus as pore pressure increases, the effective normal stress will decrease. This effective normal stress can also be understood as the frictional resistance against the shearing stress along the fracture plane (Hsieh, 1979). If there is a sufficient enough increase in fluid pressure such that the shearing stress overcomes frictional resistance, the fault will slip and result in an earthquake. This is known as the Hubbert-Rubey mechanism, named after the findings in their seminal 1959 *Geological Society of America Bulletin* study "Role of fluid pressure in mechanics of overthrust faulting," as elucidated by Paul Hsieh:

> "The original work of Hubbert and Rubey (1959) actually concerns the role of pore pressure in the mechanics of overthrust faulting. They introduced the concept of rock movements caused by a Mohr-Coulomb-type failure in a fluid-filled rock environment. This concept was first cited by Evans (1966) in his paper on injection–earthquake relationship and subsequently gained wide acceptance as the mechanism through which injection has caused the earthquakes." (Hsieh, 1979)

In his "A review of theories of mechanisms of induced seismicity" that was published in *Engineering Geology*, Kisslinger relates that fluid injection induced earthquakes "are adequately explained" by a combination of the concept of effective pressure in a water-filled porous mechanism and the Coulomb-Mohr failure criterion, which embodies the three factors and their interrelationship that determines whether or not a particular fracking wastewater injection well will induce earthquakes (Kisslinger, 1976). Kisslinger further concludes that reservoir-related earthquakes, like those caused by fluid injection in bore holes, are induced by the same mechanisms, but in light of the lower injection pressures, "additional physical or chemical effects of the water on the materials may play an important role, [such as] a weakening of the materials in old fault zones by the introduction of water or static fatigue in silicate rocks due to stress corrosion (Kisslinger, 1976).

## How to Turn On and Turn Off Earthquakes: The Parameters of Induced Seismology

Now that it has been clarified what events have to transpire in subterranean realms for earthquakes to be induced by fracking wastewater disposal, the question then becomes *how do these mechanisms relate to specific surface behaviors*? The things that we do above ground that directly impact what happens not only 13,000 feet below the surface, but beneath those sedimentary layers in the Precambrian crystalline basements where faults lie within impervious rock formations.

Davis and Frohlich, in their 1993 *Seismological Research Letters* study "Did (or will) fluid injection cause earthquakes? Criteria for a rational assessment," provide us with a starting point by establishing criteria through which one can determine whether or not a given earthquake was induced by wastewater disposal (Davis & Frohlich, 1993). These criteria "include proximity to injection wells, a change from background seismicity, and a correlation with wastewater injection parameters" (Keranen et al., 2013). These parameters related to wastewater injection referred to by Keranen and others, all of which are ultimately controlled by decisions made and actions taken by the deep-well injection companies on the surface, include fluid pressure, total fluid volume, and rate of fluid injection. As noted by William Ellsworth, "the physical connection between operational parameters such as injected volume" and fluid pressure can be complex (Ellsworth, 2013).

## Fluid Pressure: Inducing Seismology By Exceeding Critical Value

The discovery by David Evans published in his 1966 *Geotimes* study, which led to speculations that earthquakes might be controllable, was that the subterranean high-pressure injection of fluid was responsible for the triggering of earthquakes at the Rocky Mountain Arsenal near Denver, Colorado in the early to mid 1960s. While earthquakes were being induced by the injection of pressurized wastewater into stressed rock formations, the reduction in fluid pressure caused a sharp decrease in frequency of seismic activity (Raleigh et al., 1976). A 1972 *Tectonophysics* study by Healy and others entitled "Prospects for earthquake prediction and control" more explicitly expressed this understanding and laid further groundwork for experimentally testing this hypothesis that, "Changes in fluid pressure may control timing of seismic activity and make it possible to control natural earthquakes by controlling variations in fluid pressure in fault zones" (Healy, et al., 1972).

Raleigh, Healy and Bredehoeft's landmark 1976 *Science* study "An Experiment in Earthquake Control at Rangely, Colorado" did demonstrate the capacity to turn on and turn off earthquakes and "established the correlation between fluid pressure and earthquakes beyond reasonable doubt," that they concluded the "control of the San Andreas fault could ultimately prove to be feasible." However, despite these earth-shattering revelations, perhaps the most important takeaway from these experiments was that, "successful prediction of the approximate pore pressure required for triggering of earthquakes according to the Hubbert-Rubey theory was possible" (Raleigh et al., 1976), as demonstrated by experimental verification of theoretical projections.

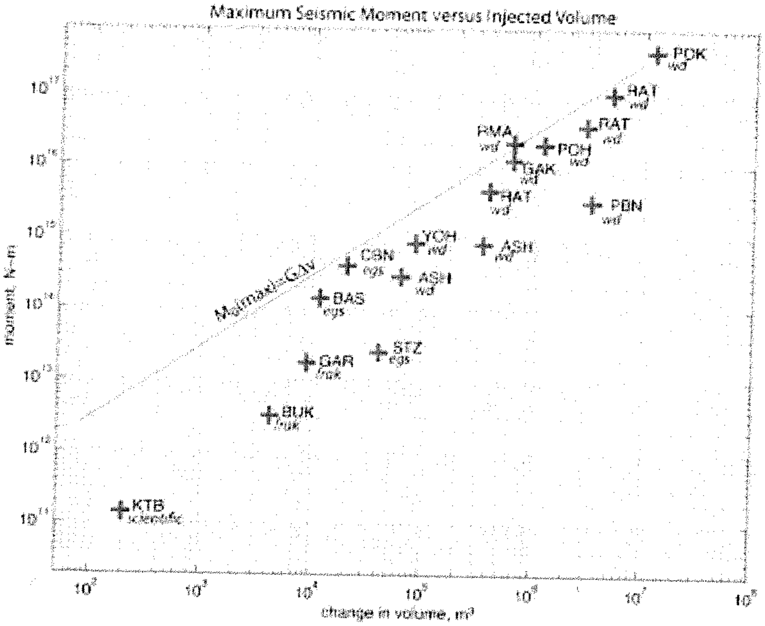
## Predicting Earthquake Behavior, Controlling Earthquakes By Manipulating Fluid Pressure

Utilizing the Mohr-Coulomb failure criterion in applying the Hubbert-Rubey theory, Raleigh and colleagues projected that 257 bars (25.7 MPa) would be the Rangely site's critical fluid pressure. The critical fluid pressure, the pressure required to trigger an earthquake, is governed by the equation:

$\tau_{crit} = \mu(S_n - P_c)$, with

$\tau_{crit}$ = shear stress at failure point,
$\mu$ = coefficient of static friction of the rocks,
$S_n$ = effective normal stress, and
$P_c$ = critical fluid pressure that induces seismicity.

"The fluid pressure required to trigger earthquakes on preexisting fractures" was experimentally tested against the theoretical




projections through use of "laboratory measurements of the frictional properties of the reservoir rocks and an in situ stress measurement made near the earthquake zone" (Raleigh et al., 1976).

Experimental results, which were obtained by varying fluid pressure through the process of "alternately injecting and recovering water from wells that penetrated the seismic zone" (Raleigh et al., 1976), demonstrated that when the injection wells were subjected to fluid pressures above 257 bars the earthquake frequency increased, and when the fluid pressure was less than 257 bars the earthquakes subsided. The idea is that for any given injection well and pre-existing fault situation a critical fluid pressure can be determined, such that "we may ultimately be able to control the timing and the size of major earthquakes [...] wherever we can control the fluid pressure in a fault zone" in relation to that critical fluid pressure (Raleigh et al., 1976).

Hsieh and Bredehoeft (1981), in an expansion of Hsieh's 1979 master's thesis (Hsieh, 1979), analyzed the Rocky Mountain Arsenal injection wells and earthquakes in similar fashion, utilizing Hubbert-Rubey theory to identify the fluid pressure critical value, "the pressure build-up above which earthquakes occur" (Hsieh, 1979). Their conclusion was that, "At the Rocky Mountain Arsenal near Denver, earthquakes occurred within the crystalline basement when the fluid pressures were raised over 320 m above hydrostatic conditions [32 bars, 3.2 MPa] between a depth of about 0.7–7 km (Hsieh and Bredehoeft, 1981; Zhang et al, 2013). Another way to frame this is that the earthquakes were confined strictly to those parts of the reservoir where the pressure build-up exceeded 32 bars (Hsieh, 1979). According to Davis and Frohlich (1993), Hsieh and Bredehoeft's breakthrough was that they were "able to explain the spatial and temporal extent of seismic activity in Denver in terms of the flow of fluids along a permeable semi-infinite rectangular region which approximately contained the activity."

## Total Injected Fluid Volume and Maximum Earthquake Magnitude

The relationship between total fluid volume injected and induced seismology has been noted by many, whether it is the "qualitative correlation between earthquake rates and the injected volume" that has served as a tool for investigating the triggered earthquake phenomena (Oprsal and Eisner, 2013), or the case history-driven evidence suggesting a connection between the total volume of injected wastewater and the maximum induced earthquake magnitude (Hayes, 2012). The U.S. Geological Survey's Art McGarr has compiled the data from these case histories and reports from fracking, waste disposal and geothermal induced seismic events, and has graphed Total Injected Volume vs. Maximum Earthquake Magnitude for 17 different cases of demonstrated fluid disposal triggered earthquakes (Holland and Keller, 2012; Verdon, 2013a; Verdon, 2013b):

| Total Gal. Injected (thousands) | Magnitude Richter Scale | Location |
|---|---|---|
| 53 | 1.4 | Bavaria Germany (KTB) |
| 1,057 | 2.3 | Blackpool, England (BUK) |
| 2,325 | 2.8 | Garvin County, Oklahoma (GAR) |
| 3,170 | 3.4 | Basel, Switzerland (BAS) |
| 9,774 | 3.7 | geothermal at CBN |
| 10,567 | 2.9 | Soultz, France (STZ) |
| 15,850 | 3.6 | Ashtabula, OH (ASH) |
| 21,134 | 3.9 | Youngstown, Ohio (YOH) |
| 89,818 | 3.8 | Ashtabula, OH (ASH) |
| 103,026 | 4.4 | Raton Basin, Colorado (RAT) |
| 158,502 | 4.6 | Guy, Arkansas (GAK) |
| 158,502 | 4.7 | Rocky Mountain Arsenal (RMA) |
| 766,093 | 5.0 | Raton Basin, Colorado (RAT) |
| 845,344 | 4.3 | Paradox Basin, Colorado (PBN) |
| 1,320,850 | 5.3 | Raton Basin, Colorado (RAT) |
| 3,170,040 | 5.7 | Prague, Oklahoma (POK) |

While "McGarr found a relationship between the maximum magnitude of induced earthquakes and the total volume of fluid injected into a site" (Balcerak, 2013), James Verdon reminds us that the McGarr model "is only empirical, there is no real physics behind it" (Verdon, 2013a). McGarr's model does, however, create an interesting framework for further theoretical and experimental work, while also leading to the derivation of the McGarr equation for injection-induced seismicity:

$M_0(max) = G\Delta v$, with

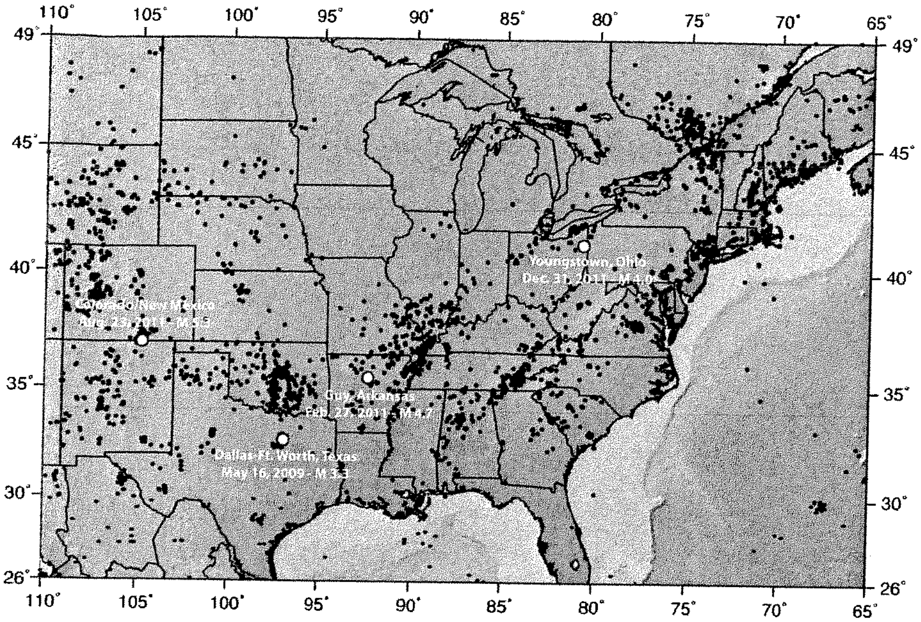
$M_0(max)$ = magnitude of largest seismic moment,
G = shear modulus of rock
(ratio of shear stress to shear strain), and
$\Delta v$ = total volume of fluid injected.

Despite potential shortcomings, Verdon does admit that, "In the meantime, we are left with the empirical McGarr equation as our main guide" (Verdon, 2013a). He also makes certain to clarify: "It should of course be remembered that the McGarr equation does not tell you the maximum magnitude you will get in an operation. [...] The McGarr line tells you the maximum magnitude you could get if you are very unlucky" (Verdon, 2013a). While McGarr continues to clarify the undeniable connection between the total injected fluid volume and the potential maximum magnitude of induced earthquakes, he does not find the rate of fluid injection to impact the magnitude of triggered earthquakes, but rather he found "that the rate of injection of fluid influences the frequency of induced earthquakes" (Balcerak, 2013).

## Rate of Fluid Injection and the Work of Cliff Frohlich

A third surface-controlled parameter that can impact fracking wastewater disposal induced seismicity is that of rate of fluid injection. While the rate of fluid injection and withdrawal played role in the Rangely, Colorado earthquake control experiments (Healy, et al., 1972), few scientists outside of Cliff Frohlich are investigating what he has observed to be a relationship between high rates of fluid injection and induced seismicity. From varies studies of the Barnett Shale play in Texas, Frohlich has found that injection wells nearest induced earthquake groups consistently reported maximum monthly injection rates in excess of 6.34 million gallons (24,000 cubic meters) of fluid, "and generally these injection rates had been maintained for a year or more prior to the onset of earthquake activity" (Frohlich, 2012).

While Frohlich has indicated in interviews that he is very much interested in pursuing this line of inquiry in other fracking wastewater injection regions (Choi, 2012), his own studies have already indicated that other faulted areas demonstrate different maximum monthly injection rates required to induce earthquakes, such as a fluid injection rate of 9.5 to 12.7 million gallons (32,000 to 48,000 cubic meters) per month in the case of Paradox Valley, Colorado (Frohlich et al, 2010). While there is still a lot of research and experimentation required to clarify the precise role of the three surface parameters of fluid pressure, total fluid volume, and rate of




fluid injection in triggering earthquakes, William Ellsworth concurs that experimental results distinctly suggest that these factors all "may be a predictor of seismic potential" (Ellsworth, 2013).

## Conclusion

The mechanisms that underlie fracking wastewater disposal induced earthquakes have been clarified and verified since 1966, making the Hubbert-Rubey theory just a year younger than the theory of plate tectonics and its general acceptance. By capturing the interrelationships between primary earthquake inducement factors that include effective normal stress, shear stress and pore pressure, they set the stage for a couple of decades worth of rich experimentation. All of which became nearly forgotten until fracking industrialization's rude awakening, a literal shaking the foundations of where we work, where we shop and where we live. Luckily, "after a decades long lull in triggered quake studies, researchers are playing catch-up with the latest round of temblors" (Kerr, 2012). And so, in the spirit of existential philosopher Martin Heidegger's conception of truth, we find ourselves in the process of *revealing that which had been concealed.*

One of the great concerns of many of the seismologists and geologists working on this issue is the reality of the earthquake domino effect that have been observed as a result of wastewater injection-induced seismicity. University of Oklahoma seismologist Katie Keranen relates this as the operative scenario in the Prague, Oklahoma magnitude 5.7 earthquake that struck on November 6, 2011: "We had one fault-plane go, a second one, and then a third one. They ruptured in sequence" (Behar, 2013). Lamont-Doherty Earth Observatory seismologist Geoffrey Abers elucidates, "the amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock" (The Earth Institute, 2013).

This is also of great concern to those potentially impacted individuals who live in Southern Illinois, existing between two active seismic zones, the New Madrid and the Wabash. With Southern Illinois facing the promise of mass fracking industrialization and its associated toxic and radioactive wastewater in need of disposal in deep-injection wells, it is not lost on many experts the danger that even small earthquakes can pose in this active seismic region. Geoffrey Abers acknowledges that, "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought (The Earth Institute, 2013). A study conducted by the University of Illinois Mid-America Earthquake Center in 2008 projected that if an earthquake the magnitude of the quakes that hit near New Madrid during 1811-1812 were to strike today, "there would be 3,500 fatalities, 2.6 million people without electricity and $300 billion in direct economic losses. Bridges, docks, highways and water infrastructure would be in shambles" (IEMA, 2013).

If mass fracking industrialization is to take hold of Southern Illinois, a land amidst two active seismic zones, then higher intelligence must be allowed to govern this process, its regulations, and their application. Stanford University geophysicist Mark Zoback answers this call by providing an empirically derived practical framework for reducing the probability of induced seismicity, with five straightforward steps:

(1) It is important to avoid injection into active faults and faults in brittle rock.

(2) Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.

(3) Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.

(4) Protocols should be established in advance to define how operations will be modified if seismicity is triggered.

(5) Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard (Zoback, 2012).

These five steps provide both the state (in the form of regulators) and industry (in the form of operating companies) with a structure for reducing the risks involved in fracking wastewater disposal via deep-injection wells and the induced earthquakes that can accompany their utilization.



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## Shale Plays, Lower 48 States




022525

# The Mechanisms that Connect the Disposal of Fracking Wastewater into Deep-Injection Wells to a Significant Increase in Midcontinent Seismic Activity

by Brent Ritzel [brent@siu.edu]

## Introduction

This paper explores the recent significant increase in *felt earthquakes* in the midcontinent of the United States over the past decade in relation to fracking industrialization and its associated voluminous wastewater disposal needs. Studies and expert insight from geologists and seismologists from over the past fifty years will be utilized in order to render evidenced-based conclusions regarding these matters that have often remained at the opinion level of discourse in the public sphere.

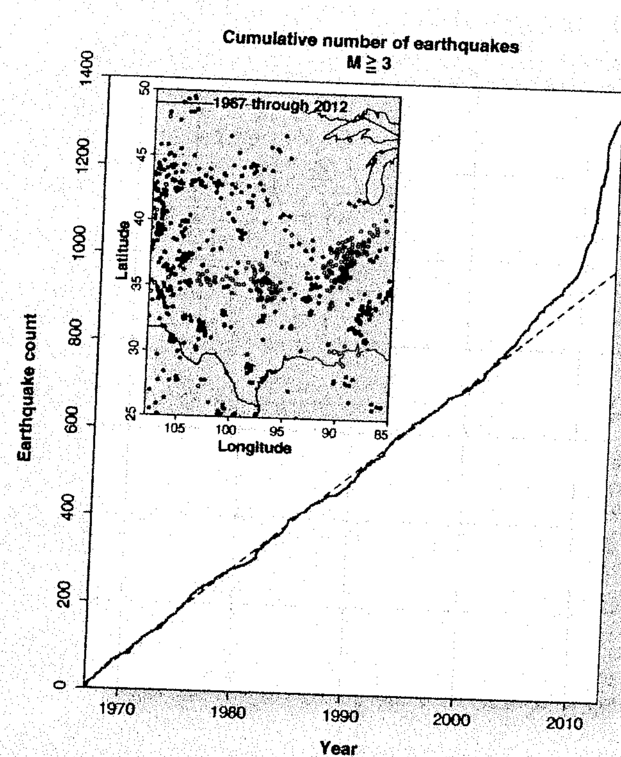
The current extent of U.S. fracking industrialization will be reviewed, including dissection of shale oil and gas production levels, the scale of proliferation of fracking wells, the volume of toxic and radioactive effluent, fracking flowback and produced wastewater disposal needs, and the impact of the exponential growth in deep-injection disposal well usage on the United States' current seismic reality. Two important limiting conditions, the *impervious* unknowns regarding subterranean geological formations *and* the fact that disposal wells will fail and leak, provide context for discussion of our obscured yet viable long term understanding of the mechanisms underlying the whole phenomena of fracking wastewater disposal induced earthquakes.

## Historic Shift in Frequency of Midcontinent Earthquakes

Seismologists like the U.S. Geological Survey's William Ellsworth started noticing a historically unique trend about a dozen years ago, "that there were an unusual number of earthquakes in the middle of the country," in areas that have not been known for earthquakes (Rugh, 2013). The Guy-Greenbrier area of Arkansas, with total population of just over 5,000, was traditionally a quake-free area. Throughout all of 2007 the area had only one earthquake of magnitude 2.5 or greater, followed by only two such quakes in 2008. However, in 2009 there were 10, and in 2010 there were 54 earthquakes of magnitude 2.5 or greater (Kerr, 2012). On February 27, 2011, Guy experienced a magnitude 4.7 earthquake.

Neighboring state Oklahoma went through a similar pattern as a whole, experiencing just a few earthquakes per year from 1972 to 2007, 12 in 2008, 50 in 2009, and more than 1,000 in 2010, culminating with a magnitude 5.7 earthquake on November 6, 2011. While Oklahoma saw a more than hundred-fold increase in overall earthquakes, it also saw a twenty-fold increase in earthquakes with magnitude 3.0 or greater in those same three years from 2008 to 2010 (Ellsworth et al, 2012). Meanwhile, the Barnett Shale region of north central Texas has experienced "unprecedented levels of seismicity" since shale gas development began in late 1998, with "nine earthquakes of magnitude 3.0 or larger occurred, compared with none in the preceding 25 years." Overall, the states reporting unusually elevated levels of seismic activity include Arkansas, Colorado, New Mexico, Ohio, Oklahoma Texas, and Virginia (Ellsworth, 2013).

This pattern seen in both localized and statewide contexts is also reflected in data concerning the frequency of magnitude 3.0 or greater earthquakes in the entire U.S. midcontinent region, with the annual number of magnitude 3.0 or greater earthquakes having "increased almost tenfold in the past decade" (Lovett, 2013). The "middle part of the continent" went from a remarkably consistent average 21 per year from 1970 to 2000, to an average of 29 per year from 2001 to 2008, to 50 magnitude 3.0 or greater quakes in 2009, to 87 in 2010, to somewhere in the range of 134 to 188 in 2011




Cumulative count of earthquakes with magnitude ≥ 3.0 in the central and eastern United States, 1967–2012. The dashed line corresponds to the long-term rate of 21.2 earthquakes/year.
*(Inset)* Distribution of epicenters in the United States midcontinent region.

(Demus, 2012; Ellsworth, 2013; Henry, 2012; Lovett, 2013). As William Ellsworth *et al* (2012) reported in their *Seismological Research Letters* study, "A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region" (Ellsworth et al, 2012). Especially in areas that have historically lacked earthquakes, like the Youngstown, Ohio area, as Columbia University's Lamont-Doherty Earth Observatory seismologist John Armbruster relates, "Having that many earthquakes [...] where there aren't a lot of earthquakes, was suspicious" (Fountain, 2012).

What all these different scenarios share is a common time frame for the onset of fracking industrialization, and an ever-expanding need for deep-injection disposal wells [DIDWs] to handle the massive volumes of associated fracking flowback and produced wastewater. A 2013 *Science* study (van der Elst et al, 2013) by a team of seismologists led by Nicholas van der Elst of Columbia University's Lamont-Doherty Earth Observatory found, "that at least half of the magnitude-4.5 or larger earthquakes that have struck the interior United States in the past decade have occurred near injection-well sites" (Lovett, 2013). A 2013 *Geology* study (Keranen et al., 2013) by a team of seismologists led by Katie Keranen

concluded while earthquakes with magnitude 5.0 or greater are a rarity east of the Rocky Mountains, "the number per year recorded in the midcontinent increased 11-fold between 2008 and 2011, compared to 1976–2007" (Keranen, 2013). When interviewed concerning colleague response to the study, Keranen indicated that, "Pretty much everybody who looks at our data accepts that these events were likely caused by injection" (Behar, 2013).

## Fracking Wastewater Deep-Injection Disposal Wells and Induced Earthquakes: The Jury's Verdict

While speculation and confusion dominate the lay population's conversation regarding the origins of this historic increase in midcontinent earthquakes, there is a strong consensus among geologists and seismologists that the recent uptick in earthquakes is primarily due to the recent increase in fracking industrialization and disposal of its associated wastewater.

William Ellsworth of the U.S. Geological Survey Earthquake Science Center concludes: "Clearly it is happening. Earthquakes have been happening in some unusual parts of the United States. At this point, we do not know if all or just some part of that increase is attributable to industrial activities like wastewater injection" (Vergano, 2013). These risks associated with deep-injection wells inducing earthquakes, which according to Scott Ausbrooks (geologist with the Arkansas Geological Survey) have "been known for decades," are especially heightened in known seismic zones, such as the Wabash and New Madrid Seismic Zones, as "what is clear... is that deep reservoirs in tectonically active zones carry a real risk of inducing damaging earthquakes" (Ellsworth, 2013).

For Cliff Frohlich, senior research scientist at the University of Texas at Austin's Institute for Geophysics, the problem is that faults are ubiquitous, they are most everywhere, and "most of them are stuck, because rock on rock is pretty sticky. But if you pump a fluid in there to reduce the friction, they can slip" (Behar, 2013). Frohlich continues regarding the recent uptick in seismic activity, "These earthquakes could have been anywhere. They weren't. Virtually all of them were near injection wells" (Behar, 2013).

*Popular Science* writer Francie Diep notes a strong consensus among those best equipped to comprehend the situation: "Since companies began doing [wastewater deep-injection] more often, U.S. Geological Survey and other scientists have noticed more earthquakes occurring in the Midwest, which isn't normally so seismically active. Three different geologists told me this, unprompted, when I was researching the Prague quakes earlier this year" (Diep, 2013). Those Prague, Oklahoma earthquakes included the strongest quake in Oklahoma history, a magnitude 5.7 that struck within a mile of three injection wells filled with fluid leftover from conventional oil dewatering operations (Behar, 2013; Holland & Keller, 2012). The quake destroyed 14 homes, injured two individuals, and was felt more than 600 miles away in Chicago (Choi, 2012; Ellsworth, 2013).

While a team of seismologists from Columbia University, University of Oklahoma and the U.S. Geological Survey concurred on the waste-injection origin of the series of quakes (Keranen et al., 2013), United Kingdom-based applied geophysicist James Verdon points out that, "the Oklahoma Geological Survey has subsequently released a rebuttal (Keller & Holland, 2013) stating that as far as it is concerned, there is not enough evidence to tie the quake to injection activities" (Verdon, 2013a).

## Fracking Wastewater DIDWs Are Primary Fracking-Related Seismic Hazard

A team of geologists and seismologists led by William Ellsworth posit in their 2012 study "Are seismicity rate changes in the midcontinent natural or manmade" that the slight increase in seismicity that began in 2001 was primarily due to a Raton Basin coal bed methane field west of Trinidad, Colorado along the Colorado-New Mexico border. They further conclude that the "acceleration in activity that began in 2009 appears to involve a combination of source regions of oil and gas production, including the Guy, Arkansas region, and in central and southern Oklahoma" (Ellsworth et al., 2012).

While some have raised concerned over seismicity related to the fracking event itself, the primary seismic hazard from fracking industrialization is its associated wastewater disposal into Class II deep-injection wells. Shale gas and oil extraction features four behaviors during the entire fracking industrialization life cycle that can induce some degree of seismicity or affect local geological stresses. These include the drilling of wells, the hydraulic fracturing of the shale, the removal of gas and fluids from the well during production, and deep-injection well wastewater disposal (Frohlich et al., 2010).

William Ellsworth points out that with nearly 100,000 wells having been fracked over the last twelve years, the largest induced earthquake from the hydraulic fracturing of the shale was magnitude 3.6, a barely felt earthquake that by itself poses no serious risk.

However, attitudes have shifted regarding wastewater injection induced seismology, as prior to 2011 the seismic event widely accepted by the scientific community as having been the largest wastewater injection induced earthquake in U.S. history was the magnitude 4.8 quake that took place on August 9, 1967 near Denver, Colorado (Ellsworth, 2013). Over the last decade, and especially since 2011, matters have literally shifted.

## Shutting Down of Wells that Induced Earthquakes

Geologists and seismologists are not the only engaged professionals raising concerns about fracking wastewater disposal related induced seismology. State oil and gas officials in both Arkansas and Ohio have shut down fracking wastewater disposal wells that have been connected with induced earthquakes. In the case of induced seismology in the Guy-Greenbrier area or Arkansas, the state's governor, Oil and Gas commission, and the general public all concurred to shut down the responsible injection-wells as, "nearly 1000 recorded quakes had struck the area since the wells had started up" (Kerr, 2012).

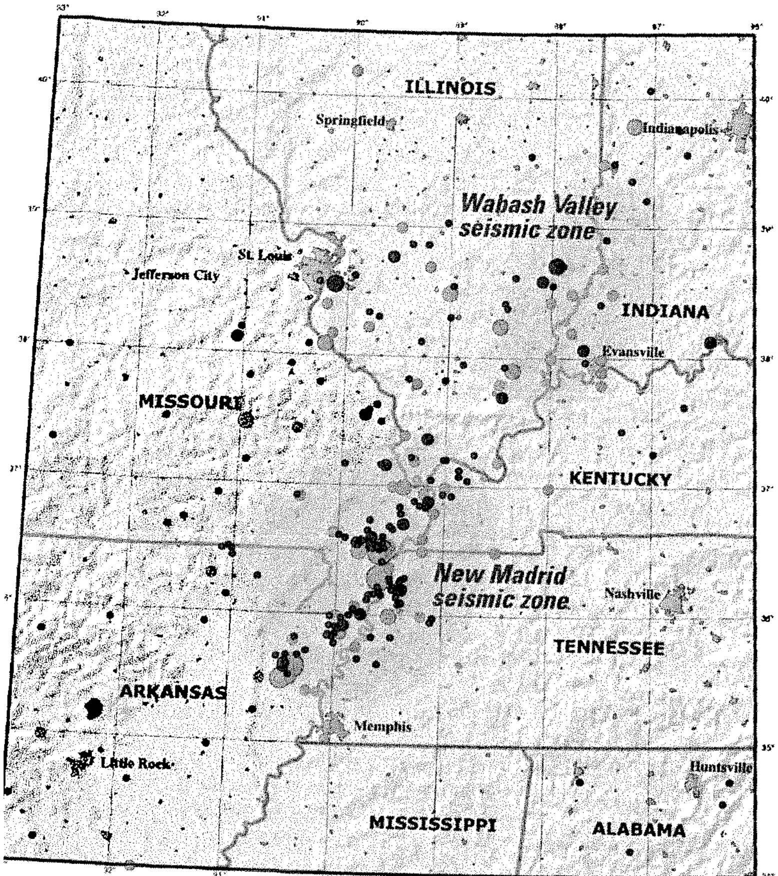
A moratorium was declared within a 1,150 square mile area around Guy-Greenbrier on deep-injection wastewater disposal activities, while seismic-risk studies of the entire Fayetteville shale play were also required. Additionally, "Affected residents filed a class-action lawsuit against Chesapeake Energy and BHP Billiton Petroleum—the first time anyone has sued oil and gas companies for causing an earthquake" (Behar, 2013). University of Memphis seismologist Stephen Horton related that once the wells were shut down the quakes tapered away and ultimately ceased (Kerr, 2012).

## The Youngstown, Ohio Fracking Wastewater Disposal Induced Earthquakes

When a magnitude 2.7 earthquake struck near Youngstown, Ohio on December 24, 2011, it was the tenth such earthquake in the 2.0 to 2.7 magnitude range since March of that year connected with fracking wastewater injection well Northstar 1 owned by D&L Energy Group. The well, which came online in December 2010 (just three months prior to start of seismic activity), received the vast majority of its wastewater from fracking projects in Pennsylvania (Fountain, 2012). Nearly 60% of all the fracking wastewater disposed of in Ohio injection-wells in 2012, 257 million gallons, originated in others states, marking a 19% one-year increase in out-of-state fracking wastewater injected into subterranean Ohio (Johanek, 2013). Prior to January 2011 Youngstown, Ohio had not experienced an earthquake dating back to 1776 when scientists first began recording their observations (Choi, 2013).

Upon analysis of the December 24, 2011 earthquake by the Ohio Department of Natural Resources it was determined that the quake originated less than 2,000 feet below the Northstar 1 well (Fountain, 2012). No sooner had the State of Ohio put an immediate cessation to injection at the well, when an earthquake with a 16 times greater magnitude of 3.9 struck the following week, on New Year's Eve, December 31, 2011. At that point state officials instituted a moratorium on the injection of fracking wastewater within a 5-mile radius of the D&L well until scientists had an opportunity to analyze the data from the string of quakes (Fountain, 2012).

By the time March 2012 rolled around, Youngstown, Ohio had recorded 109 earthquakes in the previous year (Choi, 2013), and "the indications were strong enough to prompt the state to order the




**Red circles** — indicate earthquakes that occurred from 1974 to 2002 with magnitudes larger than 2.5 located using modern instruments. *(University of Memphis)*

**Green circles** — indicate earthquakes that occurred prior to 1974. Larger earthquakes represented by larger circles. *(USGS Professional Paper 1527)*

shutdown of four injection wells in the area and issue strong new regulations" (Kerr, 2012). On July 12, 2012 Executive Order (2012-09K) was signed by Ohio Governor John Kasich, which required that operators conduct seismic studies prior to issuance of well permits (Kasich, 2012). Ohio now stands alone in requiring a seismic-risk assessment for all of its injection wells, as every other state, and the federal government, have yet to do (Behar, 2013).

Seismologist John Armbruster puts points out that within a year of the Northstar 1 well opening there were 109 total earthquakes, and "twelve felt earthquakes. After the well was shut down, the number decreased dramatically. You'd need Powerball odds for that to be a coincidence" (Behar, 2013).

## Proliferation of Shale Gas & Oil Extraction and Fracking Wells

Over the last decade the United States has seen an unprecedented increase in the proliferation of shale gas and oil extraction that has pushed domestic oil to its current place of highest level of production in 20 years, while bringing natural gas production to an all-time high (Weber, 2013). Shale gas from fracking specifically has gone from only 2% of U.S. natural gas production in 2000 to 23% of NG production in 2010 (US EIA, 2012). Because of fracking, the International Energy Agency projects that the U.S. will overtake Russia as the world's top producer of natural gas by 2015.

With this precipitous increase in shale oil and gas production, the U.S. has likewise seen an increase in the proliferation of fracking wells, with more than 82,000 drilled or permitted in 17 states between 2005 and 2012. At the time of this writing (November of 2013) there are likely in excess of 100,000 fracking wells permitted or drilled in the U.S. (Ellsworth, 2013). In 2012 alone there were 22,326 fracking wells drilled throughout the United States, with more than 60% of them (13,540) being drilled in Texas (Ridlington & Rumpler, 2013). During that year drilling inspectors identified more than 55,000 violations of Texas fracking laws by oil and gas companies (Soraghan, 2013a).

## Wastewater Associated with Fracking Industrialization

This dramatic increase in oil and gas production and associated fracking wells has in turn led to an increase in the need for fracking-related wastewater disposal. Each fracked well requires approximately 4 to 7 million gallons of water, fracking fluid and fracking sand to complete a hydraulic fracturing event. In the range of 20% to 80% of the fluid injected during the fracking event, an average of 2.75 million gallons of toxic and radioactive effluent per well ((Hammer & Van Briesen, 2012), returns to the surface as fracking flowback and wastewater (Miller, 2012; Moss, 2008).

The volume of wastewater to be disposed of during the fracking process is one factor that makes fracking industrialization different from anything other form of fossil fuel extraction that has been seen before, producing "50 to 100 times more" waste than conventional oil and gas wells (Cantarow, 2013). Multiply that level of industrialization in terms of number of wells, by that degree of waste management in terms of the volumes of toxic and radioactive effluent per fracked well, and the result is 280 billions gallons of total flowback and produced wastewater coming out of U.S. fracking wells each year (Ridlington & Rumpler, 2013). Unfortunately, these national numbers are woefully incomplete as wastewater produced by Texas alone represents nearly 93% of this total (260 billion gallons), and there was "no estimate" listed for seven of the seventeen fracking states included in the survey.

The shift over the last decade is undeniable, as an overwhelmed Marcellus Shale wastewater disposal infrastructure capacity can attest to, in that "developing the Marcellus shale has increased the total wastewater generated in the region by ~570%" between 2004 and 2012. This of course is a natural consequence of fracking industrialization, as toxic and radioactive wastewater "is an obligate byproduct of current methods and volumes will unavoidably increase with industry expansion" (Lutz et al, 2013).

## Various Methods for Disposing of Fracking Wastewater

While there are current alternatives to deep-well injection for disposing of fracking wastewater, scientists and regulators alike agree that the other options are generally far more expensive while embodying additional environmental risks (Lustgarten, 2013a). These alternatives, the first three of which have been utilized extensively in the Marcellus region due to lack of suitable geology for underground injection (MSAC, 2011), include: (1) Processing of wastewater at municipal wastewater treatment facility with final discharge into a local waterway; (2) Processing of wastewater at a private industrial wastewater facility, with either discharge into a local waterway or reuse of the treated effluent in fracking wells; (3) Recycling of wastewater and reuse of the partially treated effluent in fracking wells; (4) Burning of waste; (5) Disposal of waste by application on roadways and other surfaces (Lutz et al, 2013; Lustgarten, 2012a); and unfortunately, (6) "Fracking flowback is dumped into rivers, lakes and reservoirs" (Eco Watch, 2013).

Cliff Frohlich, senior research scientist at University of Texas at Austin's Institute for Geophysics, reminds us that "the people involved in this are going to do the cheapest way of doing things that is generally considered safe" (Henry, 2012a), and that is currently why more than 95% of fracking wastewater is injected into deep wells (Clark and Veil, 2009). Journalist Abrahm Lustgarten, however, reminds us that, "several key experts acknowledged that the idea that injection is safe rests on science that has not kept pace with reality, and on oversight that doesn't always work (Lustgarten, 2012a). It is not just the energy sector that is dependent on this form of waste elimination, as subterranean waste disposal is a cornerstone of the U.S. economy, with pharmaceutical, chemical and agricultural industries all being dependent upon deep-well injection for managing voluminous waste streams. Even carbon storage and sequestration that is the essential fossil fuel industry strategy for addressing climate change, as Lustgarten points out, "counts on pushing waste into rock

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formations below the earth's surface" (Lustgarten, 2012a).

## Fracking Wastewater in Deep-Injection Disposal Wells

As there has been a monumental increase in total fracking-related wastewater produced over the last decade, there has likewise been a dramatic increase in total fracking wastewater injected into disposal wells, where 95% of the toxic effluent is managed. Of the more than 680,000 total injection wells in the United States, in excess of 150,000 fall into the energy industry-specific Class II category that includes both deep-disposal wells in addition to "wells in which fluids are injected to force out trapped oil and gas" (Lustgarten, 2012a). Approximately 30,000 to 40,000 of these Class II wells are deep-disposal wells that receive the volumes of fracking flowback and produced wastewater (Diep, 2013; Ellsworth, 2013; Soraghan, 2013). The states with the most Class II injection wells are Texas (52,016), California (29,505), Kansas (16,658), Oklahoma (10,629), and Illinois (7,843) (US EPA, 2010).

A study by the Argonne National Laboratory estimated that a total of 252 billion gallons of fracking wastewater is injected into Class II deep disposal wells in the United States per year (Clark and Veil, 2009; Clarke et al., 2012). In Texas the total amount of fracking wastewater being injected into deep disposal wells went from 46 million barrels (1.45 billion gallons) in 2005 to nearly 3.5 billion barrels (110.25 billion gallons) in 2011, representing a 76-fold increase in total fracking wastewater injection volume in a six-year period (Galbraith and Henry, 2013). The total amount injected into the more than 150,000 total Class II wells among 33 states is at least 10 trillion gallons of wastewater (Lustgarten, 2012c), while over the last several decades all U.S. industries combined have injected in excess of 30 trillion gallons of toxic liquid into all classes of injection wells, "using broad expanses of the nation's geology as an invisible dumping ground" (Lustgarten, 2012a).

## Wastewater Injection Induced Earthquakes – Factors That Increase Risk

As fracking wastewater injection has dramatically increased over the last decade, so have induced earthquakes, as elucidated by Cliff Frohlich: "The earthquakes are occurring more frequently now because there's so much more fluid injection due to the fracking and the development of unconventional gas. [...] So what's happened is that we have a lot more injection going on in a lot more places, where we're producing more gas and earthquakes" (Henry, 2012a). While most of the United States' 40,000 wastewater injection wells will never cause felt seismic activity, some have and will induce earthquakes in excess of 3.0, and so far, as great as 5.7 (Diep, 2013; Ellsworth, 2013).

The USGS's Williams Ellsworth identifies a number of factors that could enhance the probability of a given injection-well inducing earthquakes in his 2013 *Science* study. They include, "the magnitude of the perturbation, its spatial extent, ambient stress condition close to the failure condition, and the presence of faults well oriented for failure in the tectonic stress field. Hydraulic connection between the injection zone and faults in the basement may also favor inducing earthquakes, as the tectonic shear stress increases with depth in the brittle crust" (Ellsworth, 2013).

Frohlich likewise stresses that it is absolutely essential to "understand why some injection wells trigger seismic activity and others do not," especially when they seemingly have similar mechanical and geological characteristics. He hypothesizes that "injection only triggers earthquakes if injected fluids reach and relieve friction on a suitably oriented, nearby fault that is experiencing regional tectonic stress" (Frohlich, 2012), such that "the materials must be pre-stressed to a substantial fraction of their breaking strength in order for seismicity to be induced" (Kisslinger, 1976). The specific mechanisms involved in fluid-relieved friction on a locked fault will be explored in greater detail below.

## Limiting Condition 1: We Don't Exactly Know What Is Going On Down There

In light of these risk factors identified by Ellsworth and Frohlich, there are two major *limiting conditions* that can significantly contribute to fault rupture and earthquake inducement from fracking wastewater's injection into deep disposal wells. The first is that we do not necessarily know where the injected wastewater is going, and what subterranean pathways it might be following, especially in relation to pre-existing faults both known and unknown. The second is that wells can, and do, fail and leak.

Class II injection wells in practice do not have detailed geologic reviews performed, so there is not particularly any understanding regarding what the well opens up to as much as two and a half miles beneath the surface, including the location of possible faults (Clarke et al., 2012). ProPublica investigative reporter Abrahm Lustgarten captures this reality of disposal well structure: "Tubes of concrete and steel extend anywhere from a few hundred feet to two miles into the earth. At the bottom, the well opens into a natural rock formation. There is no container. Waste simply seeps out, filling tiny spaces left between the grains in the rock like the gaps between stacked marbles" (Lustgarten, 2012a).

The high wellhead pressures applied to inject millions of gallons of fracking wastewater into these deep recesses are sometimes in excess of 50 MPa (493 atmospheres or 7,250 psi) (Hsieh, 1979; Zhang et al, 2013). Injection pressures that high "may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers" (Lustgarten, 2012b). As Scott Ausbrooks, a geologist with the Arkansas Geological Survey, points out, water will eventually find a way out: "Water does not like to be squeezed. Just like a room of people. The more you put in, the more crowded it gets, and at some point, people are going to start being pushed out the doors" (Behar, 2013). Cliff Frohlich describes the wastewater as being forced "downward and outward" from excessive injection, adding that fracking's toxic effluent "can meander for months, creeping into unknown faults and prying the rock apart just enough to release pent-up energy" (Behar, 2013).

## Limiting Condition 2: Deep-Injection Disposal Wells Will Fail and Leak

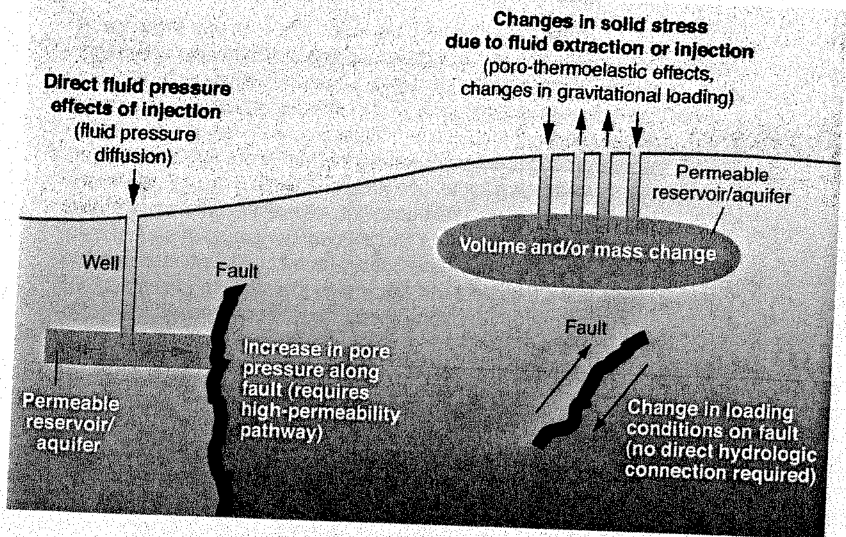
While scientists and federal regulators generally acknowledge they do not know how many of the Class II injection well sites receiving fracking wastewater are leaking, a ProPublica analysis of EPA data and case histories from October 2007 to October 2010 regarding more than 220,000 well inspections shows that 3.2% of the wells failed and "showed signs that their walls were leaking" (Lustgarten, 2012a). ProPublica's Abrahm Lustgarten further related, "records also show wells are frequently operated in violation of safety regulations and under conditions that greatly increase the risk of fluid leakage and the threat of water contamination."

According to federal water protection regulation descriptions more than 7,500 well test failures from those three years studied involved *fluid migration* and *significant leaks*, with most of those failures being due to cracks or holes that have damaged the well structure itself (Lustgarten, 2012a). Williams Ellsworth notes that while the current wastewater deep-injection disposal well regulatory framework was designed to protect aquifers and groundwater sources from contamination, the regulations fail to address seismic safety (Ellsworth, 2013).

Because of the *limiting conditions* that we do not necessarily know where the injected wastewater is going and that deep-injection wells fail and leak at an estimated rate of 3.2%, wastewater migrates not only to areas unknown, but also to regions where we specifically do not want it to go: fault zones. These fault zones tend to be located deep beneath the surface in the region of the lithosphere known as the Precambrian Crystalline Basement.

## Fracking Wastewater Injection and Induced Seismology

William Ellsworth noted in his 2013 *Science* study that, "There has been a growing realization that the principal seismic hazard from injection-induced earthquakes comes from those associated with disposal of wastewater into deep strata or basement formations" (Ellsworth, 2013). The operative notion is that in order for seismic activity to be induced, not only does that fault have to be pre-stressed, but it also must be reachable where they are located in the Precambrian crystalline basement by the meandering injected wastewater and its associated fluid pressure. Cliff Frohlich




reiterates this point during a 2012 interview, suggesting "fluid injection may trigger earthquakes only if fluids reach and relieve friction on a nearby fault" (Choi, 2012).

A consensus among geologists support the understanding that a vast majority of the fracking wastewater DIDW induced earthquakes did not originate within the sedimentary reservoirs into which the toxic and radioactive fluid was directly injected. Rather this seismicity originated within the generally impermeable metamorphic and igneous crystalline basement that lies 1 to 6 kilometers deeper beneath the sedimentary platform (Horton, 2012; Hsieh and Bredehoeft, 1981; Nicholson and Wesson, 1990; Seeber et al., 2004; Zhang et al., 2013).

Zhang et al., in their 2013 *Groundwater* study, stated that the ever-increasing midcontinent earthquakes "probably occurred along faults that were likely critically stressed within the crystalline basement." More specifically, they found that induced seismic activity was a result of the fracking wastewater either, 1) being injected into a basal sedimentary reservoir that lacks a confining unit underneath the injection reservoir horizon, thus allowing for migration into Precambrian layers, or 2) being injected "directly into the underlying crystalline basement complex" (Zhang et al, 2013).

## Migrating Fluid and Precambrian Crystalline Basements

An essential practical conclusion from the *Groundwater* study (Zhang et al, 2013) is the factor that has the single largest impact in preventing seismic induction within the underlying crystalline basement is the presence of a confining unit barrier between the sedimentary reservoir and the lower Precambrian layer. William Ellsworth describes those injection wells that "dispose of very large volumes of water and/or communicate pressure perturbations directly into basement faults" (Ellsworth, 2013) as problematic disposal wells. Geophysicist Barry Raleigh, whose 1976 *Science* study "An experiment in earthquake control at Rangely, Colorado" demonstrated how earthquakes could be turned on and off by utilizing manipulation of fluid pressure, elucidates that the deep, low-permeability, brittle igneous and metamorphic rock of the crystalline basement "doesn't have a lot of capacity for taking any of these fluids. As a storage medium, they're pretty crappy" (Kerr, 2012).

Readily *felt earthquakes* larger than magnitude 4.0 that have been induced by injection of fracking wastewater into deep disposal wells additionally point to a deeper subterranean origin to these larger earthquakes. "Burdened by far more overlying rock, the deep rock is already carrying stress that," when combined with "the added pressure of the injection trigger," manifests conditions ripe for fault rupture and potentially destructive seismic activity (Kerr, 2012). Zhang et al. (2013) hypothesize that "elevated pore pressures could propagate downward along distributed fracture networks or along conductive fault zones in Precambrian crystalline rocks" (Zhang et al, 2013), meaning that the pressure from fluids can be potentially transmitted to hidden fractures at great depths, given the right conditions. In fact, David M. Evans, in his seminal 1966 *Geotimes* study, relates that even "if the Precambrian fracture system extends to a depth of 12 miles, then fluid pressure could [still] be transmitted to that depth by moderate surface injection pressure as long as the fracture system is open for transmission of that pressure" (Evans, 1966).

## The Long Understood Relationship Between Subterranean Fluid Disposal & Induced Seismology

Some may point to 77 CE Rome for the origins of the human demonstration of the relationship between elevated fluid pressure and induced geological failure, a well-documented case in which Romans utilized the technique to "undermine and instantly remove vast quantities of mountainside to extract gold from the buried mother lode at Las Médulas in northwest Spain" (Goodway, 2012). Others might claim that we have shared this understanding for almost a century, such as members of the Committee on Induced Seismicity Potential in Energy Technologies, who claim that "induced seismic activity has been documented since at least the 1920s" (Clarke et al., 2012), referencing a 1926 study that ran in the *Bulletin of the Seismological Society of America* regarding "Local subsidence of the Goose Creek oil field (Texas)" (Pratt and Johnson, 1926).

While these obscure examples add clarity to this generally familiar yet elusive phenomenon, it is David M. Evans' 1966 *Geotimes* study "Man-made earthquakes in Denver" that is popularly credited with establishing the connection between injection of waste fluids and induced earthquakes (Choi, 2012; Ellsworth, 2013; Frohlich, 2012; Henry, 2012; Kerr, 2012; Soraghan, 2013), such that "since 1966, scientists have generally agreed that injection may induce earthquakes in tectonically favorable situations" (Davis and Frohlich, 1993). Keep in mind that Plate Tectonic Theory did not come into general acceptance until just one-year prior, in 1965, to the verification of this form of human induced earthquake phenomena.

## The Mechanisms Underlying Earthquakes Induced by Fracking Wastewater DIDWs

In regards to the fracking wastewater disposal-induced earthquakes that have been escalating in frequency in the United States' midcontinent over the last decade, U.S. Geological Survey's William Ellsworth concludes that the mechanism responsible for inducing this seismic activity is the "well-understood process of weakening a preexisting fault by elevating the fluid pressure" (Ellsworth, 2013). Ellsworth clarifies that the three specific events that can trigger the nucleation of an earthquake by bringing the fault to failure are, 1) reducing the effective normal stress on a locked fault, 2) increasing the shear stress along a fracture plane, and 3) elevating the pore pressure of the fluid in the rock. Nucleation is the process that marks the beginning of an earthquake with an initial rupture that propagates along the fault surface. Fault failure or slippage can trigger this process, and in turn, generate an earthquake (Ellsworth, 2013).

## Effective Normal Stress and Induced Seismology

If the effective normal stress, the frictional forces that hold a fault a place, is lowered, it can result in fault slippage and trigger earthquake nucleation. Increased fluid pressure relieves enough of squeeze on the fault to release it and induce an earthquake (Kerr, 2012). Injecting fluids that act as a pressurized cushion to relieve the effective normal stress that keeps a fault locked over-pressures a fault (Sheppard et al, 2013). Heather Savage, a geophysicist at Columbia University's Lamont-Doherty Earth Observatory, relates that, "When you over-pressure the fault, you reduce the stress that's pinning the fault into place and that's when earthquakes happen" (Earth Institute, 2013).

Effective normal stress is equal to the difference between the applied normal stress and pore pressure (Ellsworth, 2013). Applied normal stress is the total stress on a rock (Hsieh, 1979), or the weight of a given block (Evans, 1966), and pore pressure is the pressure of fluid in the rock's pores and fractures (Ellsworth, 2013), such that

increased pore pressure causes a decrease in frictional force, the effective normal stress (Warpinski, 2012).

## Shear Stress and Induced Seismology

Raising or increasing the shear stress along a fracture plane can also result in induced seismology, such that once the shear stress overcomes the effective normal stress (multiplied by the coefficient of friction and added to cohesion) in a geological system, the fault will slip, fail, and result in an earthquake (Warpinski, 2012). Faults are locked due to frictional forces, which are the result of in situ stresses pressing vertically on the fault plane. Raising the shearing stress to the point of overcoming effective normal stress such that the fault slips is also known as the Mohr-Coulomb failure criterion. Paul Hsieh, recently named 2011 United States Federal Employee of the Year for his role in bringing to a close the BP oil spill in the Gulf of Mexico, remarks in his pivotal 1979 master's thesis that, "Shearing stresses will remain the same no matter how pore pressure varies. This results from the fact that fluid cannot support any shearing stress" (Hsieh, 1979).

Raleigh and others clarify this direct impact that injecting wastewater has on stressed fractures given its inability to support any shearing stress:

> "The pressurized fluid enters a fracture and supports a part of the normal stress equivalent to the pressure of the fluid. As the fluid has no shear strength, the effective normal stress and the frictional resistance to sliding are lowered. If the fracture is subject to shear stress greater than the product of this effective normal stress and the coefficient of friction, the rocks will slip and generate an earthquake" (Raleigh et al., 1976).

## Pore Pressure and Induced Seismology

Finally, elevating the pore pressure of the fluid in the rock can readily lead to seismic events given the proper conditions, like a stressed fault in contact with pressurized, migrating liquid. As the measure of the pressure of the fluid in the rock's pores and fractures, pore pressure is equal to the difference between applied normal stress and effective normal stress (Ellsworth, 2013). Thus as pore pressure increases, the effective normal stress will decrease. This effective normal stress can also be understood as the frictional resistance against the shearing stress along the fracture plane (Hsieh, 1979). If there is a sufficient enough increase in fluid pressure such that the shearing stress overcomes frictional resistance, the fault will slip and result in an earthquake. This is known as the Hubbert-Rubey mechanism, named after the findings in their seminal 1959 *Geological Society of America Bulletin* study "Role of fluid pressure in mechanics of overthrust faulting," as elucidated by Paul Hsieh:

> "The original work of Hubbert and Rubey (1959) actually concerns the role of pore pressure in the mechanics of overthrust faulting. They introduced the concept of rock movements caused by a Mohr-Coulomb-type failure in a fluid-filled rock environment. This concept was first cited by Evans (1966) in his paper on injection–earthquake relationship and subsequently gained wide acceptance as the mechanism through which injection has caused the earthquakes." (Hsieh, 1979)

In his "A review of theories of mechanisms of induced seismicity" that was published in *Engineering Geology*, Kisslinger relates that fluid injection induced earthquakes "are adequately explained" by a combination of the concept of effective pressure in a water-filled porous mechanism and the Coulomb-Mohr failure criterion, which embodies the three factors and their interrelationship that determines whether or not a particular fracking wastewater injection well will induce earthquakes (Kisslinger, 1976). Kisslinger further concludes that reservoir-related earthquakes, like those caused by fluid injection in bore holes, are induced by the same mechanisms, but in light of the lower injection pressures, "additional physical or chemical effects of the water on the materials may play an important role, [such as] a weakening of the materials in old fault zones by the introduction of water or static fatigue in silicate rocks due to stress corrosion (Kisslinger, 1976).

## How to Turn On and Turn Off Earthquakes: The Parameters of Induced Seismology

Now that it has been clarified what events have to transpire in subterranean realms for earthquakes to be induced by fracking wastewater disposal, the question then becomes *how do these mechanisms relate to specific surface behaviors*? The things that we do above ground that directly impact what happens not only 13,000 feet below the surface, but beneath those sedimentary layers in the Precambrian crystalline basements where faults lie within impervious rock formations.

Davis and Frohlich, in their 1993 *Seismological Research Letters* study "Did (or will) fluid injection cause earthquakes? Criteria for a rational assessment," provide us with a starting point by establishing criteria through which one can determine whether or not a given earthquake was induced by wastewater disposal (Davis & Frohlich, 1993). These criteria "include proximity to injection wells, a change from background seismicity, and a correlation with wastewater injection parameters" (Keranen et al., 2013). These parameters related to wastewater injection referred to by Keranen and others, all of which are ultimately controlled by decisions made and actions taken by the deep-well injection companies on the surface, include fluid pressure, total fluid volume, and rate of fluid injection. As noted by William Ellsworth, "the physical connection between operational parameters such as injected volume" and fluid pressure can be complex (Ellsworth, 2013).

## Fluid Pressure: Inducing Seismology By Exceeding Critical Value

The discovery by David Evans published in his 1966 *Geotimes* study, which led to speculations that earthquakes might be controllable, was that the subterranean high-pressure injection of fluid was responsible for the triggering of earthquakes at the Rocky Mountain Arsenal near Denver, Colorado in the early to mid 1960s. While earthquakes were being induced by the injection of pressurized wastewater into stressed rock formations, the reduction in fluid pressure caused a sharp decrease in frequency of seismic activity (Raleigh et al., 1976). A 1972 *Tectonophysics* study by Healy and others entitled "Prospects for earthquake prediction and control" more explicitly expressed this understanding and laid further groundwork for experimentally testing this hypothesis that, "Changes in fluid pressure may control timing of seismic activity and make it possible to control natural earthquakes by controlling variations in fluid pressure in fault zones" (Healy, et al., 1972).

Raleigh, Healy and Bredehoeft's landmark 1976 *Science* study "An Experiment in Earthquake Control at Rangely, Colorado" did demonstrate the capacity to turn on and turn off earthquakes and "established the correlation between fluid pressure and earthquakes beyond reasonable doubt," that they concluded the "control of the San Andreas fault could ultimately prove to be feasible." However, despite these earth-shattering revelations, perhaps the most important takeaway from these experiments was that, "successful prediction of the approximate pore pressure required for triggering of earthquakes according to the Hubbert-Rubey theory was possible" (Raleigh et al., 1976), as demonstrated by experimental verification of theoretical projections.

## Predicting Earthquake Behavior, Controlling Earthquakes By Manipulating Fluid Pressure

Utilizing the Mohr-Coulomb failure criterion in applying the Hubbert-Rubey theory, Raleigh and colleagues projected that 257 bars (25.7 MPa) would be the Rangely site's critical fluid pressure. The critical fluid pressure, the pressure required to trigger an earthquake, is governed by the equation:

$\tau_{crit} = \mu(S_n - P_c)$, with

- $\tau_{crit}$ = shear stress at failure point,
- $\mu$ = coefficient of static friction of the rocks,
- $S_n$ = effective normal stress, and
- $P_c$ = critical fluid pressure that induces seismicity.

"The fluid pressure required to trigger earthquakes on preexisting fractures" was experimentally tested against the theoretical



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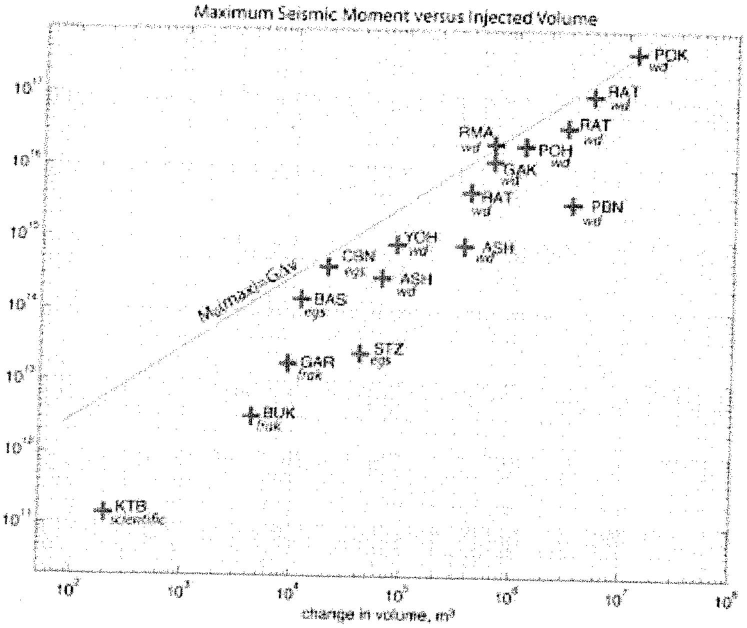



projections through use of "laboratory measurements of the frictional properties of the reservoir rocks and an in situ stress measurement made near the earthquake zone" (Raleigh et al., 1976).

Experimental results, which were obtained by varying fluid pressure through the process of "alternately injecting and recovering water from wells that penetrated the seismic zone" (Raleigh et al., 1976), demonstrated that when the injection wells were subjected to fluid pressures above 257 bars the earthquake frequency increased, and when the fluid pressure was less than 257 bars the earthquakes subsided. The idea is that for any given injection well and pre-existing fault situation a critical fluid pressure can be determined, such that "we may ultimately be able to control the timing and the size of major earthquakes [...] wherever we can control the fluid pressure in a fault zone" in relation to that critical fluid pressure (Raleigh et al., 1976).

Hsieh and Bredehoeft (1981), in an expansion of Hsieh's 1979 master's thesis (Hsieh, 1979), analyzed the Rocky Mountain Arsenal injection wells and earthquakes in similar fashion, utilizing Hubbert-Rubey theory to identify the fluid pressure critical value, "the pressure build-up above which earthquakes occur" (Hsieh, 1979). Their conclusion was that, "At the Rocky Mountain Arsenal near Denver, earthquakes occurred within the crystalline basement when the fluid pressures were raised over 320 m above hydrostatic conditions [32 bars, 3.2 MPa] between a depth of about 0.7–7 km (Hsieh and Bredehoeft, 1981; Zhang et al, 2013). Another way to frame this is that the earthquakes were confined strictly to those parts of the reservoir where the pressure build-up exceeded 32 bars (Hsieh, 1979). According to Davis and Frohlich (1993), Hsieh and Bredehoeft's breakthrough was that they were "able to explain the spatial and temporal extent of seismic activity in Denver in terms of the flow of fluids along a permeable semi-infinite rectangular region which approximately contained the activity."

## Total Injected Fluid Volume and Maximum Earthquake Magnitude

The relationship between total fluid volume injected and induced seismology has been noted by many, whether it is the "qualitative correlation between earthquake rates and the injected volume" that has served as a tool for investigating the triggered earthquake phenomena (Oprsal and Eisner, 2013), or the case history-driven evidence suggesting a connection between the total volume of injected wastewater and the maximum induced earthquake magnitude (Hayes, 2012). The U.S. Geological Survey's Art McGarr has compiled the data from these case histories and reports from fracking, waste disposal and geothermal induced seismic events, and has graphed Total Injected Volume vs. Maximum Earthquake Magnitude for 17 different cases of demonstrated fluid disposal triggered earthquakes (Holland and Keller, 2012; Verdon, 2013a; Verdon, 2013b):

| Total Gal. Injected (thousands) | Magnitude Richter Scale | Location |
|---|---|---|
| 53 | 1.4 | Bavaria Germany (KTB) |
| 1,057 | 2.3 | Blackpool, England (BUK) |
| 2,325 | 2.8 | Garvin County, Oklahoma (GAR) |
| 3,170 | 3.4 | Basel, Switzerland (BAS) |
| 9,774 | 3.7 | geothermal at CBN |
| 10,567 | 2.9 | Soultz, France (STZ) |
| 15,850 | 3.6 | Ashtabula, OH (ASH) |
| 21,134 | 3.9 | Youngstown, Ohio (YOH) |
| 89,818 | 3.8 | Ashtabula, OH (ASH) |
| 103,026 | 4.4 | Raton Basin, Colorado (RAT) |
| 158,502 | 4.6 | Guy, Arkansas (GAK) |
| 158,502 | 4.7 | Rocky Mountain Arsenal (RMA) |
| 766,093 | 5.0 | Raton Basin, Colorado (RAT) |
| 845,344 | 4.3 | Paradox Basin, Colorado (PBN) |
| 1,320,850 | 5.3 | Raton Basin, Colorado (RAT) |
| 3,170,040 | 5.7 | Prague, Oklahoma (POK) |

While "McGarr found a relationship between the maximum magnitude of induced earthquakes and the total volume of fluid injected into a site" (Balcerak, 2013), James Verdon reminds us that the McGarr model "is only empirical, there is no real physics behind it" (Verdon, 2013a). McGarr's model does, however, create an interesting framework for further theoretical and experimental work, while also leading to the derivation of the McGarr equation for injection-induced seismicity:

$M_0(max) = G\Delta v$, with

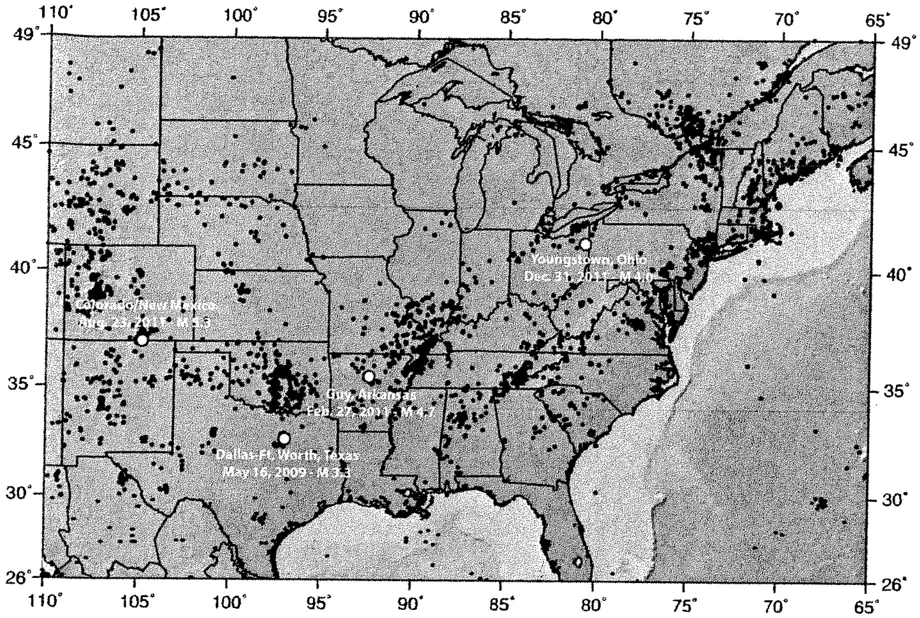
$M_0(max)$ = magnitude of largest seismic moment,
G = shear modulus of rock
(ratio of shear stress to shear strain), and
$\Delta v$ = total volume of fluid injected.

Despite potential shortcomings, Verdon does admit that, "In the meantime, we are left with the empirical McGarr equation as our main guide" (Verdon, 2013a). He also makes certain to clarify: "It should of course be remembered that the McGarr equation does not tell you the maximum magnitude you will get in an operation. [...] The McGarr line tells you the maximum magnitude you could get if you are very unlucky" (Verdon, 2013a). While McGarr continues to clarify the undeniable connection between the total injected fluid volume and the potential maximum magnitude of induced earthquakes, he does not find the rate of fluid injection to impact the magnitude of triggered earthquakes, but rather he found "that the rate of injection of fluid influences the frequency of induced earthquakes" (Balcerak, 2013).

## Rate of Fluid Injection and the Work of Cliff Frohlich

A third surface-controlled parameter that can impact fracking wastewater disposal induced seismicity is that of rate of fluid injection. While the rate of fluid injection and withdrawal played role in the Rangely, Colorado earthquake control experiments (Healy, et al., 1972), few scientists outside of Cliff Frohlich are investigating what he has observed to be a relationship between high rates of fluid injection and induced seismicity. From varies studies of the Barnett Shale play in Texas, Frohlich has found that injection wells nearest induced earthquake groups consistently reported maximum monthly injection rates in excess of 6.34 million gallons (24,000 cubic meters) of fluid, "and generally these injection rates had been maintained for a year or more prior to the onset of earthquake activity" (Frohlich, 2012).

While Frohlich has indicated in interviews that he is very much interested in pursuing this line of inquiry in other fracking wastewater injection regions (Choi, 2012), his own studies have already indicated that other faulted areas demonstrate different maximum monthly injection rates required to induce earthquakes, such as a fluid injection rate of 9.5 to 12.7 million gallons (32,000 to 48,000 cubic meters) per month in the case of Paradox Valley, Colorado (Frohlich et al, 2010). While there is still a lot of research and experimentation required to clarify the precise role of the three surface parameters of fluid pressure, total fluid volume, and rate of




fluid injection in triggering earthquakes, William Ellsworth concurs that experimental results distinctly suggest that these factors all "may be a predictor of seismic potential" (Ellsworth, 2013).

## Conclusion

The mechanisms that underlie fracking wastewater disposal induced earthquakes have been clarified and verified since 1966, making the Hubbert-Rubey theory just a year younger than the theory of plate tectonics and its general acceptance. By capturing the interrelationships between primary earthquake inducement factors that include effective normal stress, shear stress and pore pressure, they set the stage for a couple of decades worth of rich experimentation. All of which became nearly forgotten until fracking industrialization's rude awakening, a literal shaking the foundations of where we work, where we shop and where we live. Luckily, "after a decades long lull in triggered quake studies, researchers are playing catch-up with the latest round of temblors" (Kerr, 2012). And so, in the spirit of existential philosopher Martin Heidegger's conception of truth, we find ourselves in the process of *revealing that which had been concealed.*

One of the great concerns of many of the seismologists and geologists working on this issue is the reality of the earthquake domino effect that have been observed as a result of wastewater injection-induced seismicity. University of Oklahoma seismologist Katie Keranen relates this as the operative scenario in the Prague, Oklahoma magnitude 5.7 earthquake that struck on November 6, 2011: "We had one fault-plane go, a second one, and then a third one. They ruptured in sequence" (Behar, 2013). Lamont-Doherty Earth Observatory seismologist Geoffrey Abers elucidates, "the amount of wastewater injected into the well was relatively small, yet it triggered a cascading series of tremors that led to the main shock" (The Earth Institute, 2013).

This is also of great concern to those potentially impacted individuals who live in Southern Illinois, existing between two active seismic zones, the New Madrid and the Wabash. With Southern Illinois facing the promise of mass fracking industrialization and its associated toxic and radioactive wastewater in need of disposal in deep-injection wells, it is not lost on many experts the danger that even small earthquakes can pose in this active seismic region. Geoffrey Abers acknowledges that, "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought (The Earth Institute, 2013). A study conducted by the University of Illinois Mid-America Earthquake Center in 2008 projected that if an earthquake the magnitude of the quakes that hit near New Madrid during 1811-1812 were to strike today, "there would be 3,500 fatalities, 2.6 million people without electricity and $300 billion in direct economic losses. Bridges, docks, highways and water infrastructure would be in shambles" (IEMA, 2013).

If mass fracking industrialization is to take hold of Southern Illinois, a land amidst two active seismic zones, then higher intelligence must be allowed to govern this process, its regulations, and their application. Stanford University geophysicist Mark Zoback answers this call by providing an empirically derived practical framework for reducing the probability of induced seismicity, with five straightforward steps:

(1) It is important to avoid injection into active faults and faults in brittle rock.

(2) Formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes.

(3) Local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity.

(4) Protocols should be established in advance to define how operations will be modified if seismicity is triggered.

(5) Operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard (Zoback, 2012).

These five steps provide both the state (in the form of regulators) and industry (in the form of operating companies) with a structure for reducing the risks involved in fracking wastewater disposal via deep-injection wells and the induced earthquakes that can accompany their utilization.



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## Shale Plays, Lower 48 States

Public Comments
turned in
December 19, 2013

Carbondale, IL

# Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 $M_w$ 5.7 earthquake sequence

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## ABSTRACT

**Significant earthquakes are increasingly occurring within the continental interior of the United States, including five of moment magnitude ($M_w$) ≥ 5.0 in 2011 alone. Concurrently, the volume of fluid injected into the subsurface related to the production of unconventional resources continues to rise. Here we identify the largest earthquake potentially related to injection, an $M_w$ 5.7 earthquake in November 2011 in Oklahoma. The earthquake was felt in at least 17 states and caused damage in the epicentral region. It occurred in a sequence, with 2 earthquakes of $M_w$ 5.0 and a prolific sequence of aftershocks. We use the aftershocks to illuminate the faults that ruptured in the sequence, and show that the tip of the initial rupture plane is within ~200 m of active injection wells and within ~1 km of the surface; 30% of early aftershocks occur within the sedimentary section. Subsurface data indicate that fluid was injected into effectively sealed compartments, and we interpret that a net fluid volume increase after 18 yr of injection lowered effective stress on reservoir-bounding faults. Significantly, this case indicates that decades-long lags between the commencement of fluid injection and the onset of induced earthquakes are possible, and modifies our common criteria for fluid-induced events. The progressive rupture of three fault planes in this sequence suggests that stress changes from the initial rupture triggered the successive earthquakes, including one larger than the first.**

## INTRODUCTION

Three earthquakes with $M_w$ of 5.0, 5.7, and 5.0 (moment magnitudes from Global Centroid Moment Tensor Catalog, GCMT; http://www.globalcmt.org) occurred within the North American midcontinent near Prague, Oklahoma, United States (Fig. 1) on 5, 6, and 8 November 2011 ~180 km from the nearest known Quaternary-active fault. Earthquakes with $M_w$ ≥ 5.0 are rare in the United States east of the Rocky Mountains; however, the number per year recorded in the midcontinent increased 11-fold between 2008 and 2011, compared to 1976–2007. Of the total seismic moment released in the region, ~66% occurred in 2011 (from the GCMT). The $M_w$ 5.7 earthquake was the largest instrumentally recorded in Oklahoma. It created shaking up to intensity VIII in the epicentral region, destroyed 14 homes, damaged many other buildings, injured 2 people, and buckled pavement (U.S. Geological Survey, 2011). In this study we refer to the $M_w$ ≥ 5.0 earthquakes of 5, 6, and 8 November 2011 as events A, B, and C, respectively. Moment tensor solutions (from the GCMT;

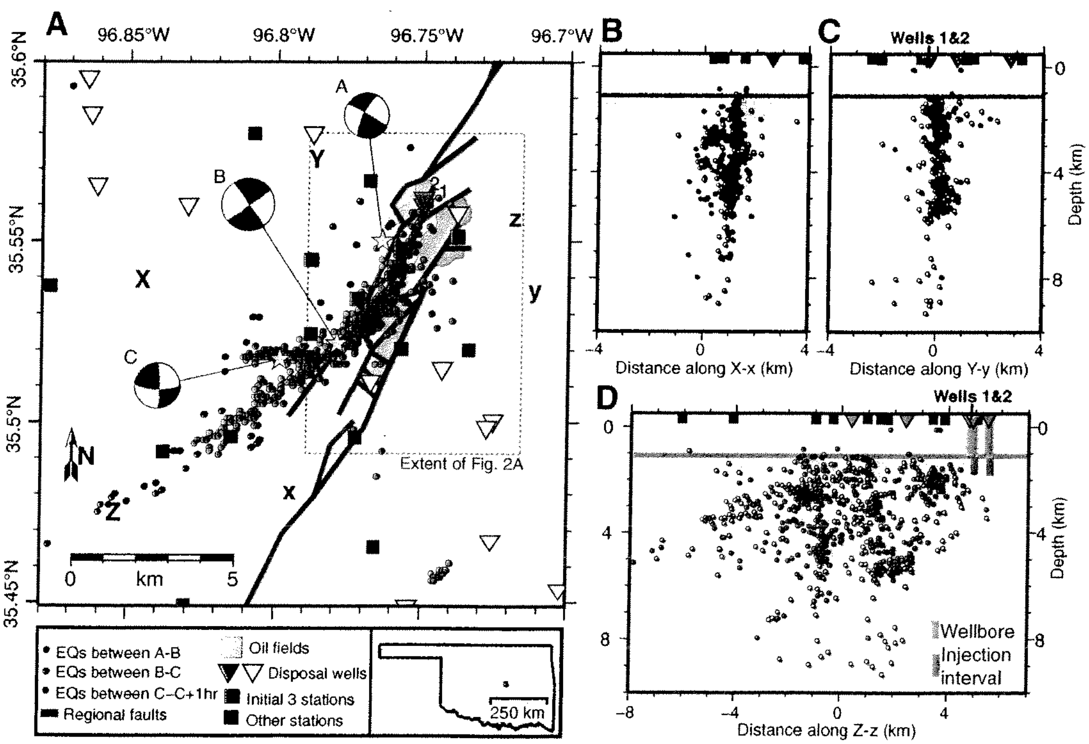


Figure 1. A: Seismicity, centroid moment tensor mechanisms, seismic stations, active disposal wells, and oil fields in central Oklahoma, United States. Epicenters of major earthquakes (EQs) are plotted at Oklahoma Geological Survey location for event A and at our relocations for events B and C, where we had sufficient control (Table DR1 [see footnote 1]). Event A likely nucleated on fault defined by aftershock locations (permitted within location error). Faults are merged from regional compilation (Joseph, 1987) and detailed local study (Way, 1983), mapped using seismic lines, well logs, and formation tops. Wells 1 and 2 inject near aftershocks of event A. B–D: Cross sections of seismicity projected from within 4 km of plane of each section. Vertical lines beneath wells indicate well path, red where perforated or open hole. Green bands denote Hunton and Simpson Groups, and yellow bands denote Arbuckle Group. Arbuckle Group overlies basement; base depth of Arbuckle Group locally is uncertain (between 1.8 and 2.2 km depth). Depths are relative to sea level, land elevation is ~300 m. Inset shows state of Oklahoma and location of map area.

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Fig. 1; Table DR1 in the GSA Data Repository[1]) indicate strike-slip rupture on steeply dipping fault planes with different fault-plane orientations. Local earthquake activity began in February 2010 with an $M_w$ 4.1 earthquake within a few kilometers of event A.

The 2010 and 2011 Prague earthquakes occurred in the structurally controlled Wilzetta oil field, within the complex, ~200-km-long, Pennsylvanian-age Wilzetta fault system (Way, 1983). Structural traps in the Wilzetta field are formed by the offset of porous limestone along high-angle faults (Fig. 2). Production of oil from the Wilzetta North field, where the earthquake sequence initiated, occurred primarily in the 1950s and 1960s from the Hunton Limestone; limited production continues. There are three active fluid injection wells located within 1.5 km of aftershocks of event A, and two within the Wilzetta North field (Fig. 1). Fluid injection in these wells began after 1993 and occurs into units from the Hunton Limestone to the deeper Arbuckle Group, predominantly dolomitic limestone, between ~1.3 and 2.1 km depth (Oklahoma Corporation Commission Well Data System: http://www.occpermit.com/WellBrowse; Fig. 2).

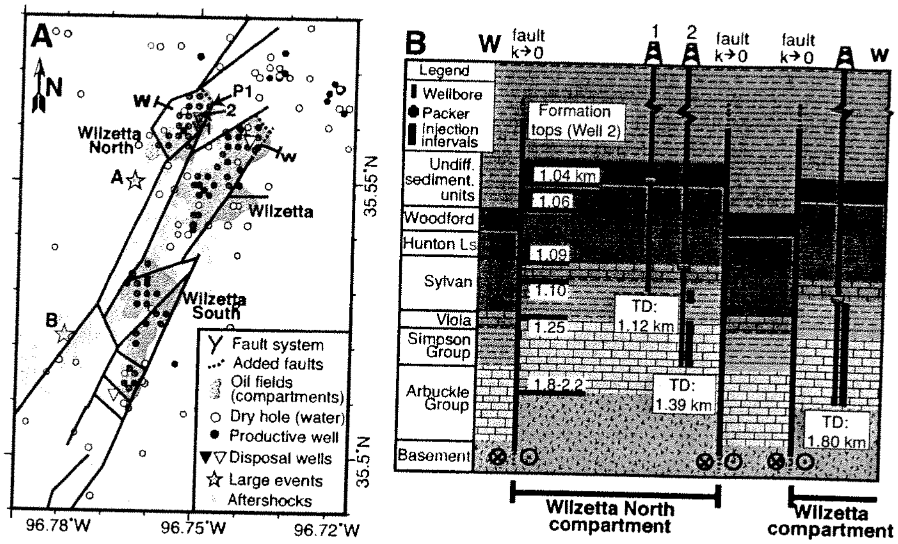


**Figure 2. Subsurface geology and compartmentalization in Wilzetta oilfields, Oklahoma, United States. A: Wilzetta fault system (area shown in Fig. 1) including fault-bounded compartments, disposal wells, earthquakes, and exploration wells into Hunton Limestone or deeper units. Boundaries between producing and dry wells closely correlate to mapped faults. Wells 1, 2, and P1 are discussed in text. B: Schematic cross-section W-w across Wilzetta North and Wilzetta compartments. High-permeability reservoirs are interbedded with low-permeability shale units vertically, and faults are low-permeability barriers to fluid flow. Well paths and injection intervals are from Oklahoma Corporation Commission Well Data System (http://www.occpermit.com/WellBrowse) database. Relative offset of fault blocks is based on formation tops at closely spaced production wells (not shown). Depths to formation tops and total depth (TD) of each injection well are noted (in km below sea level).**

Earthquakes are commonly considered induced by wastewater disposal if they adhere to criteria established by Davis and Frohlich (1993) that include proximity to injection wells, a change from background seismicity, and a correlation with wastewater injection parameters. In this study we demonstrate a relationship between the 2011 Oklahoma seismicity and fluid injection, and suggest modifications to the criteria for induced earthquakes. We use the term "induced" without implying a relationship between anthropogenic stresses and earthquake magnitude, following the Committee on Induced Seismicity Potential (National Research Council of the National Academies, 2012).

## METHODOLOGY

### Seismic Data and Network

We deployed seismometers within 24 h of event A, and recorded the later 2 large earthquakes and thousands of aftershocks. The first 3 seismometers deployed, within 2 km of events A and B, recorded 7 h of locatable seismicity prior to event B. Additional seismometers (3) were deployed in the 24 h after event B, and 12 in the following 5 days, using digital three-component seismometers from the University of Oklahoma and the PASSCAL RAMP (Program for Array Seismic Studies of the Continental Lithosphere, Rapid Array Mobilization Program) pool. The locally recorded data were supplemented by EarthScope Transportable Array stations (Meltzer et al., 1999) at 25–150 km distance. Many stations were within 1 focal depth of the nearest earthquakes, providing accurate depth estimates; nonlinear inversions on sample hypocenters give 95% confidence bounds of <500 m in epicenter and <800 m in depth for earthquakes recorded by 3 stations before event B, and <50–100 m in epicenter and depth for those recorded by the full 18 station local array. Most ray paths were <10 km from source to station, with <2 s between S and P wave arrivals. Several hundred aftershocks per hour occurred within the first few hours of each large earthquake.

We report results based on P and S wave arrivals for (1) all identifiable events after the array installation before event B (the $M_w$ 5.7), (2) 1–2 h time windows immediately following events B and C, and (3) larger aftershocks within 2 mo of the mainshocks and recorded on >15 stations. In most cases, both P and S wave arrival times could be picked to a precision of 10 ms or better from the local stations. Arrivals were picked manually; the high event rate caused standard automatic detection schemes to fail.

The one-dimensional velocity model (Fig. DR1 in the Data Repository) was determined by inversion methods that solve jointly for P and S wave velocities and hypocenters (Abers and Roecker, 1991) for aftershocks recorded on >15 stations. The global root mean square residual in the velocity model is 0.029 s, and influences of possible lateral variations appear to be minimal. (For details of the network, the velocity model, and location selection, see the Data Repository.)

## RESULTS

### Aftershock Locations and Fault Rupture Areas

For this study we located 1183 aftershocks recorded by the dense network, and show the best located 798 (see the Data Repository). We use the extent of the aftershocks measured within a few hours to days after the mainshocks to estimate the area of the faults that ruptured, as is common if an event does not rupture to the surface (e.g., Kanamori and Anderson, 1975). The aftershocks we use in this study represent <10% of the total number of earthquakes, as only a few hours of data from time periods following each $M_w \geq 5.0$ event have been examined thoroughly. Hypocenters for events A, B, and C are less well constrained than the aftershocks (see the Data Repository). However, the fault rupture sequence is clear from the focal mechanisms of the large events combined with the aftershock pattern.

The earthquakes located delineate the major seismic zones as narrow, steeply dipping planes in the sedimentary section and basement (Fig. 1), well correlated to previously identified fault structures (Way, 1983; Joseph, 1987). The strikes (from the GCMT) of events A (27°) and B

[1]GSA Data Repository item 2013191, network and event details, velocity model, and 2010–2011 injection data, is available online at www.geosociety.org/pubs/ft2013.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

(54°) parallel the two predominant orientations within the Wilzetta fault zone, and the strike of event C (91°) defines a clear secondary orientation. Therefore, three separate segments within the Wilzetta fault network ruptured successively during the sequence. The slip on the apparent fault planes of the three largest earthquakes are consistent with an east-northeast direction of maximum horizontal stress. Significantly, the northern tip of the aftershock zone for event A is in sedimentary units near an active disposal well (Fig. 1); the closest earthquakes are 200 ± 250 m distant from the wells. The depths of 83% of the aftershocks are <5 km; 30% of early aftershocks (and 20% of all earthquakes) were located within the sedimentary units into which fluids are injected (Fig. 1).

### Fluid Triggering and Correlation of Seismicity to Fluid Injection Data

Earthquake triggering by fluid injection occurs if pore pressure at the fault increases beyond a critical pressure threshold (Hubbert and Rubey, 1959; Healy et al., 1968; Raleigh et al., 1976), lowering effective normal stress on a fault close to failure. In the induced seismicity experiment at Rangely, Colorado, downhole reservoir pressure measurements were available and the seismicity rate rose and fell within months of changes in reservoir pressure (Raleigh et al., 1976). Pressure data available for the Wilzetta North field are limited to monthly reported wellhead pressure (pressure at the surface while pumping), and no direct measurements of pressure within the reservoir are accessible. We thus follow standard methods and investigate possible temporal correlations between seismicity rate and surface injection parameters (e.g., Healy et al., 1968; Frohlich et al., 2011; Horton, 2012).

No short-term monthly correlation is evident in the Wilzetta field (Fig. DR2). Such a temporal correlation to surface injection parameters is rare, though evident at the Rocky Mountain Arsenal in Colorado (Healy et al., 1968). A more common observation in cases of induced seismicity is the onset of earthquakes soon after the initiation of fluid injection. Seismicity began within months of the start date of injection at the Rocky Mountain Arsenal (Healy et al., 1968), in Arkansas (Horton, 2012), and at the Dallas–Fort Worth (Texas) airport (Frohlich et al., 2011). However, within oilfields near Prague, Oklahoma, the first noted earthquake ($M_w$ 4.1, 2010) did not occur until 17 yr after injection commenced (Fig. 3A). It is difficult to know if small earthquakes were occurring prior to 2010 near Prague, given the lack of nearby seismic stations; none were recorded or reported. A similarly long delay was observed at the Cogdell oil field in Texas (Davis and Pennington, 1989), where induced earthquakes began 20 yr after injection initiated.

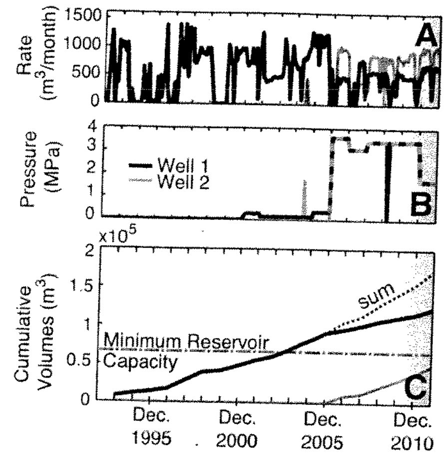


**Figure 3. Available injection data. A: Monthly volumes of wastewater disposed at injection wells 1 and 2 (Fig. 2) near nucleation of event A. Monthly volumes were reported for 2002–2011; daily average volumes are multiplied by number of days per month for 1993–2002. B: Wellhead pressure for periods when pump is active, for same wells. C: Cumulative volume injected at wells 1 and 2 (from yearly totals). Minimum capacity of reservoir is denoted as horizontal dashed line and equals volume of oil extracted from Wilzetta North field, estimated by dividing total volume extracted from three Wilzetta fields by fractional area of Wilzetta North. This is absolute minimum estimate of reservoir fluid capacity; no data are available for water extracted or reinjected during production. Gray shading notes earthquakes in 2010–2011.**

### Increasing Injection (and Reservoir?) Pressure

Wellhead pressure in the Wilzetta North field appears fixed at a constant value during pumping, as it was at Rangely, Colorado (Gibbs et al., 1972), with multiyear intervals of constant surface pressure punctuated by step increases (Well 1; Fig. 3). Initially, fluid was injected into the Hunton Limestone in Well 1 at zero reported wellhead pressure (Oklahoma Corporation Commission Well Data System) (Fig. 3B), signifying an underpressured reservoir (below hydrostatic pressure) depleted by earlier hydrocarbon production. Wellhead pressure increased in steps, starting in 2001 at ~0.2 MPa (25–40 psi) and reaching a maximum of 3.6 MPa (525 psi) in 2006 (Fig. 3). The final tenfold increase in wellhead pressure, and the concurrent addition of a second disposal well into deeper units, came after the volume of water injected into the Hunton Limestone at Well 1 exceeded the volume of oil extracted from the Hunton strata at wells throughout the compartment (Way, 1983) (Fig. 3C). The volume of oil extracted is only an approximate estimate of reservoir capacity, and likely an underestimate; no data are available for water volume extracted or reinjected during production.

In the Wilzetta field, hydrocarbon accumulations were isolated to fault blocks of <1 km² areal extent, surrounded by water-saturated zones, indicating that the compartment-bounding faults were likely seals against fluid migration over geologic time. Such low-permeability barriers are common in sedimentary basins (Bradley and Powley, 1994) and can inhibit the diffusion of fluid pressure. In an idealized sealed reservoir, reservoir pressure gradually rises as injection volume increases (Fig. 4A), and the pressure difference between wellhead pressure (corrected for the water column) and reservoir pressure decreases (Fig. 4B), along with flow rate. When wellhead pressure is increased, as in the Wilzetta North field (Fig. 3), pressure gradient and flow rate increase. With sufficient time, volume injected, and wellhead pressure, pressure at the fault may exceed the critical pressure (Fig. 4B) and trigger slip. The time required for pressure at the fault to rise to the critical threshold in a closed compartment depends upon injection rate and reservoir volume and permeability, explaining delays before the onset of induced seismicity such as observed in this study and at the Cogdell oil field (Davis and Pennington, 1989).

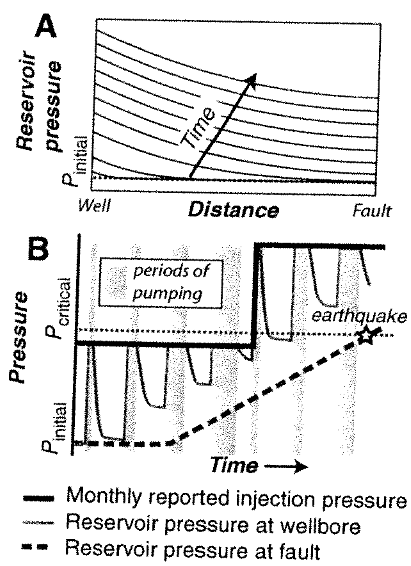


**Figure 4. A: Reservoir pressure in simplistic sealed reservoir. Fluid pressure in reservoir, including at fault, rises through time as reservoir fills. Left edge of model is injection wellbore; right edge represents sealed fault. B: Predicted reservoir pressure compared to reported monthly wellhead pressure (plus weight of water column), apparently constant because pressure is reported only during pumping. Reservoir pressure near wellbore equals reported injection pressure while pumping, but drops when pump stops. Over multiple pumping cycles, time-averaged formation pressure near well rises slowly (A), and pressure gradient decreases, lowering flow rate and requiring longer periods of pumping (shaded in gray) to maintain constant monthly disposal volume. When wellhead pressure is increased, pressure gradient increases and pumping becomes more efficient.**

Neither reservoir pressure data nor detailed flow rates, required to fully test this hypothesis, are available for the Prague, Oklahoma, wells. Injection rate in Oklahoma is reported as a monthly volume and the averaging of flow rate per month smooths out higher frequency variations. Alternative hypotheses to raise fluid pressure at the fault unrelated to the identified compartments, including the concurrent increase in wellhead pressure and the addition of a second injection well in 2006, cannot be rejected without reservoir pressure data. However, the agreement between original oil volume extracted and cumulative water injected prior to seismicity (Fig. 3) supports the notion that a critical volume was reached through injection in the Wilzetta North compartment.

Minor production is reported from the Hunton Limestone 500 m to the north, near the edge of the compartment (Fig. 2; well P1) (Oklahoma Corporation Commission Well Data System). It is unknown if the well is in pressure communication with the injection wells, because we have no measurements of reservoir pressure to determine connectivity. However, fluid pressure can rise throughout portions of a semirestricted reservoir following injection, and high fluid pressure can be maintained for years even if one side is infinitely open, as observed at the Rocky Mountain Arsenal (Hsieh and Bredehoeft, 1981).

## DISCUSSION

Continuing injection over 18 yr into subsurface compartments in the Wilzetta field may have refilled a compartment, eventually reducing the effective stress along reservoir-bounding faults and triggering the 2010–2011 earthquakes. Injection has continued and earthquakes with magnitudes ≥3.0 continue to occur. We interpret event A ($M_w$ 5.0) to have been induced by increased fluid pressure, exceeding the largest earthquake known to be induced by injected fluid ($M_w$ 4.8; National Research Council of the National Academies, 2012). Aftershocks of event A appear to deepen away from the well, and may imply downward pressure propagation into basement. Event B, of much larger magnitude ($M_w$ 5.7), and event C may also be considered consequences of injection; however, Coulomb stress calculations show that the fault geometries are consistent with triggering by stress transfer (Cochran et al., 2012). The triggering implies that the faults were close to failure, supporting the view that favorably oriented faults are critically stressed throughout the continents (Zoback et al., 2002). In this manner, small- to moderate-sized injection-induced events may result in release of additional tectonic stress. The scalar moment released in the Oklahoma sequence exceeds predictions based on the volume of injected fluid (McGarr, 1976) by several orders of magnitude, requiring the release of substantial tectonic stress.

The 2011 Prague, Oklahoma, earthquakes necessitate reconsideration of the maximum possible size of injection-induced earthquakes, and of the time scale considered diagnostic of induced seismicity. Typically, a response of seismicity to injection within months has been sought to diagnose earthquake triggering (Raleigh et al., 1976; Davis and Frohlich, 1993). Here we present a potential case of fluid injection into isolated pockets resulting in seismicity delayed by nearly 20 yr from the initiation of injection, and by 5 yr following the most substantial increase in wellhead pressure.

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# Seismic structure of the Central US crust and shallow upper mantle: Uniqueness of the Reelfoot Rift

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ABSTRACT

Using seismic surface waves recorded with Earthscope's Transportable Array, we apply surface wave imaging to determine 3D seismic velocity in the crust and uppermost mantle. Our images span several Proterozoic and early Cambrian rift zones (Mid-Continent Rift, Rough Creek Graben—Rome trough, Birmingham trough, Southern Oklahoma Aulacogen, and Reelfoot Rift). While ancient rifts are generally associated with low crustal velocity because of the presence of thick sedimentary sequences, the Reelfoot Rift is unique in its association with low mantle seismic velocity. Its mantle low-velocity zone (LVZ) is exceptionally pronounced and extends down to at least 200 km depth. This LVZ is of variable width, being relatively narrow (~50 km wide) within the northern Reelfoot Rift, which hosts the New Madrid Seismic Zone (NMSZ). We hypothesize that this mantle volume is weaker than its surroundings and that the Reelfoot Rift consequently has relatively low elastic plate thickness, which would tend to concentrate tectonic stress within this zone. No other intraplate ancient rift zone is known to be associated with such a deep mantle low-velocity anomaly, which suggests that the NMSZ is more susceptible to external stress perturbations than other ancient rift zones.

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## 1. Introduction

Three M~7–8 events in the New Madrid Seismic Zone in 1811–1812 are among the largest historical earthquakes in the United States (NMSZ) (Johnston, 1996; Hough, 2008). Studies of large paleoliquefaction features indicate that there were at least two sequences of large earthquakes in about 1450 and 900 A.D. that look like repeats of the 1811–1812 sequence (Tuttle et al., 2002). Additional studies reveal a history of large earthquakes in the Holocene at several other localities around the margins of the NMSZ (e.g. Harrison et al., 1999; Al-Shukri et al., 2005). The NMSZ is a 300-km-long and narrow zone of predominantly strike–slip faulting within the Reelfoot Rift, a reactivated Precambrian rift zone (Fig. 1). These large and rare intraplate events are enigmatic because the lack of pervasive crustal deformation suggests that the NMSZ has been active for a geologically relatively short time (Schweig and Ellis, 1994), contemporary strain rates are small compared to the rate of Holocene activity (Newman et al., 1999; Calais et al., 2010; Frankel et al., 2012), and the mechanism of stress concentration is unresolved (Grana and Richardson, 1996; Stuart et al., 1997; Liu and Zoback, 1997; Kenner and Segall, 2000; Grollimund and Zoback, 2001; Pollitz et al., 2001; Mazzotti, 2007).

Focal mechanism studies and other stress indicators indicate that intraplate–earthquakes in the central and eastern US, including the SSW-NNE-trending NMSZ, are consistent with an ENE-WSW compressive stress field that acts on pre-existing faults (Sbar and Sykes, 1973; Zoback and Zoback, 1980; Braile et al., 1982; Zoback and Zoback, 1989). The existence of pre-existing faults in the NMSZ provides a zone of weakness but does not indicate how the faults are loaded. A lower crustal detachment fault has been proposed to concentrate crustal stress (Stuart et al., 1997), though such a fault has not been corroborated by seismic data. A mechanical strength contrast between the Reelfoot rift and the Missouri batholith can localize stress in the zone of their intersection (Long, 1976; Campbell, 1978; Hildenbrand, 1985), but this mechanism still requires a recent increase in strain rate arising from external factors.

Geophysical models to explain the initiation and repeated occurrence of large seismic events in the NMSZ have focussed on the origin of Holocene and late Pleistocene stress perturbations and crustal heterogeneities. A weak (i.e. low-viscosity) lower crust can focus stresses on the overlying crust (Liu and Zoback, 1997; Kenner and Segall, 2000; Pollitz et al., 2001), but there is no independent evidence that such a low-viscosity zone exists. Exceptional models that invoke mantle weakness are the models of Grollimund and Zoback (2001) and Forte et al. (2007), which invoke a pre-existing weak mantle to generate flow fields likely connected with the crustal stress field—driven by either glacio-isostatic adjustment or Farallon slab sinking, respectively.

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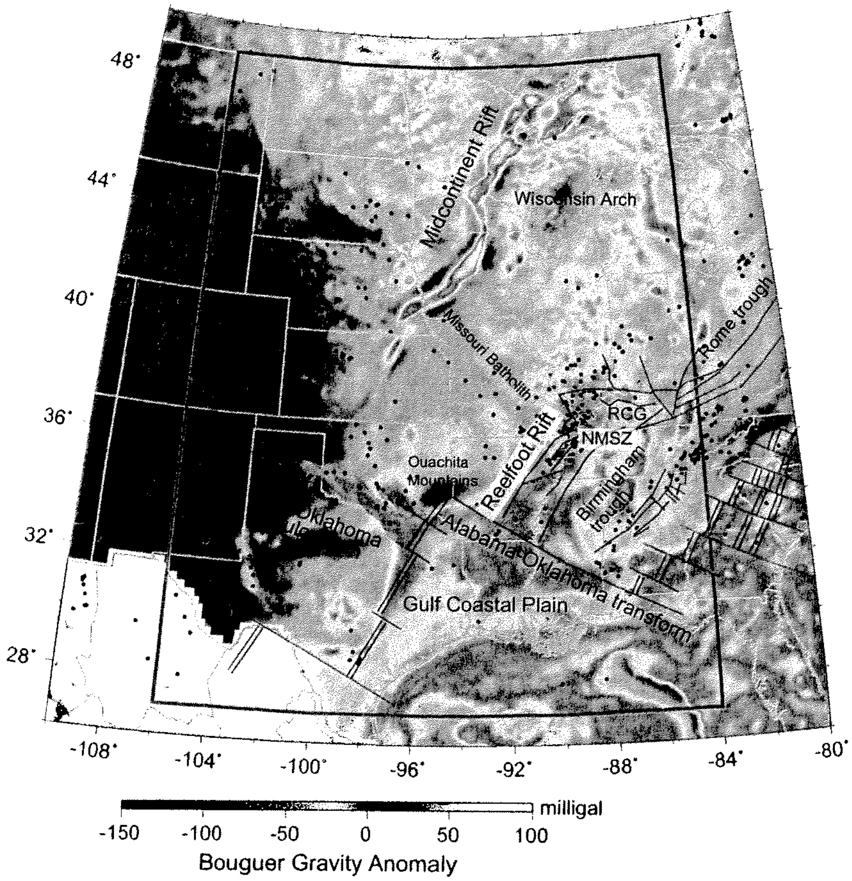


**Fig. 1.** Bouguer gravity map of the central United States with lines of inferred basement faults superimposed following Thomas (2006). Gravity data was obtained from the National Geophysical Data Center at: http://www.ngdc.noaa.gov/. Small black circles are epicenters of $M \geq 3.0$ events of depth ≤50 km from 1978 to 2008 obtained from the National Earthquake Information Center (NEIC) catalog at http://earthquake.usgs.gov/eqcenter/. RCG, Rough Creek Graben; NMSZ, New Madrid Seismic Zone.

The notion of a weak mantle is disputed by McKenna et al. (2007) on the basis of the lack of evidence for a thermal anomaly.

The Central and Eastern United States (CEUS) is a mosaic of several Proterozoic igneous and volcanic provinces subjected to repeated episodes of continental collision and rifting (Thomas, 2006; Whitmeyer and Karlstrom, 2007). The CEUS contains several Proterozoic and early Cambrian rift zones (Fig. 1) with associated crustal extension, igneous intrusion and volcanism (Van Arsdale, 2009a; Thomas, 2010). The Reelfoot Rift is one of the ancient rift zones and was formed in early Paleozoic (Van Arsdale and Cox, 2007). Geophysical investigations of the Reelfoot Rift and NMSZ have revealed fragmentary details of the crust and underlying mantle structure. A high-velocity seismic anomaly within the deep crust below the NMSZ has been inferred with seismic and magnetotelluric data (Mooney et al., 1983; Hildenbrand and Hendricks, 1995) and interpreted as a remnant of basaltic intrusion. Local and regional body wave tomography suggests that the mantle beneath the Reelfoot Rift is of relatively low velocity (Bedle and van der Lee, 2006; Zhang et al., 2009). The crustal structure has been placed into a regional context using ambient noise tomography using Rayleigh waves at periods up to 15 s by Liang and Langston (2008), who found good correlations of crustal seismic velocity with ancient rift structures.

In this study we use seismic data from Earthscope's Transportable Array (TA) to estimate Rayleigh wave phase velocity structure at periods up to 125 s, permitting the estimation of 3D perturbations in seismic shear-wave velocity in the uppermost mantle of the Central US. This provides new constraints on the deep structure of all ancient rifts and yields a new perspective on the possible relationship of mantle structure with ancient inherited crustal structures throughout the Central US. We believe that this is key to understanding what distinguishes the Reelfoot Rift from other ancient rifts and the mechanism of stress concentration at the NMSZ.

## 2. Surface-wave imaging

We employ the non-plane surface-wave imaging method of Pollitz and Snoke (2010), which uses fits of Rayleigh wave spectra to determine local phase velocity at fixed periods. The overall strategy of the method is described in the Appendix. The surface wave data set is updated from Pollitz and Snoke (2010), using 125,326 seismograms recording seismic waves generated by 305 teleseismic events of magnitude ≥6.3 and depth ≤75 km which occurred through early September 2012. Complex amplitude spectra of fundamental-mode Rayleigh waves are obtained at selected periods by means of a three-step process. First, for each vertical component seismogram, a spectrogram is constructed using a moving-window taper designed for the period being considered. Second, complex amplitude spectra are obtained at the group-velocity peaks corresponding to the fundamental mode. Third, quality criteria are applied based on the consistency of the group-velocity peaks as a function of period, resulting in a large edited dataset. At a fixed period and spatial location, a grid search is used to fit the complex amplitude spectra in terms of a multi-plane wave fit at trial phase velocities, resulting in an optimal phase local phase velocity (i.e. that associated with minimum

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misfit); this process is repeated throughout the study area to obtain a continuous map of phase velocity. The phase velocities used in this study are measured at 13 periods (125, 100, 83, 67, 59, 50, 40, 33, 27, 25, 22, 20, and 18 s).

The formal resolution of the phase velocity maps determined with this method is difficult to obtain because the method is a form of imaging rather than tomography (Pollitz and Snoke, 2010). The imaging of phase velocity structure involves neither an inversion nor a forward model, and thus a resolution test involving trial structures (e.g. checkerboard test) is not straightforward. This limitation is shared by the related eikonal tomography method (Lin et al., 2009). (The resolution in our non-plane-wave or the Lin et al. (2009) imaging method could be addressed, in principle, with a large set of numerically determined synthetic seismograms on a laterally heterogeneous earth with fine-scale structure, which could then be put through the imaging procedures of the respective methods.) The length scale of local averaging prescribed by Pollitz and Snoke (2010, Eq. (12)) is of the same order as the ~70 km spacing between the TA instruments, so we regard this as the horizontal resolution of our imaging. The procedure may be judged by the number of rays which pass through sets of TA stations. This is shown in Fig. 2, which shows the direct raypaths from all teleseismic sources (after editing) to all TA stations which provided useful data from recordings of 50-s-period surface waves generated by those sources. The figure illustrates that density of ray coverage is densest in the western part of the study area, where the TA has resided the longest, but is still large in the eastern part of the study area. Numerous raypaths pass through any set of 7 TA stations in the study area (Fig. 2), approximately the number of TA stations that effectively contribute to a local phase velocity determination (Pollitz and Snoke, 2010, Section 3), ensuring a robust determination of local wavenumber and hence phase velocity.

The sensitivity of the shortest period spans the crust and peaks at 25 km depth, and the longest period has a broad sensitivity kernel roughly centered on 180 km. 3D structure is derived from the phase velocity maps using the procedure described in Appendix A of Pollitz and Snoke (2010). Using scaling relations between P-wave and S-wave velocity, this results in the distribution of vertically polarized shear-velocity $v_s$ in the crust and upper mantle. The formal depth range of 3D perturbations is from earth's surface to 240 km depth, somewhat deeper than the depth of maximal sensitivity in order to avoid 'squeezing' of deeper structure into the base of the model domain. The determination of 3D structure uses the Taylor (1989) crustal structure combined with the PREM mantle structure (Dziewonski et al., 1981) as a reference structure (Fig. 3), and it includes a correction for crustal thickness (Fig. 4).

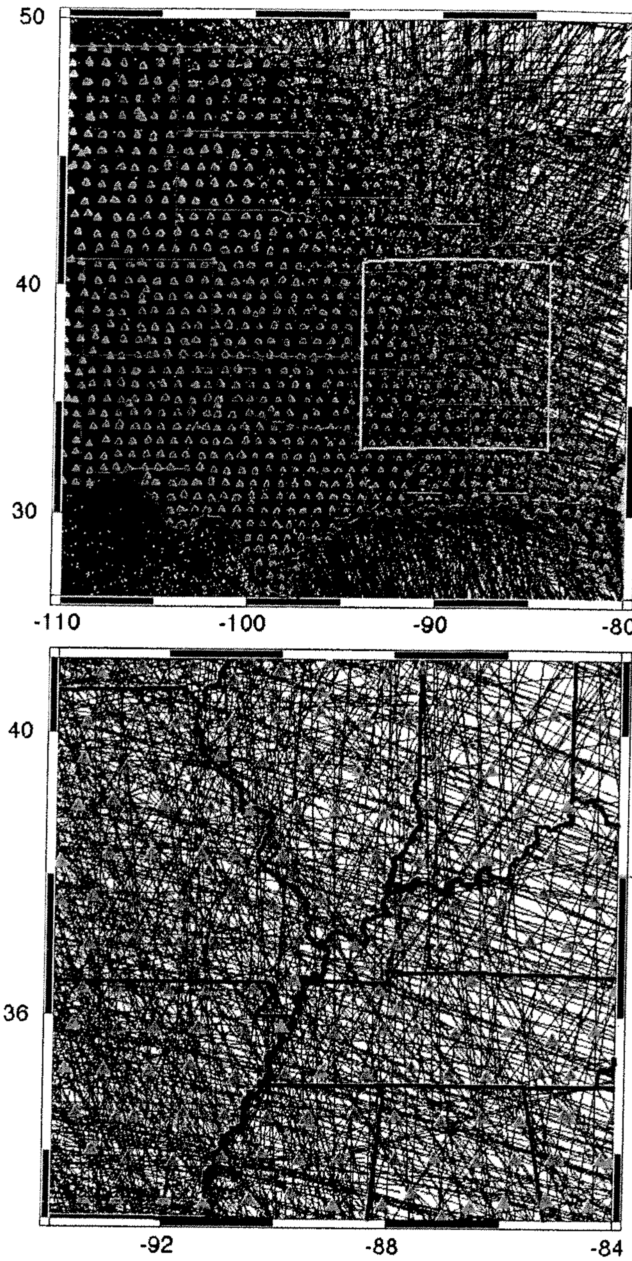


**Fig. 2.** Raypaths between teleseismic sources and TA stations (green triangles) retained after editing at period 50 s. The number of raypaths is subsampled by a factor of 10 in the plots. Bottom plot is a closer view of the Mississippi Embayment region from the upper plot. State boundaries within the United States are shown in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

## 3. Results

Rayleigh wave phase velocity maps are presented in Fig. 5, and associated errors at selected periods in Fig. 6. The shorter period maps (i.e. at period ≤27 s) reveal that zones of low phase velocity are correlated with several failed rift zones, i.e. the Mid-Continent Rift, the Rough Creek Graben—Rome trough, the Birmingham trough, and the Southern Oklahoma Aulacogen. The Reelfoot Rift emerges as a coherent low-velocity feature at longer periods ≥50 s. Our phase velocity results are very similar to those obtained independently using Helmholtz tomography (Shen et al., submitted for publication).

Corresponding depth slices of perturbation in logarithmic 3D shear-velocity $v_s$ are shown in Fig. S1. Two of these slices are shown in greater detail in Fig. 7, and alternative perspectives are shown in Fig. S2 in a sequence of regional depth slices and Figs. S3–S6 in volume rendered images. The long linear high-velocity structure stretching from Wisconsin to western Texas at depth ≥65 km may represent depleted mantle associated with the Yavapai and Mazatzal provinces (Whitmeyer and Karlstrom, 2007), and similarly for the high-velocity mantle underlying the area from Indiana to northern Alabama which is part of the Granite-Ryolite Province. All rift structures but the Reelfoot Rift have a shallow expression of the low-velocity zone (LVZ) restricted to depth ≤65 km, whereas the mantle LVZ beneath the Reelfoot Rift extends to depth of at least 200 km (at the limit of the resolving

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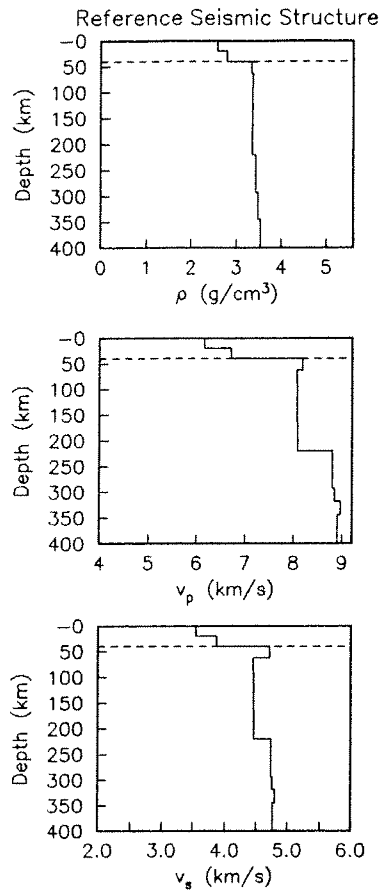


**Fig. 3.** Reference seismic structure of the central US using the crustal structure of Taylor (1989) and mantle structure of PREM (Dziewonski et al., 1981). In the upper 200 km this model is similar to the CR model of the Midwestern US (Chu et al., 2012).

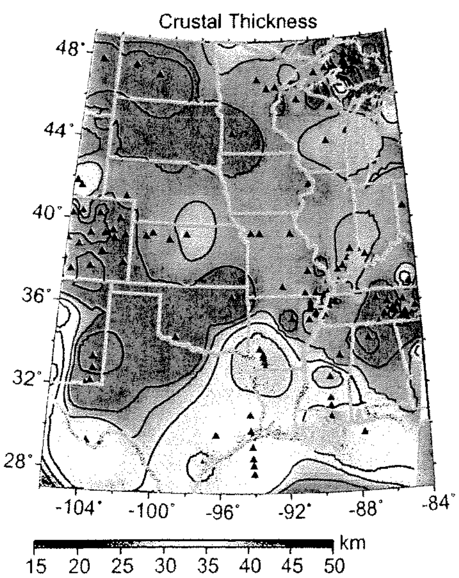


**Fig. 4.** Smoothed crustal thickness over the central-eastern US derived mainly from active-source profiles (Chulick and Mooney, 2002) (with additional subsequent profiles). Contour interval is 5 km. Locations of crustal thickness estimates in that database are indicated with triangles.

power of the surface waves) (Fig. S1). The NMSZ and its principal strike–slip fault (Blytheville fault) lie within a zone of low-velocity mantle, as seen in vertical cross-section AA' in Fig. 8. This pattern of low mantle $v_s$ is consistent with the inferred low-$v_p$ mantle beneath the Reelfoot Rift to at least 160 km depth (Zhang et al., 2009) or deeper (Bedle and van der Lee, 2006).

At its southern end, the Reelfoot Rift is terminated by the Alabama–Oklahoma transform associated with the opening of the Iapetus Ocean (Van Arsdale, 2009a; Thomas, 2010), which is nearly coincident with the structural boundary of the Gulf of Mexico associated with the opening of the Atlantic (Van Arsdale, 2009b). This boundary is seen in our Rayleigh wave imaging (i.e. the 18 s phase velocity map in Fig. 5), similar to boundary seen in Fig. 7f of Liang and Langston (2008). At its northern end, the surface expression of the Reelfoot Rift overlies the narrowest part of the mantle low-velocity zone (Fig. S1).

Seismic velocity in the crust below the NMSZ is relatively fast (profiles AA' and BB' in Fig. 8), in agreement with inferences of a 'rift pillow' within the underlying lower crust (Mooney et al., 1983; Hildenbrand and Hendricks, 1995; Stuart et al., 1997). At long wavelength, our inferred pattern of low crustal velocities to the NW of the NMSZ and high crustal velocities to its SE agrees with the Rayleigh wave phase velocity maps of Liang and Langston (2008); at short wavelength this apparently yields to a different pattern involving relatively high crustal velocity to its west and low crustal velocity to its east (Zhang et al., 2009).

The Chulick and Mooney (2002) crustal thickness map is incomplete over much of the central US. Receiver function studies using the Transportable Array (e.g. Abt et al., 2010; Moidaki et al., 2013) suggest that crustal thickness $T_c$ may differ from the crustal thickness derived from active source seismology (Chulick and Mooney, 2002) by 5 km or greater. For example, small-scale variations of $\pm 5$ km are seen near the Midcontinent Rift (Moidaki et al., 2013) where the Chulick and Mooney (2002) crustal thickness pattern is smooth. We investigate the effect that an error in crustal thickness may have on inferred structure at depth. For this purpose we perform a number of separate inversions for 3D structure, one using a reference value $T_c = 40$ km and others using different values $T_c$ that would represent erroneous departures from a 'true' value of 40 km. The bias introduced by using an erroneous crustal thickness is shown in Fig. 9. Errors up to $\pm 2\%$ in logarithmic shear-velocity may result in the crust, and errors up to 1% may result in the deeper mantle.

Short-period phase velocities have better vertical resolution than long-period phase velocities, i.e. the short-period phase velocities will generally map into a shallower and narrower depth region than long periods because of the shape of the depth-dependent sensitivity kernels (e.g. Pollitz and Snoke, 2010, Fig. S2). Although this can result in the erroneous mapping of crustal structure into structure at depth (e.g. Pollitz, 2008, Fig. 19), this is unlikely the case around the Reelfoot Rift. Short-period ($\leq 25$ s) phase velocities are generally high around the Reelfoot Rift (Fig. 5) and are mapped as positive $v_s$ anomalies in the crust (Fig. S1), in contrast with the low phase velocities at longer period and correspondingly low-$v_s$ mantle anomalies (Figs. 7 and S1).

## 4. Discussion

The low-$v_s$ zone beneath the Reelfoot Rift extends to at least ~200 km into the upper mantle (Figs. S1 and 8). All other ancient rift zones in the CEUS, which are thought to represent zones of inherent weakness capable of rupturing in earthquakes, are associated with much less penetrative discontinuities (i.e. restricted to the crust and uppermost mantle).

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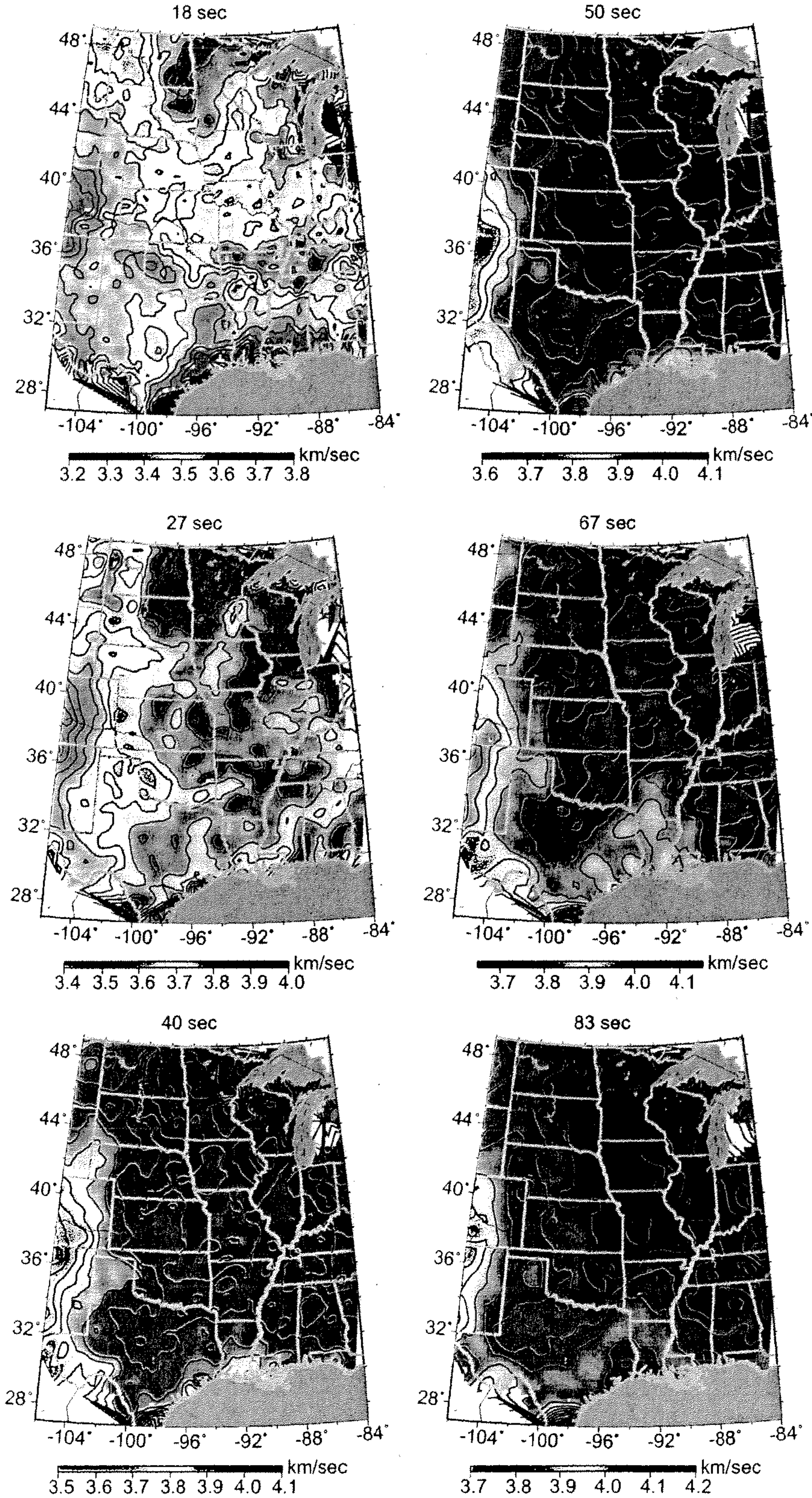


**Fig. 5.** Phase velocity maps of fundamental-mode Rayleigh waves at the indicated periods. Associated standard errors in Fig. 6 tend to be greater at shorter period and greater in the eastern part of the study area because of the data coverage provided by the Transportable Array.

All of the ancient rifts and aulacogens identified in Fig. 1 are associated with positive gravity anomalies to varying degrees, likely because of the presence of shallow basaltic intrusions associated with rifting, as has been documented directly for the Midcontinent Rift (Allen et al., 1992). All are also associated with relatively low crustal seismic velocity (Figs. S1 and 7). Any volumes

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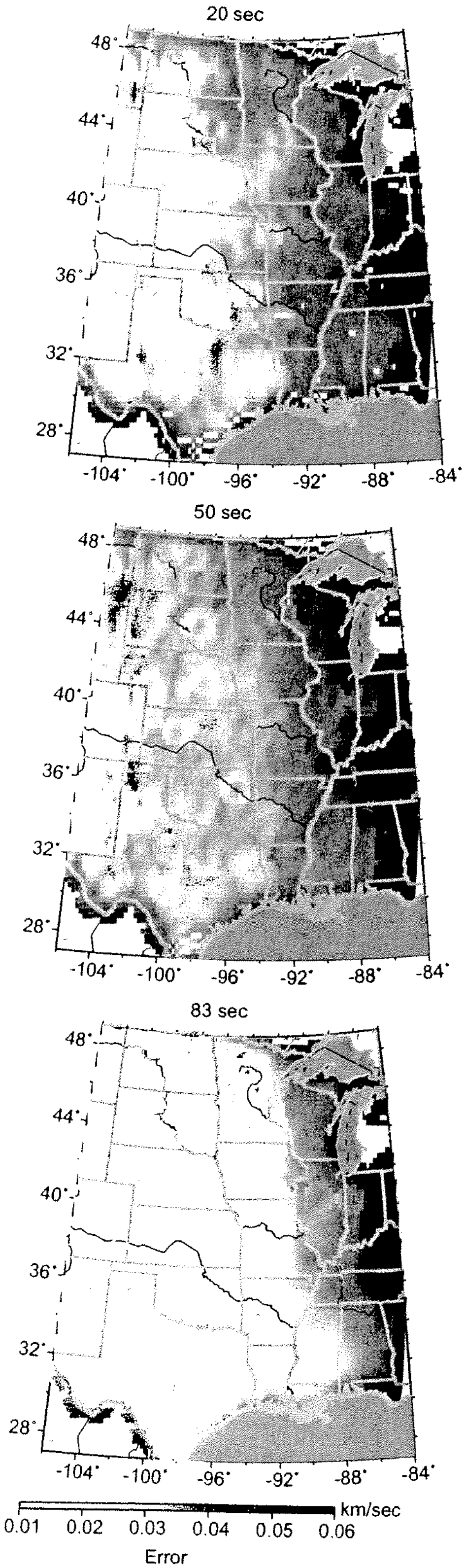


**Fig. 6.** Standard errors in phase-velocity distribution.

of high-velocity basaltic intrusions in these rifts are outweighed by the presence of thick sedimentary sequences on the flanks of the rifts (Liang and Langston, 2008), leading to a net low-velocity signal detected by those surface waves sensitive to predominantly crustal structure (period ≤40 s, Fig. 5).

The Reelfoot Rift formed as part of a series of failed rift basins in the Early-to-Middle Cambrian (520–500 Ma) concurrently with the Rome Trough and Rough Creek Graben to its northeast (Thomas, 2006). These rifts formed within a pre-existing tectonic terrane – the Eastern Ryolite-Granite Province – which was likely continuous over a broad area including the incipient rifts (Whitmeyer and Karlstrom, 2007). The low-$v_s$ signal is most pronounced at depth ≥100 km and varies laterally along the Reelfoot Rift and a northeastern extension that coincides with the Wabash Valley Seismic Zone (WVSZ) (Kim, 2003; Merino et al., 2010), judging from the mantle $v_s$ pattern (Figs. S1 and 7). The mantle low-$v_s$ zone is ~200 km wide zone below the southern Reelfoot Rift, thins to ~50 km around the northern Reelfoot Rift, and widens to ~100 km along the WVSZ. Whether this variable width is a measure of variable extension associated with Cambrian rifting, or it reflects the width of the zone subjected to subsequent modification, is unclear.

The zone of low-$v_s$ mantle extending southwestward from the NMSZ approximately coincides with the Mississippi Embayment (ME), where sediment thickness can be high, raising the possibility that low-velocity sediments could project to great depth as an artifact of the 3D velocity inversion. This is not the case because sediment thickness is not remarkably large in the northern ME compared with surrounding regions (such as the Illinois Basin), according to the sediment thickness map presented in Fig. 4 of Mooney and Kaban (2010). Sediment thickness is relatively large, exceeding 5 km, only in the ME south of Tennessee. This pattern is mimicked in the phase velocity patterns at periods sensitive to crustal structure (≤33 s), which are characterized by relatively high phase velocities in the northern ME and very low phase velocities further south, i.e. south of the fossil Alabama–Oklahoma transform. Low phase velocities beneath the northern ME are realized only at longer periods ≥50 s, which demands a deep source for the corresponding low seismic velocities.

The origin of the low-$v_s$ mantle may be either thermal or compositional. We propose that, as a pre-existing zone of fractured lithosphere, the passage of the Bermuda hotspot beneath the Mississippi Embayment ca. 100 Ma (Van Arsdale and Cox, 2007) led to infiltration of melt in the shallow mantle throughout the NE-SW-trending axis of the embayment. This is consistent with the notion that pre-existing rifted continental lithosphere is more susceptible than surrounding cratonic lithosphere to penetration by magmatism from an impinging plume head (Burov et al., 2007). This led to thermal uplift of the entire Mississippi Embayment (Van Arsdale and Cox, 2007) and may have resulted in compositional changes within the pre-existing weak zone in two ways:

(1) Metasomatism of a mantle peridotite is capable of lowering $v_s$. For example, antigorite, phlogopite, chlorite, and talc are stable at the pressure and temperature conditions of the observed $v_s$ anomaly (Pawley and Wood, 1995; Bose and Ganguly, 1995; Ulmer and Trommsdorff, 1999; Trønnes, 2002; Frost, 2006; Grove et al., 2006), and the presence of these minerals is expected to reduce seismic velocity (Hacker et al., 2005; Mainprice et al., 2008). The hotspot may have provided a source of water to accomplish such mineral transformations. Metasomatic alteration has also been proposed in an Archean subduction zone setting, in order to explain a localized and dipping low-velocity zone within the central Slave craton, Canada (Chen et al., 2009). The alteration envisaged for the Reelfoot Rift alternatively could have taken place during the Alleghanian Orogeny during closure of the Iapetus; a NE-SW trending high-density body along the Grenville–Appalachian suture, proposed to be a remnant slab associated with this

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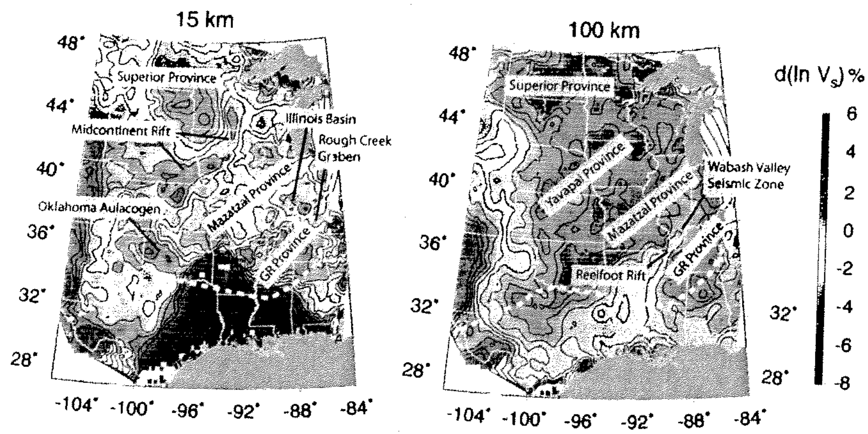


**Fig. 7.** Close-up view of perturbation in $v_s$ with respect to the central US reference model (Fig. 3) in horizontal depth slices at 15 and 100 km depth. Salient features are the shallow expressions of the Midcontinent Rift, Oklahoma Aulacogen, and Rough Creek Graben and the deep expressions of Proterozoic domains (Superior Province, Mazatzal Province, and Granite-Ryolite Province) and the Cambrian Reelfoot Rift. Geologic domains follow Whitmeyer and Karlstrom (2007). Dashed white line is the Grenville front (Thomas, 2006).

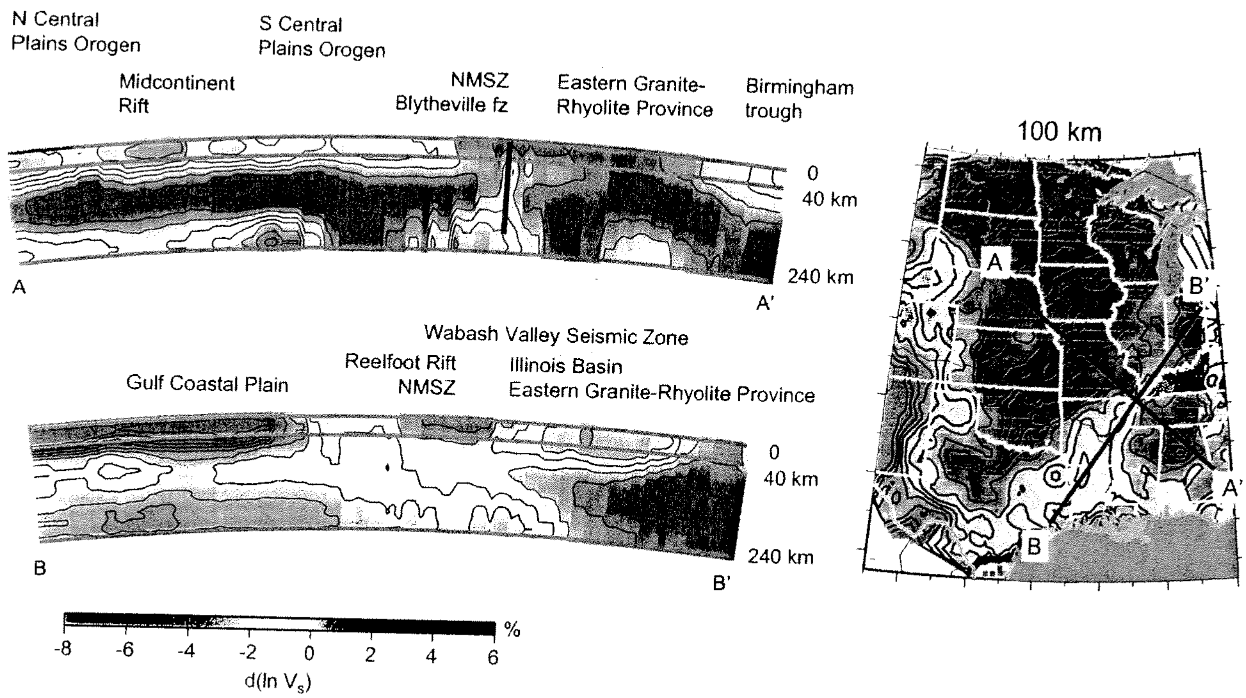


**Fig. 8.** Perturbation in $v_s$ along two vertical cross-sections passing through the NMSZ (locations in inset). Geologic domains follow Van Schmus et al. (1996).

closure (Mooney and Kaban, 2010, Fig. 13, based on the gravity modeling), supports this possibility. In any case, layered phyllosilicates are generally weak and susceptible to sliding in the stable-sliding regime (Peacock and Hyndman, 1999; Moore and Lockner, 2007); if this regime exists in the uppermost mantle beneath the Reelfoot Rift it could provide a mechanism for lowering of its shear strength.

(2) Ascending magma from the hotspot may have emplaced primitive mantle into the mantle below the Reelfoot Rift. Such mantle is relatively dense due to enrichment of Fe relative to the surrounding mantle of the East Granite-Ryolite Province, which is likely depleted, and this compositional difference will also lower $v_s$. This mechanism, involving emplacement of fertile melts in a pre-existing weak zone, has also been proposed by Villemaire et al. (2012) to explain low-velocity mantle beneath the trace of the Great Meteor hotspot beneath southeast Canada, particularly where it intersects the Ottawa-Bonnechere graben, a late Precambrian failed rift zone. A significant residual thermal anomaly is unlikely given the 100 Myr age of the last known heating event. This is supported by the formation of the Mississippi Embayment through subsidence within 30 Myr after passage of the Bermuda hotspot (Van Arsdale and Cox, 2007); further cooling is expected to produce only a low-amplitude and long-wavelength residual thermal anomaly, as indicated by thermal calculations of the temperature anomaly expected ~100 Myr after a hotspot-induced heating event (Eaton and Frederiksen, 2007).

Lateral discontinuities in mantle seismic velocity may signify a discontinuity in shear strength, as suggested above, or a discontinuity

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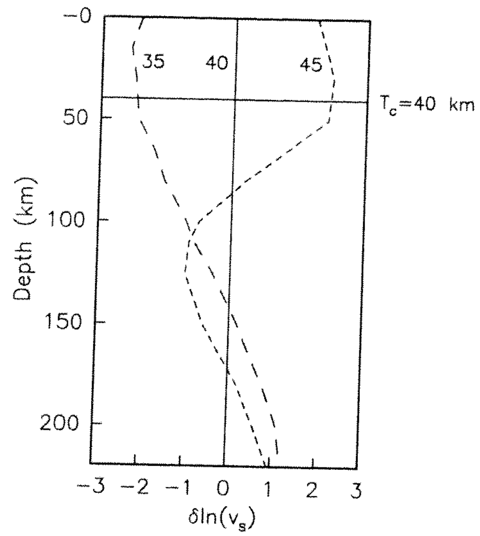


**Fig. 9.** Bias in depth-dependent logarithmic shear-velocity resulting from inverting phase velocity data using crustal thickness $T_c$=35 or 45 km when the 'true' thickness is 40 km. Numerals refer to $T_c$ in km.

in mantle viscosity. In the latter case, models of long-term mantle flow indicate that stress concentration in the crust above such a mantle discontinuity may arise from the discontinuous mantle flow field (Vilotte et al., 1986; Neil and Houseman, 1997; Dayem et al., 2009). Observationally, a mantle strength contrast is often correlated with the presence of a major strike–slip fault in plate boundary zones (e.g. San Andreas fault, North Anatolian fault, Kunlun fault) (Molnar and Dayem, 2010).

The NMSZ can be characterized as overlying a 'trough' in mantle strength, bounded by relatively strong lithosphere to its northwest and southeast—dry and depleted rocks that are part of the Granite-Ryolite Province (Fig. S2). This is similar to the situation of the Laguna Salada and related faults which ruptured in the 2010 M7.2 El Mayor-Cucapah earthquake, Baja California, which is located at a trough in mantle viscosity (Pollitz et al., 2012). Stresses within a shear zone underlain by relatively low-viscosity mantle and surrounded by much stronger lithosphere will scale inversely with the width of the shear zone (Pollitz, 2001). The relatively low elastic plate thickness within the shear zone is an effective mechanism for stress concentration around a strike–slip fault zone provided that the boundaries of the shear zone have some 'long term' relative motion, as is typical at an active plate boundary but questionable at the NMSZ (Calais et al., 2010). Whether the mantle flow field applicable to the NMSZ region is an ambient flow field (as would be typical near an active plate boundary) or a passive flow field in response to a recent forcing event, such as deglaciation, remains an open question.

## 5. Conclusions

Using seismic surface-wave imaging we have constrained the seismic shear-wave velocity structure of the CEUS down to about 240 km depth. Our images confirm the presence of high-velocity cratonic lithosphere in areas interior to rifting and convergence episodes of the Proterozoic and early Phanerozoic periods. They also show that traces of this earlier tectonic activity previously recognized in the regional crustal structure, particularly the development of failed rift zones during the opening of the Iapetus Ocean (Liang and Langston, 2008), are also evident in the regional mantle structure.

Most ancient rift zones in the central US are associated with a seismic signature restricted to the crust and shallow (≤65 km depth) mantle. The Reelfoot Rift low-velocity anomaly extends much deeper. The origin of low-velocity rock beneath the Reelfoot Rift and NMSZ is uncertain but is likely related to a combination of factors that resulted in a compositional seismic-velocity anomaly. This includes magmatism associated with early Cambrian failed rifting, further tectonism at the time of closing of the Iapetus, and magmatism related to passage of the Bermuda hotspot beneath the region ca. 100 Ma (Van Arsdale and Cox, 2007). We hypothesize that past magmatic events altered the composition of the mantle through metasomatic mineral transformations and/or the injection of primitive mantle. In any case, the NMSZ possesses a unique characteristic which sets it apart from other ancient rift zones in North America, and the hypothesized compositional heterogeneity may, through a reduction in shear strength or viscosity in the underlying mantle, reduce the effective elastic plate thickness and consequently concentrate stress in the NMSZ.

Our seismic-velocity results are based on seismic surface-wave imaging with coarse vertical resolution and horizontal resolution ~70 km, i.e. on the order of the spacing between TA instruments. The images provide a sketch of the crust and shallow upper mantle structure that will eventually be complemented by body-wave tomography using the TA as well as higher-resolution images expected to result from regional seismic experiments around the ancient rift zones (e.g. Stein et al., 2011; Marshak et al., 2011; Langston et al., 2011). Images of the mantle velocity structure may also be improved through additional estimates of crustal thickness using the Transportable Array, complementing those based on active-source seismology used here, through receiver-function analysis (e.g. Shen et al., 2013).

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## Appendix A. Methodology for determining surface-wave phase-velocity maps

Following the methodology of Pollitz and Snoke (2010), phase velocity maps are derived by modelling the surface wavefield recorded by each event as a solution of the 2-D wave equation on a spherical membrane with laterally varying phase velocity. At a given period, this equation is valid in the presence of smooth structural perturbations (Tromp and Dahlen, 1993; Friederich et al., 2000), and it is further applicable to the case of relatively rough lateral variations (those which change on the scale of one propagating wavelength) provided that the seismic network is dense enough to account for the interference of multiple plane waves arriving from different directions (Friederich et al., 2000). In an approach related to 2-plane and multiplane wave tomography (Friederich and Wielandt, 1995; Forsyth et al., 1998; Pollitz, 1999; Forsyth and Li, 2005; Yang and Forsyth, 2006; Yang et al., 2008), following Pollitz and Snoke (2010) we account for interfering plane waves and local phase velocity structure simultaneously by parametrizing each observed wavefield as a weighted sum of the HG (2-D-Hermite–Gaussian) solutions of Friederich and Wielandt (1995), which implicitly depend upon the local phase velocity. Using observations restricted essentially to a subset of USArray

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stations about a given locality, we solve simultaneously for the sets of event-HG weighting coefficients plus the local phase velocity using a grid search. This method is simpler than conventional multiplane-wave tomography and, by taking advantage of the large number of events observed by local arrays of stations, results in robust estimates of phase velocity over the entire area spanned by the TA.

The HG-paramterized solution of multiple plane waves approximately satisfies the governing equations of coupled surface waves, i.e. Eqs. (2.28)–(2.30) of Zhou et al. (2004). These equations account for scattering from structure off the source–receiver great circle and account for finite-frequency effects implicitly through the allowance of multiple plane waves arriving from a continuum of backazimuths. In other words, within a small region (that surrounding a small number of USArray stations) the HG solutions completely represent surface waves that would be produced from multiple mode branches scattered from off-great-circle structure.

Attenuative dispersion is not accounted for, i.e. infinite $Q$ is assumed for the reference structure. With an actual $Q$ value of about 200 and a frequency range of a factor of 6 used in this study, this would result in systematic errors of $\pm\sim0.15\%$ in phase velocity on the reference structure. This will map into smooth variations in inverted depth-dependent structure of the same magnitude.

The error in local phase velocity is estimated by propagating errors in measured complex amplitude spectra via Eqs. (6) and (7) of Pollitz and Snoke (2010). At a given period and locality, the errors in the complex amplitude spectra are obtained a posteriori by evaluating the residual variance of these spectra after fitting with the HG representation of multiple plane waves. Typical error in phase velocity measurements at all periods is about 0.02–0.05 km/s (e.g. Fig. 6). The lateral resolution is approximately equal to the Gaussian weighting distance used to restrict the observations contributing to phase velocity estimation at a given locality, which is about 50 km (Pollitz and Snoke, 2010, Eq. (12)).

## Appendix B. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.epsl.2013.05.042.

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body in sharks and a regionalized body with a pivoting neck joint and rigid trunk armor in arthrodires. Their evolutionary importance hinges on whether eubrachythoracid musculature is specialized or primitive relative to that of sharks. Placoderms appear to be a paraphyletic segment of the gnathostome stem group (*3*, *4*), so if any components of eubrachythoracid musculature can be shown to be general for placoderms, they can also be inferred to be primitive relative to the crown group. The status of the shallow myoseptal curvature cannot yet be determined in this regard, but the muscles of the neck joint and abdomen have specific skeletal associations that allow such phylogenetic inferences to be drawn.

Most ostracoderms, a grade of jawless stem gnathostomes (*2*) (Fig. 1A), have head shields that also encompass the shoulder-girdle region (*2*). This suggests that the gnathostome shoulder girdle originated through subdivision of the shield. Almost all placoderms have a mobile joint between the skull and shoulder girdle, implying the need for elevator and depressor muscles such as those observed in eubrachythoracids. Thus, a cucullaris operating this joint, antagonistic to specialized epaxial head elevators, is probably primitive relative to the crown gnathostome condition of a cucullaris without specialized antagonists that forms part of a broadly flexible neck.

The transverse abdominal muscles of eubrachythoracids are not as directly tied to a skeletal structure with an identifiable mechanical function. Comparison with those of a recent elephant shark indicates that these muscles are not homologous with any muscles of the pelvic fin or male clasper (supplementary text). However, the transverse abdominals may modulate shear forces between the armor and the laterally undulating body during tail-propelled swimming. A long ventral armor is also present in antiarchs, recovered as the most primitive placoderms in several recent analyses (*3*, *4*, *15*). Transverse abdominal muscles may thus be an attribute of the placoderm segment of the gnathostome stem group and, hence, primitive relative to the absence of such muscles at the base of the gnathostome crown group.

Outside of placoderms, transversely oriented abdominal muscle fibers are restricted to tetrapods and have been regarded as a tetrapod autapomorphy (*16*). Their associated connective tissues and tendons are derived from the somatopleure component of the lateral plate mesoderm (*17*), which plays an important role in hypaxial myogenesis (*18*). In lampreys, the posterior lateral plate mesoderm is not separated into splanchnic and somatopleuric components (*19*), meaning that it cannot give rise to somatopleure-derived structures such as paired fins. The presence of paired fins in placoderms shows that separation of somatopleure and splanchnopleure had occurred, supporting the inference that their transverse muscles may have been patterned by the same somatopleure-based mechanism as in tetrapods.

The arthodires of the Gogo Formation reveal an elaborate regionalized musculature, including the earliest and phylogenetically deepest examples of several muscle types. Particularly surprising is the extensive development of transverse-fiber muscles in the ventral body wall, which parallels the condition in tetrapods. Hypothetical reconstructions are not able to recover the full complexity of this musculature, either on the basis of biomechanical analysis or phylogenetic bracketing, and are thus liable to give a false picture of muscular evolution at the origin of gnathostomes. The study of exceptionally preserved fossils will continue to provide essential data for the reconstruction of vertebrate soft anatomy, particularly in groups with no close living relatives.

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**Supplementary Materials**

www.sciencemag.org/cgi/content/full/science.1237275/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S4
References (*20–30*)
Movie S1


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# Enhanced Remote Earthquake Triggering at Fluid-Injection Sites in the Midwestern United States


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A recent dramatic increase in seismicity in the midwestern United States may be related to increases in deep wastewater injection. Here, we demonstrate that areas with suspected anthropogenic earthquakes are also more susceptible to earthquake-triggering from natural transient stresses generated by the seismic waves of large remote earthquakes. Enhanced triggering susceptibility suggests the presence of critically loaded faults and potentially high fluid pressures. Sensitivity to remote triggering is most clearly seen in sites with a long delay between the start of injection and the onset of seismicity and in regions that went on to host moderate magnitude earthquakes within 6 to 20 months. Triggering in induced seismic zones could therefore be an indicator that fluid injection has brought the fault system to a critical state.


Earthquakes can be induced by underground fluid injection, which increases pore pressure and allows faults to slide under preexisting shear stress (*1*). The increase in wastewater disposal from natural gas development and other sources has been accompanied by an increase in fluid-induced earthquakes in recent years (*2*). These earthquakes include widely felt earthquakes in

Oklahoma, Arkansas, Ohio, Texas, and Colorado (Fig. 1) (*3–7*). Although most injection wells are not associated with large earthquakes, the converse is not true. At least half of the 4.5 moment magnitude ($M_w$) or larger earthquakes to strike the interior of the United States in the past decade have occurred in regions of potential injection-induced seismicity (table S1). In some cases, the onset of seismicity follows injection by only days or weeks (*1, 3, 5*), and the association with pumping at particular wells is clear. In others, seismicity increases only after months or years of active injection (*4, 8, 9*).

A long delay before seismic activation implies that faults may be moving toward a critical state for years before failure. However, currently there are no reliable methods to determine whether a particular field has reached a critical state other than by simply observing a large increase in seismicity. This lack of diagnostics is a key problem in developing operational strategies to mitigate anthropogenic activity (*2*).

Because induced seismic zones are brought to failure by increased pore pressures, we examined whether areas of induced seismicity show a high susceptibility to dynamic triggering by the small transient stresses carried by seismic waves from distant earthquakes. Dynamic triggering in natural settings has been linked to the presence of subsurface fluids, and seismicity rate changes have been shown to depend systematically on the perturbation stress (*10–13*). This suggests that dynamic triggering could serve as a probe of the state of stress in areas of wastewater injection. We refer to earthquakes that are promoted by anthropogenic activity as induced and to earthquakes that are initiated by transient natural stresses as triggered. By this definition, there can be triggered induced earthquakes.

A search of the Advanced National Seismic System (ANSS) earthquake catalog gives preliminary evidence that induced seismic zones are sensitive to dynamic triggering by surface waves (Fig. 1). Regions of suspected induced seismicity showed a pronounced increase in 3.0 $M$ and larger earthquakes spanning at least a 3-day window after large ($M_w \geq 8.6$) remote earthquakes: the 27 February 2010 8.8 $M_w$ Maule, Chile; 11 March 2011 9.1 $M_w$ Tohoku-oki; and 12 April 2012 8.6 $M_w$ Sumatra earthquakes. The broader central United States shows essentially no response to these events (Fig. 1). Most of the triggering is at three sites: Prague, Oklahoma; Snyder, Texas; and Trinidad, Colorado. Suggestively, each of these regions went on to host moderate to large earthquakes (4.3 to 5.7 $M_w$) within 6 to 20 months of the strong triggering.

Although the triggering is significant at the 96% level (table S2), a closer investigation is warranted. We therefore enhanced the catalog by applying a single-station matched filter to continuous waveforms (*14*). The matched-filter approach identifies small, uncataloged earthquakes based on their similarity to target events (*15–17*). Distinct families of earthquakes are distinguished based on the difference in $P$ and $S$ wave travel times ($S$-$P$ time), which gives the approximate radial distance from the seismic station (*15*).

The Cogdell oil field (*8*), located near Snyder, Texas, hosted a seismic swarm in September 2011 that included a 4.3 $M_w$ main shock (supplementary text). The enhanced catalog shows that the Tohoku-oki earthquake triggered a significant number of earthquakes (*14*) at this site (Fig. 2 and table S2). In fact, the rate of earthquakes within the 10 days after the Tohoku-oki earthquake was the highest observed over the entire study duration (February 2009 to present), excluding the days immediately after the 4.3 $M_w$ main shock. The triggered earthquakes show a swarm like signature, typical of fluid-induced earthquakes (*18*), with the largest of the triggered events (3.8 $M_w$, ANSS) occurring after 2.5 days of smaller events (Fig. 2C). The much earlier February 2010 Maule earthquake did not trigger at Snyder, nor did the post-swarm April 2012 Sumatra earthquake.

Prague, Oklahoma, experienced three 5.0 $M_w$ and greater earthquakes in November 2011, associated with fluid disposal in the Wilzetta field (supplementary text) (*4*). The enhanced catalog shows that the February 2010 Maule event triggered a strong sequence of earthquakes near the eventual epicenter of the first 5.0 $M_w$ earthquake (Fig. 3 and table S2). The rate of earthquakes in the several days after the Maule trigger far exceeds that of any other time within the period of observation, up to the $M_w \geq 5.0$ earthquakes themselves, which is similar to the observation at Snyder. There are no events detected within ±32 km relative distance for at least 4 months before the 2010 Maule earthquake.

The largest event in the remotely triggered sequence is a 4.1 $M_w$, 16 hours after the 2010 Maule earthquake, which may account for the large number of earthquakes that continued up to the time of the first 5 $M_w$ Prague earthquake in 2011 (Fig. 3). If the 4.1 $M_w$ earthquake can be considered a foreshock of the subsequent 5.7 $M_w$ Prague earthquake, then the 5.7 $M_w$ event is not only one of the largest earthquakes to be associated with wastewater disposal (*2*) but also one of the largest earthquakes to be linked indirectly to a remote triggering event (*4, 19*).

The April 2011 Tohoku-oki earthquake, which occurred during the ongoing sequence before the 5.7 $M_w$ Prague main shock, did not trigger additional earthquakes near the swarm (Fig. 3 and table S2). The 2012 Sumatra earthquake, on the other hand, followed the main 5.7 $M_w$ Prague earthquake by 5 months and triggered a small uptick in activity that was consistent with the far northeastern tip of the swarm (Fig. 3C). However, this triggered rate change is much smaller than that triggered by the Maule earthquake in 2010.

Trinidad, Colorado, experienced a seismic swarm in August 2011 that included a 5.3 $M_w$ main shock, possibly related to coal-bed methane extraction and reinjection of the produced water in the Raton Basin (supplementary text). The February 2010 Maule earthquake triggered a small but statistically significant response near the site of the 5.3 $M_w$ main shock (Fig. 4 and table S2). Although the total number of triggered events is small (four), the binomial probability of observ-

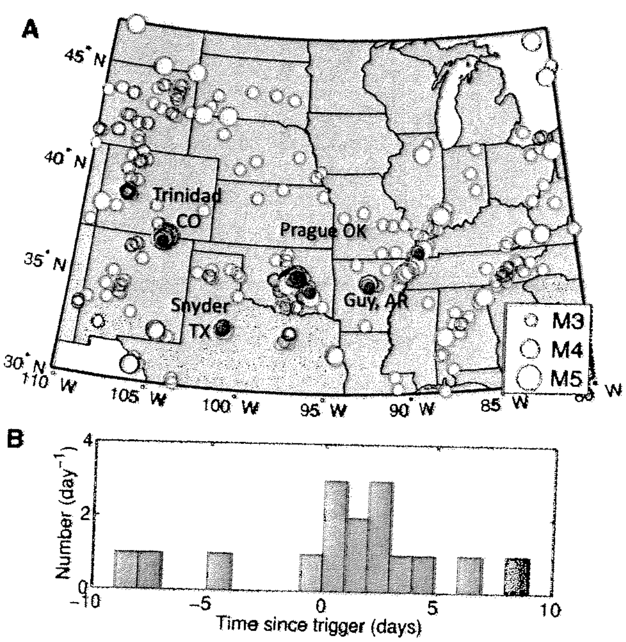


**Fig. 1. Remote triggering in the midwestern United States, from the composite ANSS catalog. (A)** Cataloged earthquakes above 3.0 $M$ between 2003 and 2013 (ANSS). Earthquakes in red occurred during the first 10 days after the February 2010, Maule; March 2011, Tohoku-oki; or April 2012, Sumatra earthquakes. Triggering occurs almost exclusively in three injection fields, labeled Prague, Trinidad, and Snyder. **(B)** Stacked earthquake counts in the 10 days before and after the three ≥8.6 $M_w$ remote earthquakes. The histogram excludes the Guy, Arkansas, swarm, which dominates event rates at the time of the 2011 Tohoku-oki earthquake but did not trigger (supplementary text).

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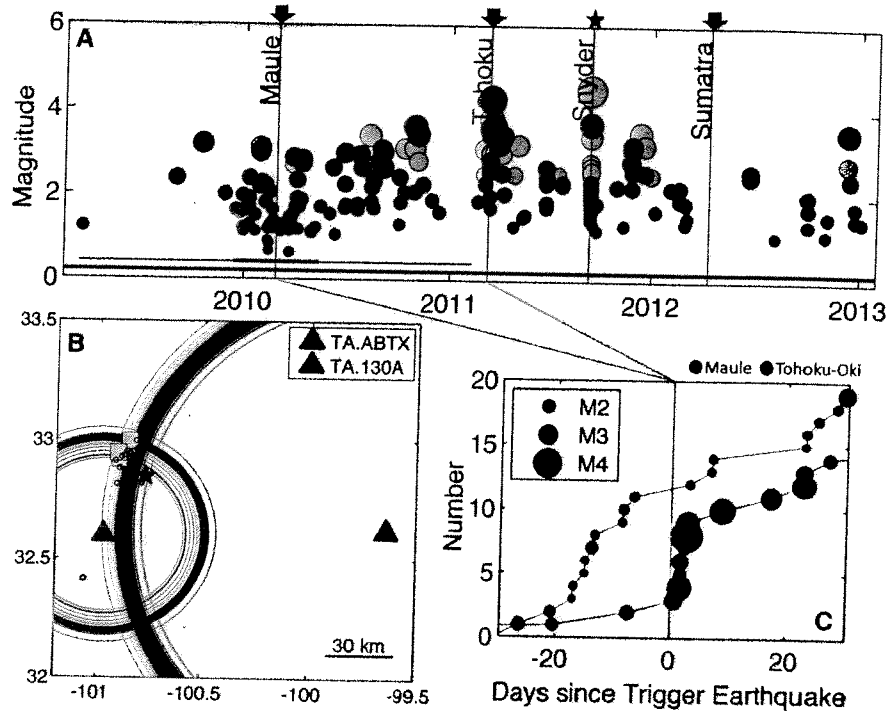


**Fig. 2. Matched-filter enhanced catalog for Snyder, Texas. (A)** Detected events, showing triggering by the 2011 Tohoku-oki earthquake. Symbols along top show strength of triggering (red, strong; green, none). Red star marks 11 September 2011 4.3 $M_w$ main shock (NEIC catalog). Colors correspond to station in (B), with ANSS catalog in gray. Seismometer operating times and the times at which we have enhanced the catalog are shown by thin and thick horizontal bars, respectively. **(B)** Mapped distances to detected events. Small circles are ANSS catalog earthquakes; a red star shows the main shock. Yellow squares are nearby active injection wells. **(C)** Cumulative event count around the 2010 Maule and 2011 Tohoku-oki earthquakes.

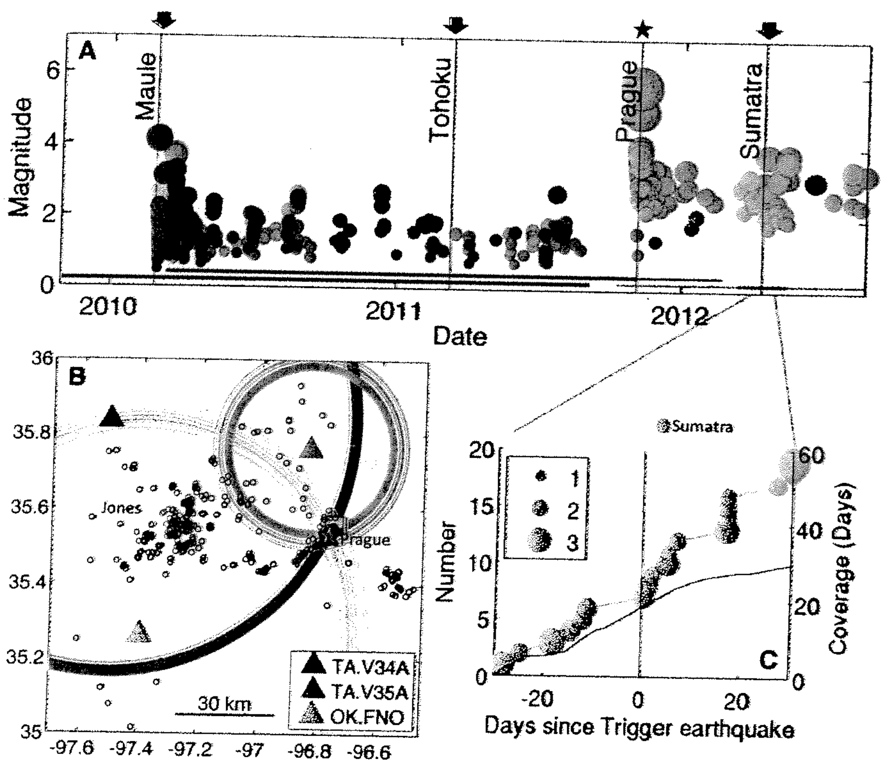


**Fig. 3. Matched-filter enhanced catalog for Prague, Oklahoma. (A)** Detected events, showing triggering by the 2010 Maule earthquake. Red star marks the 6 November 2011 5.7 $M_w$ main shock. Other details are as in Fig. 2A. **(B)** Mapped distances to detected events. Details are as in Fig. 2B. **(C)** Cumulative event count around the 2012 Sumatra earthquake. Cumulative recording time for this intermittently operating station is shown over the same period.

ing this many events in 1 day after the trigger, given five events in the entire previous year, is less than $10^{-5}$.

The March 2011 Tohoku-oki earthquake, which occurred during the active portion of the swarm, did not trigger additional seismicity at Trinidad. The 2012 Sumatra earthquake occurred 8 months after the 5.3 $M_w$ Trinidad main shock and triggered a moderate surge in activity that was consistent with the far edge of the swarm, where previous swarm activity had not occurred (fig. S2). This pattern—strong triggering by the first remote earthquake, none by the second, and marginal triggering after the swarm—is very similar to that observed in Oklahoma.

We examined several other regions in the United States that have experienced moderate magnitude earthquakes or heightened seismicity rates linked to fluid injection, including Guy, Arkansas; Jones, Oklahoma; and Youngstown, Ohio. None of these other regions appear to have responded to remote triggering (supplementary text).

The strongly triggered regions were exceptional in that they had a long history of pumping within 10 km of the eventual swarms yet were relatively quiet for much of that history. At other sites of induced moderate earthquakes (Guy, Arkansas, and Youngstown, Ohio), the lag time between the start of pumping and onset of seismicity was as little as months or weeks, presenting a relatively small window of vulnerability to dynamic triggering before the swarms.

The delay in induced seismicity in some regions could be due to complexities in the local geology (supplementary text). In Oklahoma, injection occurred into a fault-bounded pocket, and pressures may have built up slowly over time because of the size of the reservoir bounded by impermeable faults (*4*). The Cogdell field may have similar isolated pockets, formed by discrete carbonate reefs buried within impermeable shales (*8*).

Fluids have been suggested as an important component in dynamic triggering since early

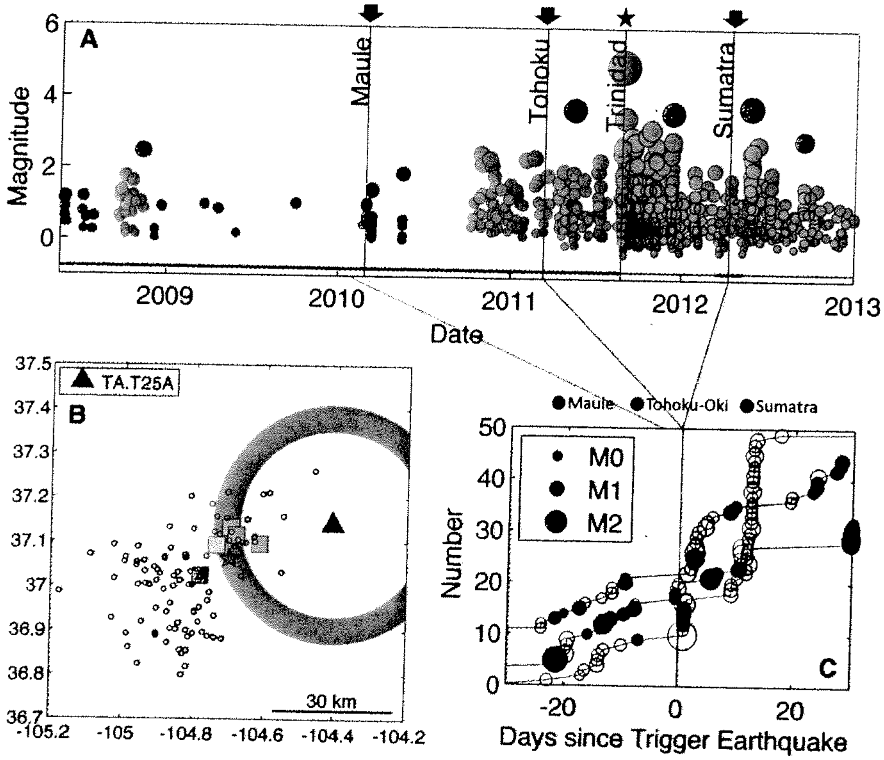


**Fig. 4. Matched-filter enhanced catalog for Trinidad, Colorado. (A)** Detected events, showing triggering by the 2010 Maule earthquake. Red star marks the 23 August 2011 5.3 $M_w$ main shock. Other details are as in Fig. 2A. **(B)** Mapped distances to detected events. Details are as in Fig. 2B. **(C)** Waveform detection counts around the 2010 Maule, 2011 Tohoku-oki, and 2012 Sumatra earthquakes (curves offset for clarity). Filled circles are within 2.5-km radial distance relative to the 5.3 $M_w$ main shock, and open circles are within ~5 km (fig. S2).

observations showed preferential triggering in active volcanic and hydrothermal systems (*13*, *20*, *21*). Some features of our observations are also suggestive of a fluid mechanism for triggering. First, in all of the studied cases the triggered earthquakes occurred with a small delay with respect to the passage of the seismic waves, initiating within less than 24 hours and continuing for days to months afterward. This pattern suggests a triggering mechanism that relies on dynamic permeability enhancement and transport of fluids (*22*, *23*), as has been suggested for natural triggered seismicity (*20*–*22*). In this scenario, stress transients alter the permeability of hydraulic conduits in the reservoir, accelerating diffusion of pore pressure into local faults. Fractures in active injection reservoirs may be particularly susceptible to this mechanism because the injection of unequilibrated fluids may lead to clogging through mineralization and sedimentation. A brief pressure transient may then flush out these clogged fractures (*22*, *24*).

In Prague and Trinidad, only the first of two large remote events caused earthquakes, despite imparting dilational and shear strains that are similar to subsequent events (table S4). This is also consistent with the permeability enhancement model, which requires a certain amount of recharge time between triggering episodes (*24*). After local fault slip is triggered, the local permeability rises dramatically because of microfracturing and dilation (*25*), promoting further fluid diffusion over several rupture dimensions (*26*). Hence, once the seismic swarm is underway the fractures may not return to a state in which they are susceptible to unclogging by small transient stresses.

We find that certain areas of fluid injection are sensitive to small changes in stress associated with the passage of seismic waves from remote large earthquakes. The observations suggest several requirements for an induced region to be sensitive to remote triggering. First, all of the triggered sites in this study had a long history of regional subsurface injection over a period of decades. Second, each triggered site was near to hosting a moderate magnitude earthquake, suggesting critically stressed faults. Last, each site had relatively low levels of seismicity rate in the immediate vicinity (10 km) before the first triggering episode. Remote triggering can therefore indicate that conditions within an injection field have crossed some critical threshold, and a larger induced earthquake could be possible or even likely. This underlines the importance of improved seismic monitoring in areas of subsurface fluid injection.

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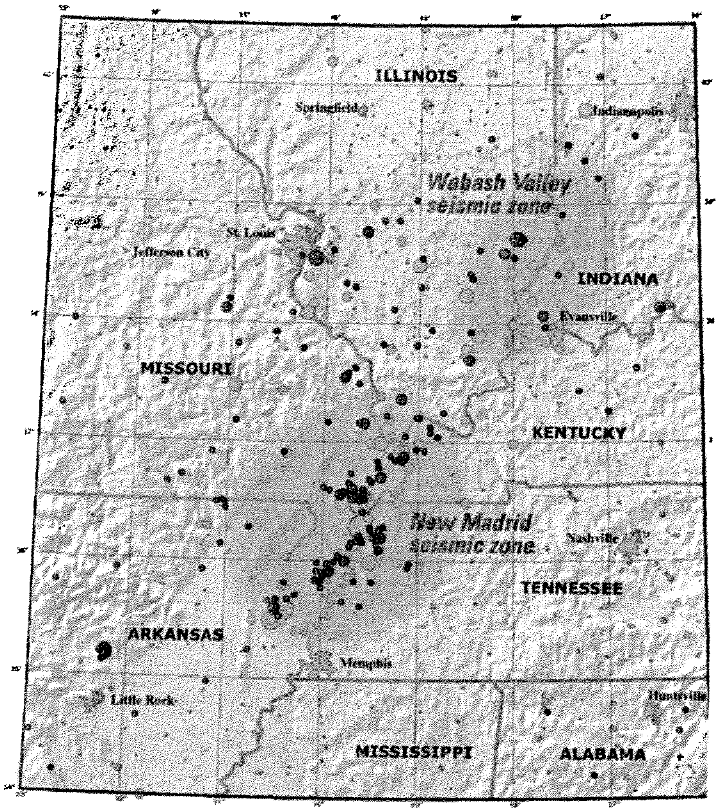
**Supplementary Materials**

www.sciencemag.org/cgi/content/full/341/6142/164/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S5
Tables S1 to S5
References (*27*–*43*)
Database S1

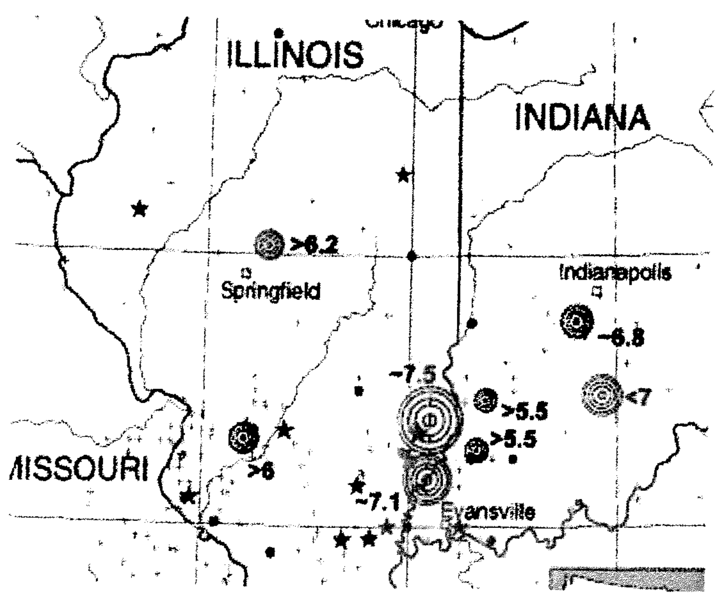
9 April 2013; accepted 23 May 2013
10.1126/science.1238948

**Seismicity, Fracking & Illinois**
**William C. Rau, Illinois Peoples' Action**
**4 September 2013**

### Wabash Valley and New Madrid seismic zones




Source: USGS 2002. Earthquake Hazard in the Heartland. http://pubs.usgs.gov/fs/fs-131-02/fs-131-02.pdf Red circles = earthquakes 1974 to 2002; Green circles = before 1974




Prehistoric quakes, estimated by study of creekbeds, sandblows; http://scienceblogs.com/greengabbro/2008/04/earthquake_in_illinois_whats_u.php

Illinois has two of the most dangerous earthquake or seismic zones in the United States: the New Madrid and Wabash Valley seismic zones. Draw a line from St. Louis to Indianapolis and everyplace below that line in Illinois is earthquake country. Magnitude 6 and 7$^+$ earthquakes have occurred in this area of the state -- and they will occur in the future. Let me repeat: they **WILL** occur again.[1]

This brute geologic fact "spells trouble with a capital T" for those who plan to frack in this area of the state or to use Class II injection wells to dispose of produced water in the same area.

First, consider what a major earthquake does to the land. Here's a description of the 1811-1812 New Madrid Earthquake:

> "The ground rose and fell like waves at sea, tearing open fissures, snapping trees and triggering landslides; waterfalls formed in the Mississippi River, boats were sunk, and islands disappeared. Whole sections of the flood plane were uplifted as other areas subsided, forming swamps and lakes, such as Reelfoot Lake, where upland forests had formerly grown."[2]

Big earthquakes turn soil into liquid--a process call liquefaction-- and would snap oil and gas pipes like violently twisted spaghetti noodles. According to the US Geological Survey, the following would happen:

> "Venting of large quantities of water, sand, and mud as a result of liquefaction could flood fields and roads and disrupt agriculture for weeks to months. Flooding of farmland, where agricultural chemicals are stored onsite, could contaminate rivers and streams."[3]

Compared to frack fluids, agricultural chemicals are pretty tame stuff, so the venting of large quantities of frack fluid tainted water over large areas of Illinois is a recipe for disaster. We're talking about the end of agricultural production in affected areas for many years to come.

Second, large quantities of gas or oil could also be vented. Were these to catch fire, or be ignited out of ecological necessity, Southern Illinois would resemble Kuwait when Saddam Hussein ignited their oil wells before he was evicted by the United States. With frack chemicals also going up in flames, we will have the Mother of all air pollution problems for many, many miles downwind of the inferno.

Third, fluid injection has been linked to increased earthquake activity.[4] Now it's one thing to inject produced water in Texas, Oklahoma, Colorado, or Ohio; it is an entirely different matter to inject fluid in a seismically active, major earthquake zone, such as the New Madrid and Wabash Valley seismic zones.

All in all, fracking and injecting waste water in earthquake zones is so incomprehensible it boggles even a diabolical imagination.

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# Fracking, the Environment, and Health

## New energy practices may threaten public health.

Melissa Owen became concerned when her 10-year-old son developed such severe nosebleeds that she used tampons to stop the bleeding. Soon after, a blistering rash appeared on his skin, and his sister began having similar nosebleeds. The Colorado family's physician attributed these symptoms to air pollution caused by the use of hydraulic fracturing—"fracking"—to extract natural gas in their community. He recommended they move.

In northeastern Pennsylvania, the Micelles family thought signing a lease to allow fracking operations on their farm would relieve some of their financial burden. But within the first week of drilling, Elizabeth Micelles noticed a sweet odor and a metallic taste in her mouth; by the second week, she and her husband and three children were experiencing fatigue, dizziness, vomiting, headaches, and nosebleeds. A visit to their NP and laboratory tests revealed that each had measurable levels of benzene, a known human carcinogen, in their blood.

These acute health problems are common among people living in communities in which "unconventional" oil and natural gas extraction, such as fracking, occurs. (These examples are composites based on the experiences of families affected by fracking as compiled by the Damascus Citizens for Sustainability.[1]) Common symptoms or complications among people living near fracking sites include[2-4]

- fatigue.
- burning eyes.
- dermatologic irritation.
- headache.
- upper respiratory (difficulty breathing), gastrointestinal (severe abdominal pain), musculoskeletal (backache), neurologic (confusion, delirium), immunologic, sensory (smell and hearing), vascular, bone marrow (nosebleeds), endocrine, and urologic problems.
- the risk of endocrine disruption.
- changes in quality of life and sense of well-being.

Longitudinal reports from long-term exposure to contaminated air and water from gas extraction don't exist, but anecdotal reports make clear that the removal of fossil fuels from the earth directly affects human health. It's well known, for instance, that the combustion of fossil fuels emits greenhouse gases that contribute to climate change,[5] and increased rates of asthma, cardiovascular disease, and lung cancer are all associated with our reliance on and use of fossil fuel energy, including coal, oil, and natural gas.[2, 6-8]

Children are at higher risk than adults for developing asthma and suffering complications from asthma owing to poor air quality, which can be caused by the burning of fossil fuels.[9, 10] As the population ages, older adults become more vulnerable to climate-related extremes in temperature and ambient air pollution from fossil fuels because of comorbidities and age-related changes, such as decreased respiratory reserve and the slowing of cardiac compensatory mechanisms.[11-14] Moreover, there are numerous occupational hazards for the fossil fuel extraction workforce, ranging from noise concerns[15, 16] to major injuries[17] and respiratory irritants that result in chronic disease.[18]

Despite these health concerns and efforts to institute a moratorium on fracking until its environmental and health effects are better understood, the United States continues to rely heavily on fossil fuel energy. Currently, 36% of annual U.S. energy consumption is derived from petroleum, 26% from natural gas, 20% from coal, and 8% from nuclear sources, with only 9% supplied by renewable energy, such as wind and solar power.[19] President Obama's administration has repeatedly emphasized its plan to continue development of all energy sources—including a significant expansion of drilling and fracking operations for natural gas and oil. Although the extraction of these nonrenewable sources of energy help the United States to meet its current energy demands and security needs, it's critical that the human and ecologic health threats associated with fracking be better understood and addressed.

### FRACKING

Extracting natural resources trapped within the pore spaces of low-permeable rock, such as shale, typically requires drilling deep—up to 8,000 feet.[20] Using a process called high-volume hydraulic fracturing, or fracking, areas of weakness and small fractures

When Jodie Simons and Jason Lamphere put a lighter to their faucet, the high methane content of the water sets it on fire. Since gas drilling started in their Pennsylvania neighborhood, they've been without clean drinking or bathing water. High levels of methane in drinking water can create a risk of explosions and asphyxiation hazards for households. Photo by Nina Berman / NOOR / Redux.

that already exist in the rock are further opened. Depending on the characteristics and depth of the rock, fracking a single well requires the high-pressure injection of anywhere from 2 to 10 million gallons of water mixed with sand[21] and 80 to 300 tons of hazardous and nonhazardous chemicals.[22]

Colborn and colleagues compiled a list of chemicals known to be used during natural gas extraction.[3] Of the more than 350 that were investigated further, 75% were found to potentially affect the respiratory and gastrointestinal systems, the liver, and various sensory organs. Moreover, more than half of these chemicals could affect the brain and nervous system.[3] It's estimated that 15% to 80% of the fluid containing these chemicals flows back through the well to the surface,[20] where it's usually stored at the well site in tanks or open, lined pits, awaiting transport to treatment facilities or to deep-well injection sites for permanent disposal.

Fracking operations have grown exponentially since the mid-1990s, when technologic advances and increases in the price of natural gas made this technique economically viable. Fracking is currently taking place in Arkansas, California, Colorado, Louisiana, North Dakota, Oklahoma, Pennsylvania, Texas, Virginia, West Virginia, and Wyoming. Other states, such as Alabama, Indiana, Maryland, Michigan, Mississippi, New Jersey, New York, and Ohio, are either considering or preparing for drilling using this method. Vermont has permanently banned fracking, and New York and North Carolina have instituted temporary bans. New Jersey currently has a bill before its legislature to extend a 2012 moratorium on fracking that recently expired, whereas Maryland has decided not to approve fracking permits until a state panel studying its safety has completed its final report, which is expected in mid-2014. Although a fracking moratorium was recently lifted in the United Kingdom, the government is proceeding cautiously because of concerns about earthquakes and the environmental impact of drilling. Fracking is currently banned in France and Bulgaria.

## HEALTH RISKS

It's believed that the potential health consequences of fracking begin at the onset of drilling and may last long after the operation has concluded. Researchers have described an array of environmental factors and health risks associated with fracking and other extraction processes.[6, 23, 24] These include water and air contamination; increased intensity in diesel-truck traffic volume; constant, elevated noise levels; occupational hazards; and stress within rural communities from a swelling population made up of drilling crews



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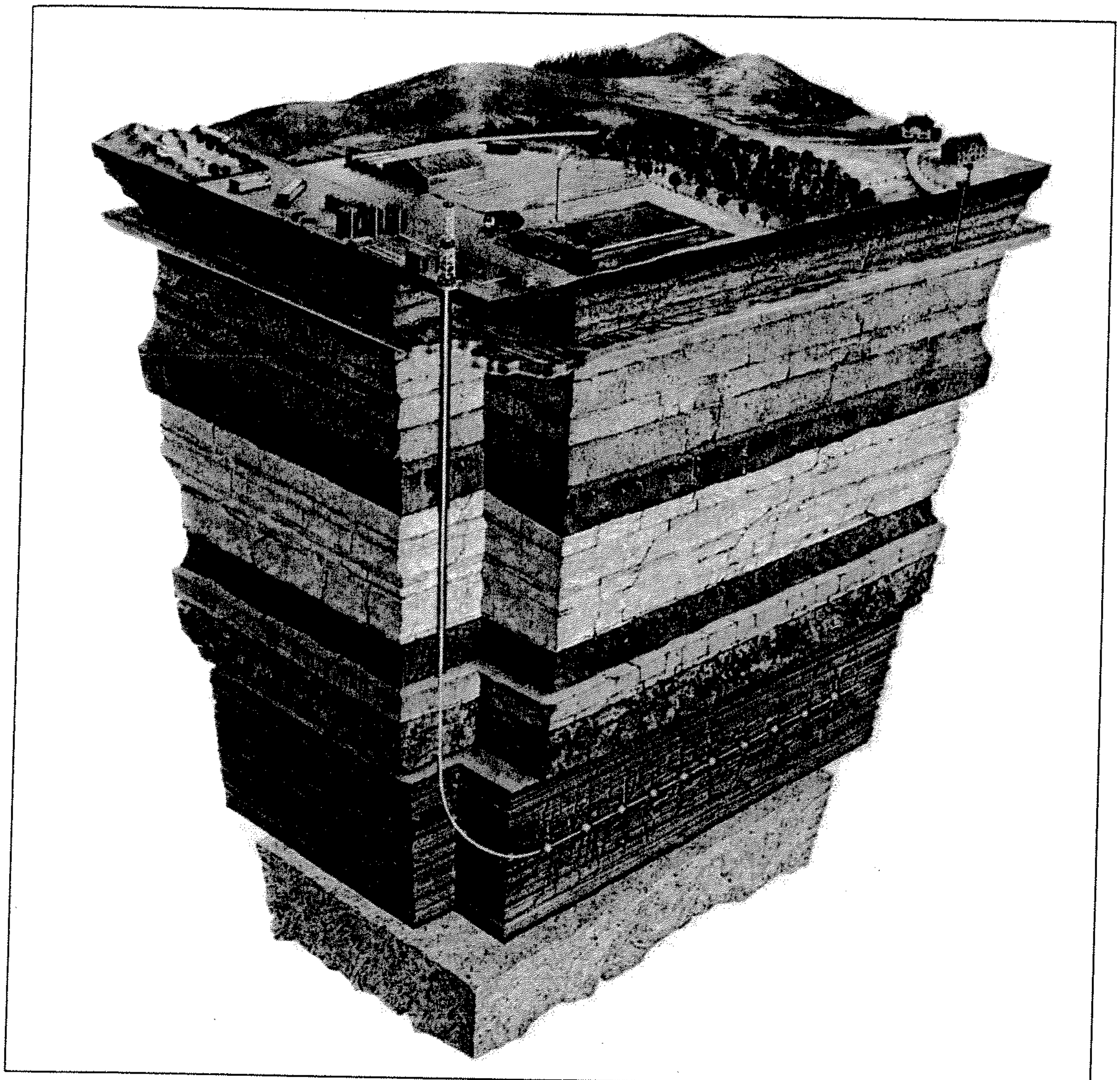

**Figure 1.** In hydraulic fracturing, or fracking—the method used to extract gas from shale deposits—rock layers are fractured by fluids (a mixture of sand, chemicals, and water) pumped under high pressure from the surface (upper left) down through horizontal wells (lower right) to form fissures in the shale. The sand keeps the fissures open, allowing the gas to flow into the well and be taken to the surface. Image by Gary Hincks / Science Source Images.

and related businesses, and the subsequent increased demands on the social and health care infrastructures.[23]

There are also potential economic and ecologic issues, including decreased property values owing to drilling site proximity, drilling malfunctions, and violations of regulations designed to protect the environment, which could lead to long-term environmental and health damages to the surrounding community. Furthermore, compared with conventional gas extraction methods, the fracking process leads to what's believed to be a 30% greater amount of methane "escape."[25] Methane can also leak from the well and during natural gas processing, transport, storage, and distribution.[25]

**Water contamination.** People obtain drinking water from either surface water, which includes rivers and reservoirs, or groundwater aquifers, accessed by public or private wells. There are already a host of documented instances in which nearby groundwater has been contaminated by fracking activities, requiring residents with private wells to obtain outside sources of water for drinking and everyday use.[26,27]

A primary health hazard is methane migration from active drilling sites to aquifers. In Pennsylvania, Osborn and colleagues found that the average methane level was 17 times higher in private drinking-water wells within one kilometer, or about 3,280 feet, of active drilling sites, compared with those in nondrilling areas.[26] High levels of methane in drinking-water supplies create a risk of explosions and asphyxiation hazards for households. In one case, the buildup of methane caused a private drinking-water well to explode.[27] Currently, the U.S. Environmental Protection Agency (EPA) doesn't regulate methane in drinking water, and there is a lack of research on the health effects of chronic exposure to methane in drinking water.[28]

Methane is only one of many chemicals of concern. In Pavillion, Wyoming, the EPA detected high concentrations of benzene, xylenes, purgeable hydrocarbons, and gasoline and diesel by-products in shallow groundwater near fracking-wastewater holding pits.[29] Collectively, these chemicals present risks of neurotoxicity, reproductive problems, and cancer.[30-32] The EPA determined that the most likely cause of the groundwater contamination was leaky pits used to store fracking fluid waste.[29] Groundwater contamination from toxic drilling wastewater poses a health risk to humans, as well as to pets and farm animals that drink or bathe in the contaminated water.

Despite the evidence of health risks related to fracking, communities and health care providers have had limited access to information about the chemicals used in the hydraulic fracturing process, as well as limits placed on their ability to inform and share information about chemical exposures. For example, Pennsylvania's Act 13 of 2012 states that drilling companies are not required to share information about the components or concentration of chemicals if these are deemed proprietary trade secrets.[33] This act also requires that health professionals submit a written request for information on proprietary solutions used in fracking and sign a "confidentiality agreement" identifying that the information is needed to diagnose or treat an individual.

Although exceptions are made for emergency situations, these policies delay nurses' and other health care providers' ability to quickly assess and treat the public or extraction workforce for potentially hazardous exposures. Furthermore, the Pennsylvania law states that health care professionals are not permitted to share exposure information. This hinders the development of effective, evidence-based assessment and treatment practices related to the health effects of these chemicals on exposed patients.[33]

**Air pollution.** The air is significantly impacted by fracking operations, including by the release of methane, which is especially likely during the initial period following hydraulic fracturing injection and during transport of the fuel to customers.[25] Public health threats related to climate change, which is partly a function of the continued release of greenhouse gases like methane, are forecast to be one of the greatest global health concerns of this century.[5] Moreover, high levels of known carcinogens in the air, such as benzene, have been attributed to natural gas drilling operations.[6]

The large fleets of diesel trucks (typically 1,000 to 2,000 per well) that are required to support the fracking process significantly increase ground level ozone and particulate matter[15,34] as well as the risk of traffic accidents.[35] Ground level ozone is a potent pulmonary irritant responsible for reduced pulmonary function and the exacerbation of asthma and emphysema.[36,37] Elevations in particulate matter are responsible for an increased incidence of asthma,[38] cardiovascular disease,[39] chronic obstructive pulmonary disease, and cancer.[40]

**Occupational hazards.** Statistics collected by the Department of Labor and analyzed by the Centers for Disease Control and Prevention show a correlation between drilling activity and the number of occupational injuries related to drilling and motor vehicle accidents, explosions, falls, and fires.[17] Extraction workers are also at risk for developing pulmonary diseases, including lung cancer and silicosis (the latter because of exposure to silica dust generated from rock drilling and the handling of sand).[41] At the well sites, workers can be exposed to dangerously high levels of silica—as many as 79% of hydraulic fracturing sites exceed the National Institute for Occupational Safety and Health standards for silica dust.[18]

Additionally, the extraction workforce is at increased risk for radiation exposure. Fracking activities often require drilling into rock that contains naturally occurring radioactive material (NORM), such as radon, thorium, and uranium.[42-44] Rock cuttings containing NORM may be buried at the drilling site or taken to a landfill. However, NORM is also brought to the surface intermingled with fracking fluids and subsequently deposited in open lined pits or holding tanks as waste.[21] While awaiting permanent disposal, the radioactive materials become concentrated, producing "technologically enhanced NORM" (TENORM).[21,44] Workers may be exposed to TENORM at the drilling site or through the spilling of waste material during transport; and while many TENORM contains low levels of radiation, extraction



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workers and people living near drill sites can potentially be exposed to elevated levels of radiation.[44]

## THE ANA'S STANCE

The "precautionary principle" or approach was developed in recent decades in response to the perceived risk to health and the environment posed by certain activities. This concept places the burden of proving that an activity is safe for human health or the environment, in the absence of scientific consensus, on the entity initiating the activity. This principle has been embraced by the American Nurses Association (ANA), which in 2003 adopted a policy that states that when there's an environmental threat to human health, nurses must advocate for public policies that reduce risk to people and the natural environment.[45] The ANA's policy says: "the Precautionary Principle implies that there is an ethical imperative to prevent rather than merely treat disease, even in the face of scientific uncertainty."

In June 2012, the ANA passed a resolution drafted by the Pennsylvania State Nurses Association entitled "Nurses' Role in Recognizing, Educating and Advocating for Healthy Energy Choices."[45-47] It calls for a national moratorium on new drilling permits for unconventional natural gas and oil extraction based on mounting evidence that fracking leads to human health threats, disruption in communities, and ecologic degradation. It emphasizes the need for nurses to be well versed in the health risks associated with fossil fuel energy and supports their engagement in patient and community education as well as in policy and advocacy work. The resolution asserts that it's critical for nurses to know that safer energy options—such as wind, hydroelectric, solar, and geothermal power—exist, and that state and national policies can help or hinder whether the use of these alternative energy sources is explored.

## NURSING IMPLICATIONS

Addressing our national energy needs while assuring the health of communities and the extraction workforce is a complex and multifaceted issue. Nurses can best promote the health of their patients, the community, and the public by embracing the precautionary approach and supporting energy policies that make human health a priority. The ANA's resolution calling for a moratorium on drilling permits provides a framework for nurses looking to influence energy policy, and calls for self-education and active support of legislation that would require better monitoring and regulation of the fossil fuel industry, particularly in regard to its effect on health.

Nursing and other health professional groups, such as the Alliance of Nurses for Healthy Environments, in addition to federal agencies, have published resources on fracking (see *Evidence-Based Resources on Fracking and Its Health Impacts*). Using these, nurses can gain a better understanding of the issues surrounding fracking and help to educate their colleagues, patients, and other members of their communities while also taking the lead in promoting better monitoring and prevention of the potential health effects associated with fracking.[48] Two of us (RM-L and NK), for example, have previously suggested that community health nurses in Pennsylvania, where there is extensive fracking operations on the Marcellus shale, incorporate evaluation of exposure risk (to air or water that may have been contaminated by drilling operations) into their patient assessments.[48]

### Evidence-Based Resources on Fracking and Its Health Impacts

**Alliance of Nurses for Healthy Environments**
A Web forum on fracking and public health.
http://bit.ly/ZYFBaU

**American Public Health Association**
*Policy Statement: The Environmental and Occupational Health Impacts of High-Volume Hydraulic Fracturing of Unconventional Gas Reserves.*
http://bit.ly/TYv13W

**Natural Resources Defense Council**
Information on the health impacts of natural gas extraction and climate change.
www.nrdc.org/energy/gasdrilling

**Physicians, Scientists, and Engineers for Healthy Energy**
Learning models and continuing education about the health effects of shale gas extraction.
www.psehealthyenergy.org

**Southwest Pennsylvania Environmental Health Project**
Information and assessment tools for health care providers working in gas extraction communities.
www.environmentalhealthproject.org

**U.S. Environmental Protection Agency**
"Questions and answers about EPA's hydraulic fracturing study."
http://1.usa.gov/Zvvl5x

Public and individual health concerns are rarely raised when energy policies are discussed on the state or federal level, and health professionals are typically excluded from these decision-making discussions. As Goldstein and colleagues noted last year, none of the advisory committees formed to investigate drilling activities on the Marcellus shale included representatives of state or federal public health agencies or individuals with expertise in the effects of environmental hazards on human health.[49]

Nurses are being joined in their efforts by a wide range of stakeholders, ranging from the health professionals in the American Public Health Association and Physicians for Social Responsibility, to national organizations such as Breast Cancer Action and Food and Water Watch, to grassroots organizations such as Catskill Mountainkeeper and Frack Free Stark County. Many of the well-known national environmentalist organizations are actively engaged as well, such as the Sierra Club, the Nature Conservancy, and the Natural Resources Defense Council. National Nurses United and the ANA have both called for banning new fracking permits. These two nursing organizations have constituents throughout the country who are engaged in legislative and other policy initiatives regarding fracking.

Both the Maryland Nurses Association and the Pennsylvania State Nurses Association have been actively engaged in efforts to address fracking. The national Alliance of Nurses for Healthy Environments has received several grants to help coordinate nurses' educational and policy efforts on fracking, to keep current on scientific studies, and to develop nursing spokespeople and leadership around this critical issue.

Increasingly, we are seeing nurses on boards, commissions, and advisory councils for environmental health. The national Children's Environmental Health Network has a nurse on its board of directors, and the EPA's Children's Health Protection Advisory Committee has several nurses. Maryland's Commission on Environmental Justice and Sustainable Communities also includes several nurses. Ensuring that nurses are involved with these councils and commissions requires that we be proactive, contacting the chairpersons and staff of such bodies, finding out when a seat will become available, having a state or national nurses association make a nomination or support a nomination, and, or course, finding nurses willing to take on these roles.

Evidence of the negative human and ecologic health effects of fracking are emerging, and it should be noted that sufficient evidence has been presented to the ANA, the American Public Health Association, and the American Medical Association's Resident and Fellow Section to result in a call for a moratorium on the issuance of new fracking permits nationally. Nurses' voices in our communities, in state legislatures, in Congress, and with the EPA can help to keep health issues front and center as we address national energy needs and policies. ▼

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**NRDC** ISSUE BRIEF

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# **In Fracking's Wake:** New Rules are Needed to Protect Our Health and Environment from Contaminated Wastewater


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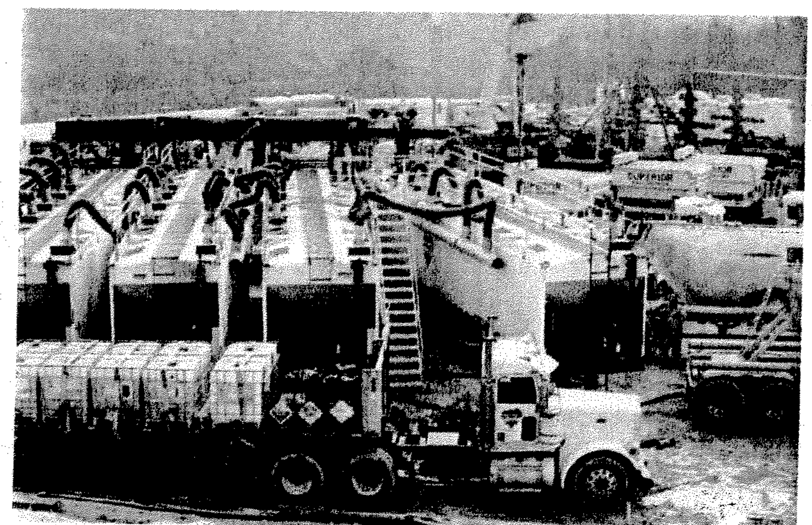

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This report combines an evaluation of federal and state laws regulating fracking wastewater with a thorough review, compiled for NRDC by an independent scientist, of the health and environmental risks posed by this high-volume waste stream and the currently available treatment and disposal methods. It finds that the currently available options are inadequate to protect human health and the environment, but that stronger safeguards at the state and federal levels could better protect against the risks associated with this waste. The most significant of the policy changes needed now are (a) closing the loophole in federal law that exempts hazardous oil and gas waste from treatment, storage, and disposal requirements applicable to other hazardous waste, and (b) improving regulatory standards for wastewater treatment facilities and the level of treatment required before discharge to water bodies.

In examining a number of different fracking wastewater disposal methods that are being used in the Marcellus Shale region, the report finds that although all are problematic, with better regulation some could be preferable while others should not be allowed at all. NRDC opposes expanded fracking without effective safeguards. States such as New York that are considering fracking should not move forward until the available wastewater disposal options are fully evaluated and safeguards are in place to address the risks and impacts identified in this report. Where fracking is already taking place, the federal government and states must move forward swiftly to adopt the policy recommendations in this report to better protect people and the environment.

This paper analyzes the problem of wastewater generated from the hydraulic fracturing process of producing natural gas, particularly with regard to production in the Marcellus Shale.* It shows that, while hydraulic fracturing (often called "hydrofracking" or "fracking") generates massive amounts of polluted wastewater that threaten the health of our drinking water supplies, rivers, streams, and groundwater, federal and state regulations have not kept up with the dramatic growth in the practice and must be significantly strengthened to reduce the risks of fracking throughout the Marcellus region and elsewhere.**

Hydrofracking and the production of natural gas from fracked wells yield by-products that must be managed carefully to avoid significant harms to human health and the environment. These wastewater by-products are known as "flowback" (fracturing fluid injected into a gas well that returns to the surface when drilling pressure is released) and "produced water" (all wastewater emerging from the well after production begins, much of which is salty water contained within the shale formation).

Both types of wastewater contain potentially harmful pollutants, including salts, organic hydrocarbons (sometimes referred to simply as oil and grease), inorganic and organic additives, and naturally occurring radioactive material (NORM). These pollutants can be dangerous if they are released into the environment or if people are exposed to them. They can be toxic to humans and aquatic life, radioactive, or corrosive. They can damage ecosystem health by depleting oxygen or causing algal blooms, or they can interact with disinfectants at drinking water plants to form cancer-causing chemicals.

* This paper focuses primarily on hydraulic fracturing in the Marcellus Shale, although the issues raised herein are relevant anywhere fracking occurs. Thanks to the knowledge gained from years of experience with fracking in the Marcellus, highlighting that region can provide insight for other regions undergoing new or expanded fracking.

** Due to the breadth and depth of this topic, there are certain issues relating to the management of shale gas wastewater that we do not attempt to address in this paper, although they can present important environmental concerns in their own right. These include stormwater issues, accidental spills, waste generated before fracking fluid is injected, and impacts of wastewater management that are not water-related. Also not addressed in this paper are the impacts of water withdrawals for use in the hydraulic fracturing process or impacts from well drilling and development (including contamination of groundwater during hydraulic fracturing).

Because of these risks, shale gas wastewater must be carefully managed. The most common management options currently in use are recycling for additional hydraulic fracturing, treatment and discharge to surface waters, underground injection, storage in impoundments and tanks, and land application (road spreading). All of these options present some risk of harm to health or the environment, so they are regulated by the federal government and the states. But many of the current regulatory programs are not adequate to keep people and ecosystems safe. Consequently, this paper concludes with policy recommendations regarding how the regulation of shale gas wastewater management should be strengthened and improved.

## MANAGEMENT OPTIONS FOR SHALE GAS WASTEWATER

There are five basic options to manage wastewater generated during the production of natural gas from shale formations: minimization of produced water generation, recycling and reuse within gas drilling operations, treatment, disposal, and beneficial reuse outside of operations. On-site options associated with minimization, recycling, and reuse are used mostly for water during the flowback period; off-site treatment and disposal methods dominate the management of produced water.

**Minimization and Recycling/Reuse.** Minimization of wastewater generation and recycling/reuse within operations take place at the well site during drilling. While these have not been popular management choices in oil and gas drilling previously, they are increasingly being used in the Marcellus Shale because traditional off-site disposal methods are not often available in close proximity to wells. On-site recycling can have significant cost and environmental benefits as operators reduce their freshwater consumption and decrease the amount of wastewater destined for disposal. However, it can generate concentrated residual by-products (which must be properly managed) and can be energy-intensive.

**Disposal.** Direct discharge of wastewater from shale gas wells to surface waters is prohibited by federal law. Consequently, when operators want to dispose of wastewater with little or no treatment, they do so predominantly through underground injection. Disposal through underground injection requires less treatment than other management methods, and when done with appropriate safeguards, it creates the least risk of wastewater contaminants' being released into the environment. However, it does create a risk of earthquakes and can require transportation of wastewater over long distances if disposal wells are not located near the production well. Almost all onshore produced water in the U.S. (a category that includes natural gas produced water) is injected, either for disposal or to maintain formation

**Figure 1. Summary of Management Options for Shale Gas Wastewater**

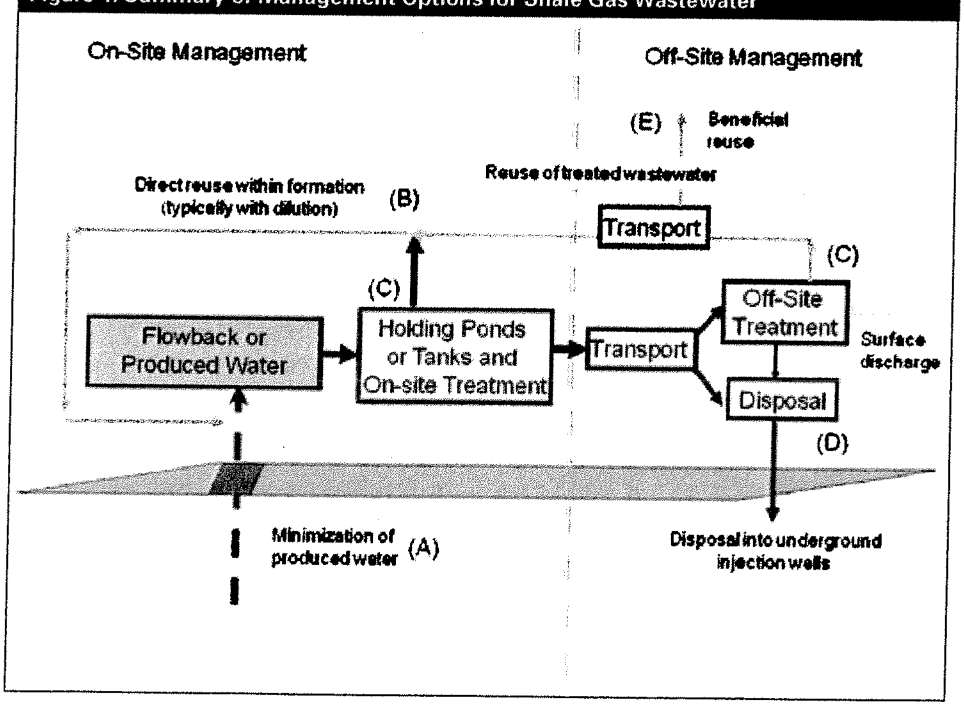




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Figure 2. Technologies for Removing Oil, Grease, and Organics from Produced Water

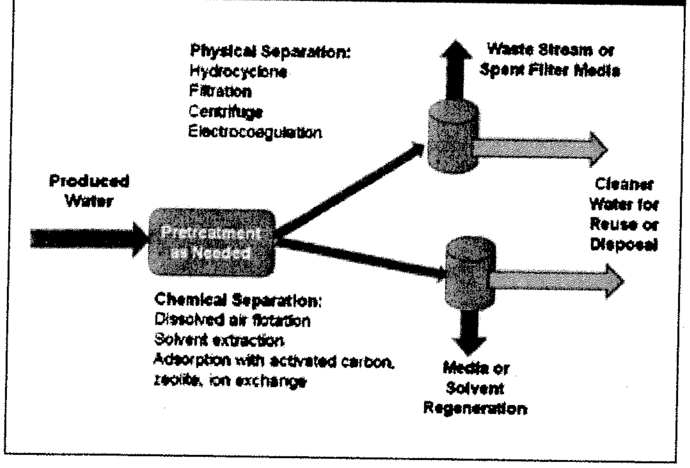
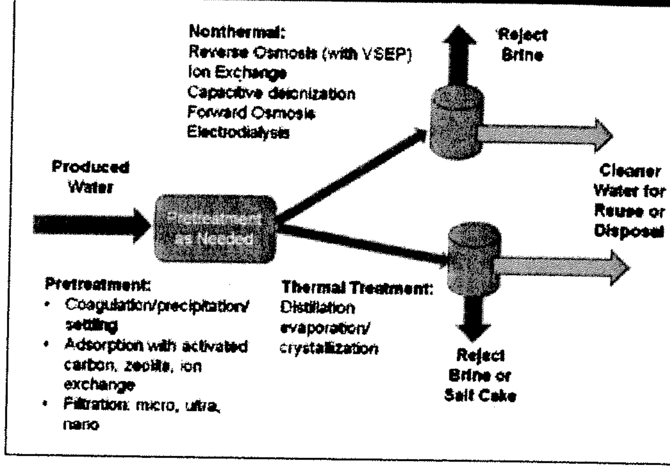



Figure 3. Technologies for Removing Dissolved Ionic Constituents from Produced Water




## TECHNICAL ANALYSIS OF TREATMENT METHODS

Many technologies are available for treating shale gas wastewater. Regardless of the ultimate fate of the wastewater, some degree of treatment is typically necessary. The choice of a specific treatment method will depend on the nature and concentration of the contaminants in the wastewater as well as the intended disposition of the treated water, which determines the necessary levels of pollutant reduction.

Discharge to surface waters requires extensive treatment to protect drinking water supplies and aquatic ecosystems. Reuse may require partial treatment to avoid reintroducing into the next well contaminants that will affect production. Wastewater used in road spreading may also require treatment to reduce pollutant concentrations in runoff. Similarly, when wastewater is injected into disposal wells, partial treatment is often done to minimize the risk of clogging the well.

For any given drilling operation, once the wastewater is characterized and the necessary water quality is known, a treatment system made up of different components can be selected. Treatment begins with removal of suspended solids, inorganic or organic, and then removal of dissolved organics and potentially scale-forming constituents. When all that remains is simple dissolved salts, desalination can be done, as would often be necessary for discharge to surface waters. Additionally, high levels of NORM will require special handling.

Other factors can also influence the selection of appropriate treatment methods, such as the energy intensity of a treatment method and the nature of the residuals generated by treatment. For all types of treatment, the separation of the contaminant from the water will generally require significant chemical and energy inputs, depending upon the process, the quality of the influent wastewater, and the desired quality of the effluent finished water. Likewise, all treatment methods generate a residual waste that contains the contaminants that have been removed or the by-products of their transformation. This residual can be a liquid stream, a solid or sludge product, or a gaseous stream, and it must be managed appropriately to avoid environmental harms. For example, brines and sludges created through treatment processes can be disposed of as solid waste or sent to disposal wells.

Applicable treatment technologies involve chemical, physical, and/or biological processes. These include settling, filtration, coagulation, centrifugation, sorption, precipitation, and desalination. Desalination can be achieved through thermal methods (like vapor compression, distillation, multi-stage flash, dew vaporization, freeze-thaw, evaporation, and crystallization) or non-thermal methods (like reverse osmosis, nanofiltration, electrodialysis, electrodeionization, capacitative deionization, membrane distillation, and forward osmosis). In Pennsylvania, treatment plants use a wide range of technologies like these; however, because desalination is the most energy intensive, many facilities treat only up to the point at which desalination would occur and then repurpose the water for additional activities in oil and gas development.

and several even have complete exemptions for shale gas wastewater (or exemptions for oil and gas wastewater of all kinds, including Marcellus Shale wastewater).

**Treatment and Discharge to Water Bodies.** The Federal Water Pollution Control Act, more commonly called the Clean Water Act, regulates the treatment and discharge of shale gas wastewater into surface water bodies. Under the Act, facilities must obtain permits if they intend to discharge shale gas wastewater, or any by-product resulting from treatment of that wastewater, into a surface water body. These permits contain limitations on pollutants that may be discharged in the wastewater.

Federal regulations completely prohibit the direct discharge of wastewater pollutants from point sources associated with natural gas production. Instead of discharging wastewater directly to surface waters, then, many hydraulic fracturing operators send wastewater to treatment facilities that are authorized to discharge under Clean Water Act permits issued (typically) by the states under authority delegated by the EPA. These facilities include POTWs and CWTs. EPA regulations set pretreatment requirements for the introduction of industrial wastewater to POTWs (known in EPA regulations as "indirect discharge") and for the discharge of industrial wastewater from CWTs. However, the Clean Water Act regulatory program is not comprehensive; for example, there are no pretreatment requirements specifically for shale gas wastewater, and discharge standards for CWTs are out of date.

States may also establish requirements for these discharges that are stricter than the federal standards. For example, the Pennsylvania Department of Environmental Protection (PADEP) has issued regulations implementing the Clean Water Act and the state's Clean Streams Law with industrial waste discharge standards. In 2010 PADEP finalized revisions to state regulations addressing the discharge to surface waters of wastewater from natural gas operations. The regulations prohibit the discharge of "new and expanding" discharges of shale gas wastewater unless the discharge is authorized by a state-issued permit. Such discharges may be authorized only from CWTs; POTWs may be authorized to discharge new or increased amounts of shale gas wastewater only if the wastewater has been treated at a CWT first.

**Underground Injection.** The federal Safe Drinking Water Act (SDWA) regulates the underground injection of wastewater. SDWA establishes the Underground Injection Control (UIC) program. This program is designed to prevent the injection of liquid wastes into underground sources of drinking water by setting standards for safe wastewater injection practices and banning certain types of injection altogether. All underground injections are prohibited unless authorized under this program.

Under the UIC program, the EPA groups underground injection wells into five classes, with each class subject to distinct requirements and standards. Because of a regulatory determination by the EPA not to classify shale gas wastewater as "hazardous" (discussed below), it is not required to be injected into Class I wells for hazardous waste. Rather, shale gas wastewater may be injected into Class II wells for fluids associated with oil and gas production. Class II wells are subject to less stringent requirements than Class I hazardous waste wells.

In the Marcellus region, Maryland, Ohio, and West Virginia have assumed primacy and implement the UIC program. New York, Virginia, and Pennsylvania have not assumed primacy, so the EPA directly implements the UIC program in those states.

**Reuse for Additional Hydraulic Fracturing.** In contrast to the injection of shale gas wastewater as a disposal practice, the injection of fluids (which may include recycled wastewater) for the hydraulic fracturing process itself is exempted from regulation under the federal Safe Drinking Water Act. As a result, if shale gas wastewater is managed or treated for the sole purpose of reuse for further hydraulic fracturing, it is not subject to federal regulation.

However, states can have their own regulations that apply to the reuse of shale gas wastewater. In Pennsylvania, facilities that process wastewater for beneficial reuse may be authorized under PADEP-issued general permits, which establish generally applicable standards. Operations authorized under these general permits do not require individualized permits for wastewater processing.

**Impoundments.** Because of an exemption from federal law (discussed below), the storage and disposal of shale gas wastewater in impoundments is regulated solely by the states. In Pennsylvania, facilities that store and dispose of shale gas wastewater in impoundments must obtain permits under PADEP solid waste regulations, which contain construction and design specifications and operating requirements for those impoundments. Pennsylvania has also enacted a law that limits the ability of municipalities to regulate the siting of impoundments; several municipalities are challenging this law in court.

**Land Application.** Because of an exemption from federal law (discussed below), the land application of shale gas wastewater is regulated primarily at the state level. While Pennsylvania's oil and gas well regulations generally prohibit operators of oil and gas wells from discharging brine and other produced fluids onto the ground, the state's solid waste management regulations state that PADEP may issue permits authorizing land application of waste. Using this authority, PADEP has issued a general permit authorizing

**Reuse for Additional Hydraulic Fracturing.** The hydraulic fracturing process itself should be federally regulated. However, when fracking occurs, reuse of wastewater for additional hydraulic fracturing can offer many benefits (although these benefits can in some cases be offset by energy use and the generation of concentrated residuals). Where appropriate, states should encourage or even require the reuse and recycling of shale gas wastewater.

- Congress should eliminate the Safe Drinking Water Act exemption for hydraulic fracturing to ensure that injection of fracturing fluid will not endanger drinking water sources.
- When the benefits of recycling outweigh disadvantages, states should encourage or require reuse of shale gas wastewater in the hydraulic fracturing process.

**Impoundments and Tanks.** States should prohibit or strictly regulate impoundments to minimize the risk of spills or leakage.

- States should not allow the storage or disposal of shale gas wastewater in open impoundments. Flowback and produced water should be collected at the well and either recycled or directly routed to disposal. In the event that storage of wastewater is necessary, it should be done in closed tanks.
- If states do not prohibit impoundments, they should regulate them more strictly with regard to location, construction, operation, and remediation.
- States should also regulate closed storage tanks more strictly; this regulation should require, among other things, secondary containment.

**Land Application.** Because application of shale gas wastewater to land and roadways can lead to environmental contamination through runoff of toxic pollutants into surface waters, it should be prohibited, or at minimum strictly regulated.

- States should prohibit the land application or road spreading of shale gas wastewater. Other available substances are equally effective but have less environmental impact, and these should be used on roads for dust suppression and de-icing.
- If land application and road spreading are not prohibited, they should only be authorized subject to strict limits on pollutant concentrations and required preventive measures to limit runoff.
- The EPA and states should enforce existing Clean Water Act requirements for controlling polluted runoff from municipal storm sewer systems to ensure that any road spreading does not violate those requirements. The EPA should also complete its ongoing development of new rules to strengthen the CWA stormwater regulatory program.

**Residual Waste.** Just as shale gas wastewater should not be categorically exempt from RCRA hazardous waste regulations, residual waste derived from the treatment of that wastewater should not be exempt from regulation if it displays the characteristics of a hazardous waste.

- Shale gas wastewater treatment residuals should be subject to RCRA's hazardous waste regulations. Congress or the EPA should require that residual waste with hazardous characteristics be regulated as hazardous by eliminating the RCRA hazardous waste exemption for oil and gas wastes.

**Public Disclosure.** Regardless of which treatment or disposal method an operator uses to manage its shale gas wastewater, it should be required to publicly disclose the final destination of the waste.

**Model Regulations.** The federal Bureau of Land Management (BLM) regulations now under development for hydraulic fracturing activities on federal lands should be as protective of health and environment as possible and should include at minimum (to the extent BLM has regulatory jurisdiction) all recommendations set forth in this paper. Since BLM has expansive authority over development of federal oil and gas resources and other activities on federal lands, strong BLM rules could serve as model regulations on which states could base their own.

*NRDC supports establishing a fully effective system of safeguards to ensure that natural gas is produced, processed, stored, and distributed in a way that helps protect our water, air, land, climate, human health, and sensitive ecosystems. NRDC opposes expanded fracking until effective safeguards are in place. For more information on NRDC's position on natural gas and fracking, go to http://www.nrdc.org/energy/gasdrilling/.*

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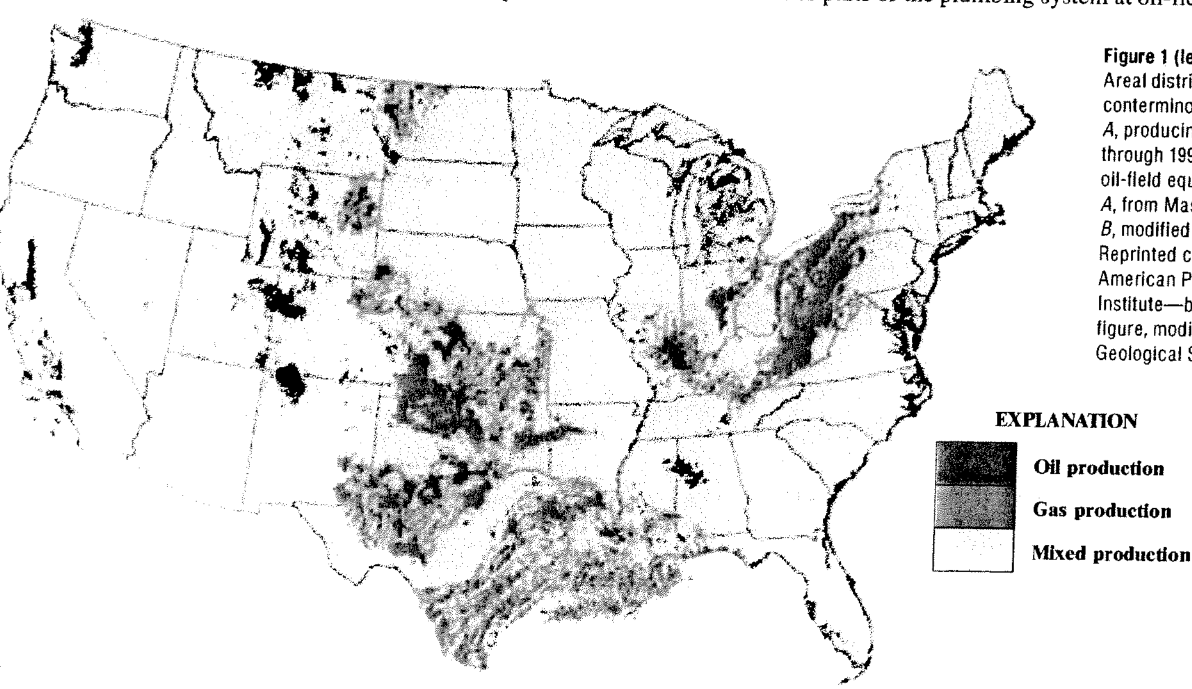
# Naturally Occurring Radioactive Materials (NORM) in Produced Water and Oil-Field Equipment— An Issue for the Energy Industry

## Introduction

Naturally occurring radioactive elements such as uranium, radium, and radon are dissolved in very low concentrations during normal reactions between water and rock or soil. Ground water that coexists with deposits of oil can have unusually high concentrations of dissolved constituents that build up during prolonged periods of water/rock contact. Many oil-field waters are particularly rich in chloride, and this enhances the solubility of other elements including the radioactive element radium. Some of this saline, radium-bearing water is unavoidably brought to the Earth's surface with the oil and must be separated and then disposed, usually by return to depth in an injection well. At some oil-field sites the pipes and tanks that handle large volumes of this "produced water" can become coated with scale deposits that contain radium. Radium-bearing scale is the type of "diffuse NORM waste" that occurs in the oil industry. Radium accumulation in oil-field equipment in the United States first became apparent in the 1980's when scrap metal dealers began to routinely detect unacceptable levels of radioactivity in shipments of oil-field pipe. Since that time the oil and gas industry has sought to better define the extent of the oil-field NORM problem, and to develop techniques for the prediction, prevention, remediation, and disposal of oil-field NORM. In parallel efforts, State and Federal regulatory agencies have worked to develop guidelines for the control of NORM that will adequately protect public health and the environment. This report summarizes current understanding of the composition and mode of occurrence of oil-field NORM in the United States, briefly reviews the status of NORM regulations, and identifies some health and environmental issues associated with oil-field NORM.

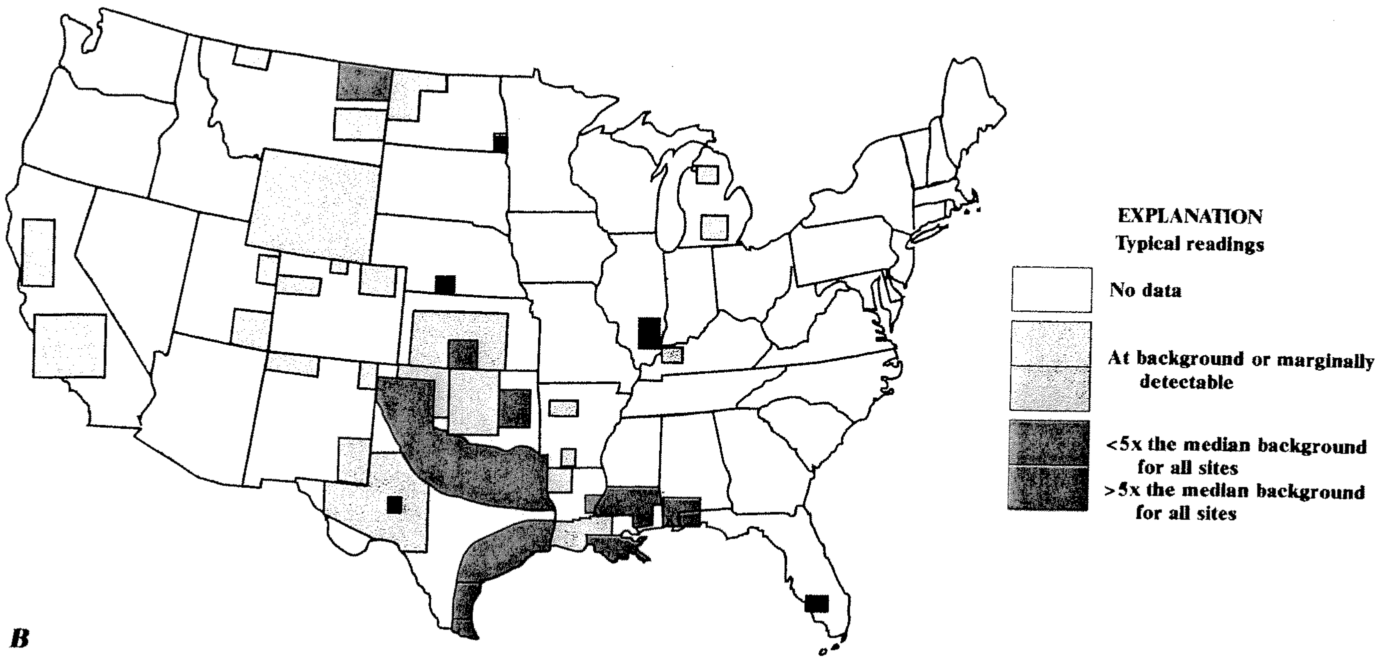
## Location of Oil-Field NORM in the United States

Deposits of oil are found in 30 States, but the vast majority (86 percent) of onshore oil production is concentrated in Texas, Oklahoma, Louisiana, Wyoming, California, Kansas, and New Mexico (fig. 1*A*). In 1989 the American Petroleum Institute sponsored a preliminary nationwide reconnaissance of measurable radioactivity at the exterior surfaces of oil-field equipment (Otto, 1989). The results of this nonstatistical sampling indicated that gamma-ray radiation levels exceeded natural background radiation levels at 42 percent of the sites. Radiation levels greater than five times the median background of all sites were found at approximately 10 percent of the sites. Most of the sites with markedly higher radioactivity were concentrated in specific geographical areas, such as the Gulf Coast, northeast Texas, southeast Illinois, and south-central Kansas (fig. 1*B*). Additional surveys by some State agencies identified radioactive oil-field equipment in northern Michigan and eastern Kentucky. Pipe, casing, fittings, and tanks that have an extended history of contact with produced water are more likely to contain radioactive deposits than other parts of the plumbing system at oil-field production




*A*

**Figure 1 (left and next page).** Areal distribution in conterminous United States of *A*, producing oil and gas wells through 1994, and *B*, radioactive oil-field equipment (next page). *A*, from Mast and others, 1998. *B*, modified from Otto, 1989. Reprinted courtesy of the American Petroleum Institute—based on original API figure, modified by U.S. Geological Survey.




*B*

sites. Soil in the immediate vicinity of production sites may be unusually radioactive if affected by spills or leakage of produced water, or if contaminated by scale removed during pipe or tank cleaning operations. Handling of used pipe at pipe storage yards may also contaminate soil with radioactive scale. Although not discussed herein, some equipment used to process and transport natural gas may contain small amounts of radioactive decay products of radon gas.

## Form of Oil-Field NORM

Oil-field equipment can contain radioactive scale and scale-bearing sludge, both of which form as coatings or sediments. The scale precipitates from produced water in response to changes in temperature, pressure, and salinity as the water is brought to the surface and is processed to separate coexisting crude oil. The scale is typically a mixture of carbonate and sulfate minerals. One of these sulfate minerals is barite (barium sulfate), which is known to readily incorporate radium (Ra) in its structure. Many studies of radioactive scale from oil-field equipment have documented that barite is the primary host of oil-field NORM and that the radioactivity is from isotopes of radium and their decay products. The two radium isotopes present in produced water and barite scale are $^{226}$Ra (half-life =1,600 years) and $^{228}$Ra (half-life =5.8 years). These two isotopes are produced by radioactive decay of uranium and thorium present in rocks of the oil-producing formations. The concentration of dissolved radium is therefore influenced by the abundance of uranium and thorium in reservoir rock and by the accessibility of water to the sites containing uranium and thorium. When radium is brought to the surface in produced water, the concentration of radium that is incorporated in barite scale is largely a function of (1) the concentration of dissolved radium and (2) the amount of produced water that moves past the site of barite precipitation.

Ongoing studies by USGS scientists are documenting variations in the mineralogy, chemistry, and radium concentration of in-place scale deposits. Better understanding of the specific location and texture of the most radioactive barite scale should contribute to more cost-effective strategies for its removal. Figure 2*A* illustrates some of the textural and mineralogical variability in a sample of scale from an old section of above-ground oil-field pipe. Lighter colored barite is present along with variable amounts of darker iron oxides. Barite occurs as intact layers as well as fragments of former layers that were transported and recemented with iron oxides. A corresponding image of radioactivity in this sample (fig. 2*B*) is recorded on a special film and illustrates the variable concentration of radium and its radioactive decay products in these layers.

## Abundance of Radium in Oil-Field NORM

Measurement of total radioactivity with a hand-held radiation detection instrument permits rapid assessment of a site for NORM contamination, but site cleanup criteria and waste disposal options are based on actual concentrations of radium isotopes. Some specialized field instruments permit rapid estimates of the concentration of radium isotopes, but such estimates require confirmation by careful laboratory analysis of selected subsets of samples. Radium concentrations are generally reported as picocuries/gram (pCi/g) of solid material or picocuries/liter (pCi/L) of water or air. A picocurie equals 2.22 disintegrations-per-minute (dpm). Figure 3*A* illustrates the distribution of total radium concentration ($^{226}$Ra and $^{228}$Ra) in barrels of oil-field NORM waste stored in Louisiana in 1992 (Wascom, 1994). The maximum radium concentration in this waste and in most reported oil-field scale from the U.S. is several thousand pCi/g, although very small quantities of scale have been reported with as much as 400,000 pCi/g of radium. For comparison, most natural soils and rocks contain approximately 0.5–5 pCi/g of total radium. A uranium ore sample containing 1 weight percent uranium has approximately 3,300 pCi/g of $^{226}$Ra. Most of the radium in older oil-field scale is $^{226}$Ra, because the shorter lived $^{228}$Ra decays with a half-life of 5.8 years.

Figure 3*B* illustrates the distribution of dissolved $^{226}$Ra concentration in 215 samples of produced water from seven major oil-producing areas (Fisher, 1998). Radium tends to be more abundant in the more saline and chloride-rich varieties of these produced waters. The maximum concentration of dissolved $^{226}Ra$ in this limited data set is several thousand pCi/L, but concentrations above 10,000 pCi/L have been reported in the U.S. Produced water also contains dissolved $^{228}Ra$, which is typically one-half to twice the concentration of $^{226}Ra$. For comparison, the U.S. EPA maximum contaminant level for drinking water is 5 pCi/L for total dissolved radium.

## Regulations for the Control of Oil-Field NORM

There currently exist no Federal regulations that specifically address the handling and disposal of oil-field NORM wastes. States that have enacted specific NORM regulations include some important oil producers such as Texas, Louisiana, New Mexico, and Mississippi. New NORM regulations or modifications to general radiation protection statutes are under consideration in other major oil-producing States such as California, Kansas, and Oklahoma. Standards for cleanup of radium-contaminated soils that typically appear in enacted or proposed NORM regulations call for an average concentration of less than 5 pCi/g in the upper 15 cm (centimeters) of soil and an average of less than 15 pCi/g in deeper increments of 15 cm. Some States allow an average of as much as 30 pCi/g of radium in the upper 15 cm of soil. For oil-field equipment, typical standards for release for other uses or for recycling require that radioactivity at the surface should not exceed some low multiple of natural background radioactivity.

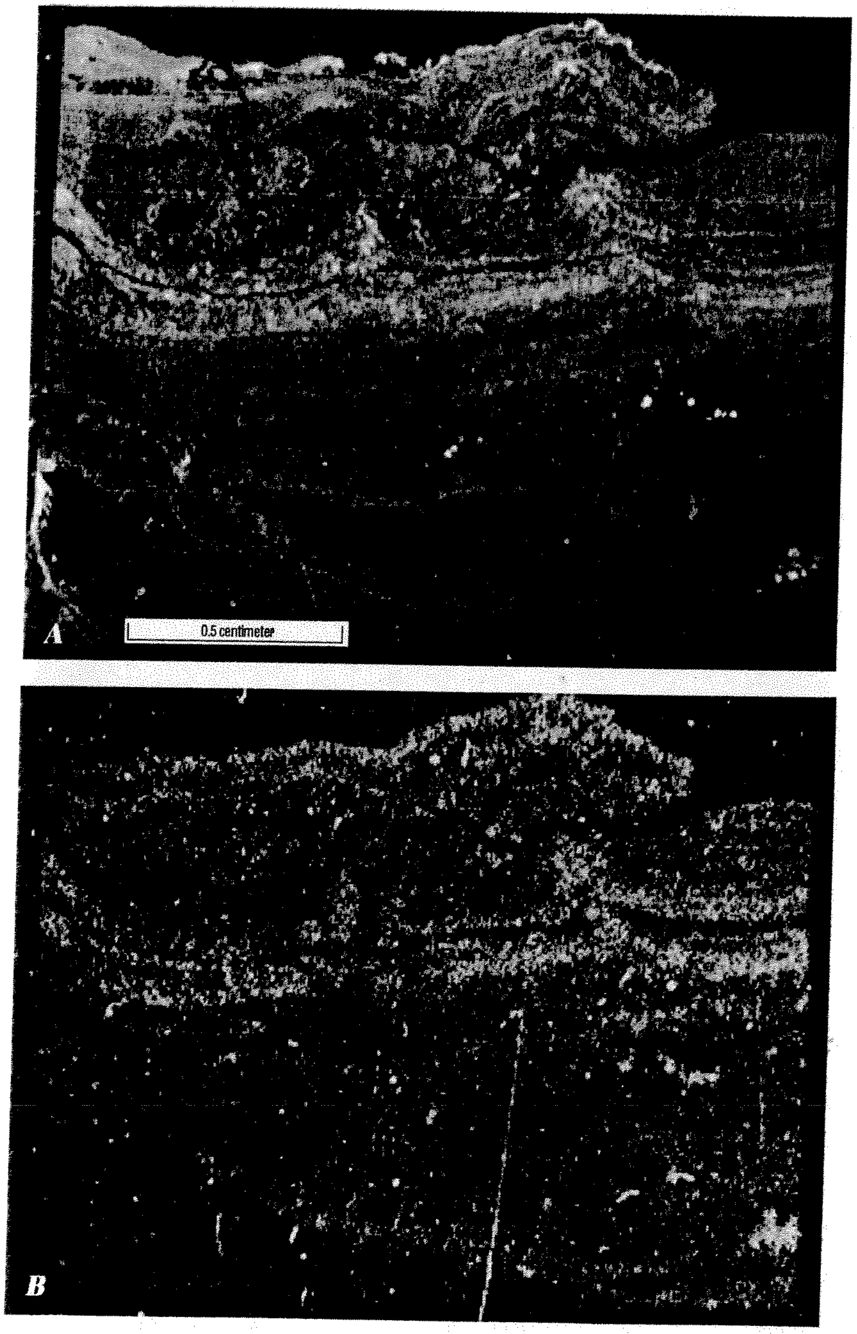


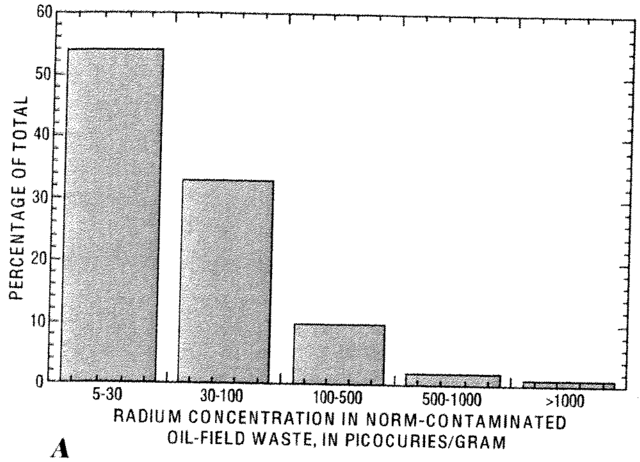

**Figure 2.** Radioactive scale deposits inside oil-field pipe (*A*) and the distribution of alpha-particle-emitting radium and radium decay products in the same sample (*B*). Brighter regions on the alpha emission image indicate areas of scale with higher concentrations of radioactive elements.

## Health and Environmental Issues of Oil-Field NORM

Once formed, barite is a very insoluble mineral. One liter of water at the Earth's surface dissolves only 0.0025 grams of barite. Efficient removal of barite deposits from oil-field equipment requires special chemicals or vigorous mechanical methods. The process of barite removal and disposal is complicated by the need to minimize radiation dose to workers and the general public. Radiation exposure pathways include external gamma radiation (major), ingestion (minor), and inhalation of particulates and radon gas (major).

Figure 4 illustrates the relative isolation of NORM waste from the general public for a variety of possible disposal options. As degree of isolation increases so does the capability for disposing of higher radium concentrations. Currently most oil-field NORM waste is stored at production sites awaiting disposal in specially designated and permitted landfills, disposal wells, or injection wells (fig. 4). Surface spreading and dilution of low-level NORM waste (fig. 4) is a past practice that is now disallowed by most States with NORM regulations. A preliminary radiological dose assessment was reported for a scenario in which individuals live on a NORM-amended soil and consume local water, livestock, and food crops (Smith and others, 1996). For soils amended with radium to the highest concentration under regulatory consideration (30 pCi/g) the additional annual radiation dose by all pathways was equivalent to the average annual background dose to the U.S. population. Current limits set by the Nuclear Regulatory Commission require that the total of such additional doses to the general public be limited to about 30 percent of the average annual background dose.

Prior to 1970 the regulations governing disposal of produced water and scale were less restrictive, and thus older oil-field production sites are more likely to have above-background concentrations of NORM in nearby soils and stream sediments. Several studies, including some by USGS researchers, have documented the presence of barite in soils contaminated with oil-field NORM.



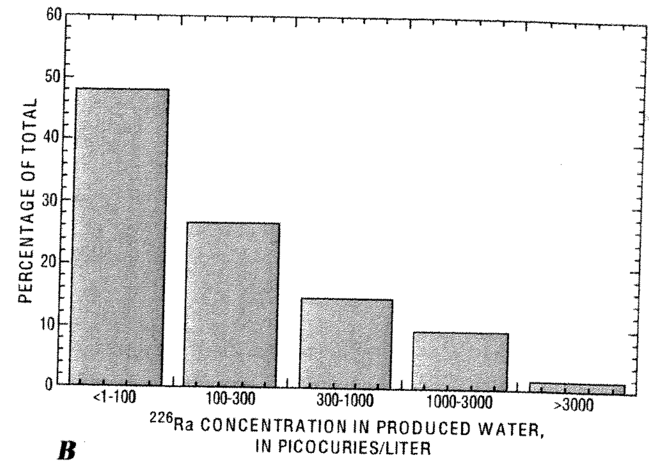




**Figure 3.** Estimated distribution of radium concentration in *A*, solid oil-field waste and *B*, produced water.

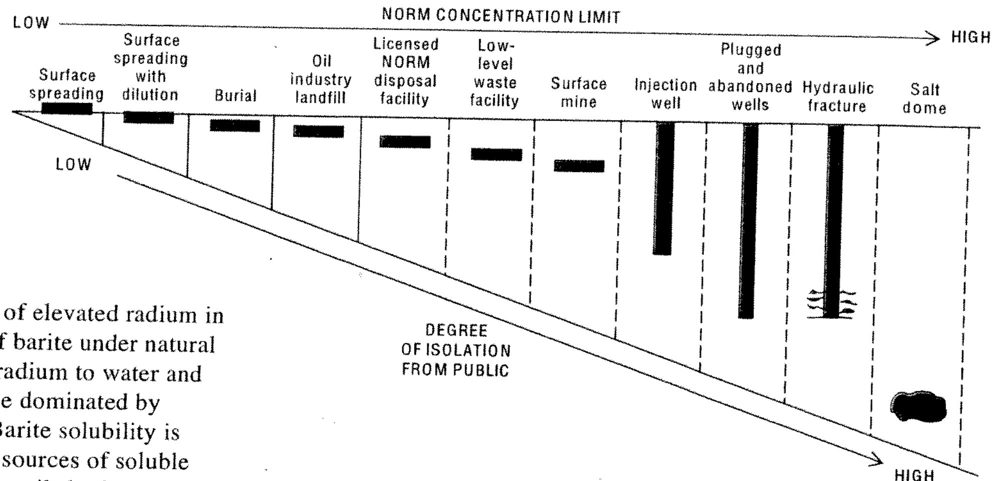



**Figure 4.** Disposal alternatives for NORM wastes. Disposal of more concentrated wastes requires greater isolation of waste from the general public. Modified from American Petroleum Institute (1992). Reprinted courtesy of the American Petroleum Institute—based on original API figure, modified by U.S. Geological Survey.

Barite scale is the most likely host of elevated radium in these soils. The extreme insolubility of barite under natural conditions limits the rate of release of radium to water and suggests that dispersal of radium will be dominated by physical transport of barite particles. Barite solubility is lowest in oxidized soils that are rich in sources of soluble sulfate such as gypsum. In organic-rich soils barite solubility is increased by the action of sulfate-consuming bacteria. The average age of formation of barite scale can be estimated based on the different rates of decay of $^{226}$Ra and $^{228}$Ra, or based on the buildup of radioactive decay products of these radium isotopes. Such information is useful for determining the sources and history of contamination at a site and for assigning possible liability.

## Current Status and Future Direction of the Oil-Field NORM Issue

The magnitude of the oil-field NORM problem in the U.S. has been estimated, but it remains to be completely assessed. Increased industry awareness and understanding of the problem coupled with government regulatory efforts have provided much better control of oil-field NORM wastes and have reduced the radiation exposure to workers and the public. Management of the present inventory of stored oil-field NORM waste and options for its disposal are designed to reduce radiation hazard to the general public. The challenge to the oil and gas industry will be to develop safer and more cost-effective methods to minimize, process, and dispose of future oil-field NORM. An additional challenge to industry and government is to identify, remediate, and if necessary, remove NORM contamination that remains at old or abandoned petroleum production sites.

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# An Exploratory Study of Air Quality near Natural Gas Operations

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**Running Head:** Air Quality near Natural Gas Operations

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**Relevant abbreviations and definitions:**

| | |
|---|---|
| COGCC | Colorado Oil and Gas Conservation Commission |
| Mcf | thousand cubic feet |
| ng/m$^3$ | nanograms per cubic meter |
| NMHCs | non-methane hydrocarbons |
| PAHs | polycyclic aromatic hydrocarbons |
| ppbc | parts per billion carbon |
| ppbv | parts per billion by volume |
| pptv | parts per trillion by volume |
| µg/m$^3$ | micrograms per cubic meter |
| µg/ml | micrograms per milliliter |
| VOCs | volatile organic compounds |

**ABSTRACT**

This exploratory study was designed to assess air quality in a rural western Colorado area where residences and gas wells co-exist. Sampling was conducted before, during, and after drilling and hydraulic fracturing of a new natural gas well pad. Weekly air sampling for 1 year revealed that the number of non-methane hydrocarbons (NMHCs) and their concentrations were highest during the initial drilling phase and did not increase during hydraulic fracturing in this closed-loop system. Methylene chloride, a toxic solvent not reported in products used in drilling or hydraulic fracturing, was detected 73% of the time; several times in high concentrations. A literature search of the health effects of the NMHCs revealed that many had multiple health effects, including 30 that affect the endocrine system, which is susceptible to chemical impacts at very low concentrations, far less than government safety standards. Selected polycyclic aromatic hydrocarbons (PAHs) were at concentrations greater than those at which prenatally exposed children in urban studies had lower developmental and IQ scores. The human and environmental health impacts of the NMHCs, which are ozone precursors, should be examined further given that the natural gas industry is now operating in close proximity to human residences and public lands.

**Key Words:** drilling, endocrine disruptors, hydraulic fracturing, natural gas, non-methane hydrocarbons, PAHs, VOCs.

## INTRODUCTION

Over the past 25 years the U.S. Environmental Protection Agency (USEPA) has supported research on ozone, particulate matter, and VOCs derived from the combustion of gasoline and diesel fuel by mobile and stationary sources. Air quality monitoring has focused primarily on large urban and industrialized areas in and around heavily populated regions across the U.S. and along chemical factory fence lines. Quantitative results dating back several decades are available from studies designed to test detection methodologies and to detect the quantity of selected VOC compounds in large urban areas or specific cities (Baker *et al.* 2008; Mohamed *et al.* 2002; Seila *et al.* 1989). This kind of air sampling has typically been done in regions of ozone non-compliance to determine the source of the precursors to ozone, providing guidance for regulating the source. Studies of urban air have also documented the damage these compounds cause to human health (Brunekreef *et al.* 2009; Chahine *et al.* 2007; Crüts *et al.* 2008; Dejmek *et al.* 2000; Green *et al.* 2009; Koren *et al.* 1989; Perera *et al.* 1999).

In the past two decades, natural gas development and production in the U.S. has increased rapidly by tapping into domestic resources. Natural gas wells are now being drilled in close proximity to urban and rural communities, and across broad expanses of public lands. Potential sources of air pollution from natural gas operations include volatile chemicals introduced during drilling and hydraulic fracturing (in which fluids are injected under high pressure to fracture the underlying formation that holds the gas), combustion byproducts from mobile and stationary equipment, chemicals used during maintenance of the well pad and equipment, and numerous NMHCs that surface with the raw natural gas. The USEPA estimates that on average the mass composition of unprocessed natural gas is 78.3% methane, 17.8% NMHCs, 1.8% nitrogen, 1.5% carbon dioxide, 0.5% hydrogen sulfide, and 0.1% water (Skone *et al.* 2011; USEPA 2011).

Two independent air sampling studies conducted near natural gas fields in Colorado have recently been published. McKenzie *et al.* (2012) measured air quality around the perimeter of natural gas wells from a stationary site among rural residences and ranches, assessing several NMHCs for the purpose of risk assessment. Petron *et al.* (2012) took a regional approach using data collected over 3 years by both fixed and mobile sampling equipment looking for sources and mixing ratios of methane and benzene and several other NMHCs. The authors identified an alkane signature as evidence of oil and gas activity. Both studies indicate a need for better air monitoring and research on air quality near natural gas operations.

The present study was designed to explore the presence of volatile chemicals, many of which are associated with the production of natural gas, in a rural natural gas production area for 1 year. The sampling period spanned the time before, during, and after development of a natural gas well pad. Development included drilling, hydraulic fracturing, and production operations. To our knowledge, no study of this kind has been published to date.

## PROJECT DESIGN

Baseline and weekly air samples were collected between July, 2010, and October, 2011, from a fixed sampling station near a well pad on which 16 vertical (directional) gas wells had been drilled, hydraulically fractured and put into production during the course of the study. Air sample data are presented along with a timeline of events on the well pad, including drilling, fracturing and production dates acquired from the website of the Colorado Oil and Gas Conservation Commission (COGCC). The COGCC serves as the primary government resource for the public regarding oil and gas development in Colorado and maintains a publicly available online information system as part of its oil and gas regulatory processes (COGCC 2012a).

### Sampling Site

Site selection was dictated by our ability to set up a permanent sampling station with access to electricity near a well pad about to be developed. In July, 2010, a permanent air sampling location was selected in Garfield County, Colorado, at approximately 5,850 feet (1783 m) elevation and 0.7 miles (1.1 km) from the well pad of interest. The site was located at a rural residence in semi-arid terrain surrounded by pinyon, juniper, sagebrush, and native grasses. One major highway (I-70) runs through the area, approximately 1.1 miles (1.8 km) north of the sampling site. According to the COGCC (2012a), there were 130 wells producing natural gas within 1 mile (1.6 km) of the sampling site at the time of the study. In addition, two other well pads were developed using vertical drilling within 1 mile (1.6 km) of the sampling site after development of the well pad of interest, and within the timeframe of the study.

### Natural Gas Well Pad

The vertical well pad of interest penetrated the Williams Fork Formation of the Mesa Verde Group at a total depth of approximately 8,300 feet (2530 km) in tight sands (FracFocus 2012). The land for the well pad was cleared of vegetation and leveled and service roads were constructed in the spring of 2010.

According to the COGCC website, drilling of the first of 16 wells started on October 22, 2010, and the last well was started on March 16, 2011. Hydraulic fracturing of the first four wells began on January 4, 2011. Fracturing reportedly began on another five wells on February15, 2011 (not including the seventh drilled well, which was not fractured until April 20th). Between April 14 and 16, 2011, six more wells were fractured. Volumes of hydraulic fracturing fluids ranged between 1.1 and 2.3 million gallons (4.2 and 8.7 million liters) per well (FracFocus 2012). Wells typically went into production within 5 days of being fractured.

According to the COGCC, the well pad was located in a sensitive area with regard to wildlife habitat and water resources, and was in close proximity to surface and domestic water wells (COGCC 2010). This required the operator to abide by a variety of requirements and best management practices designed to minimize impacts. For example, a closed loop drilling system was used that requires drilling fluids to be captured in tanks instead of separated from the cuttings and held in an open pit. A closed loop system was also used to pipe fracturing fluids to the pad and immediately capture the flow back fluids and pipe them to another facility for treatment.

## METHODS

A baseline air sample for VOCs was collected July 17, 2010. A complete set of baseline samples was taken on October 19, 2010. Weekly sampling commenced beginning November 2, 2010 through October 11, 2011. Samples were collected on all dates except for December 28, 2010 because the lab was closed for Christmas. Samples were collected every 7 days and shipped by a trained technician according to standard operating procedure for each instrument (AAC 2012a; SKC Inc. 2001; Tisch Environmental, Inc.). The 24-hour samples were taken weekly from noon Monday to noon Tuesday, and the 4-hour samples were taken from 10:00–2:00 on Tuesdays.

Samples were sent to two USEPA certified laboratories using chain of custody procedures to assure proper handling of the samples from the technician to the lab. VOCs were sampled over a 4-hour period using a Six-Liter Summa Canister. Lab analyses were conducted to test for the following VOCs: 56 speciated C2-C12 hydrocarbons using USEPA Method TO-12/USEPA PAMS Protocol (Photochemical Assessment Monitoring Stations, using gas chromatography/flame ionization detection); methane, using USEPA Method 18 (to detect fixed gases by gas chromatography/flame ionization detection/ thermal conductivity); and 68 target VOCs using USEPA Method TO-15 (to detect VOCs using gas chromatography/mass spectrometry).

PAHs were sampled over 24 hours using a Filter/PUF (Polyurethane) combination. Sixteen PAHs were tested using USEPA Method TO-13A (to detect a select group of PAHs with gas chromatography/mass spectrometry). Carbonyls were sampled over a 4-hour period using a DNPH (2-4 dinitrophenylhydrazine) coated Silica Gel Cartridge, and 12 carbonyls were tested using USEPA Method TO-11A (to detect aldehydes and ketones using high-pressure liquid chromatography with a UV detector).

The 4-hour sampling of VOCs and carbonyls was extended to 6 hours, generally from 9:00 am to 3:00 pm with a few samples taken from 10:00 am to 4:00 pm, beginning April 5, 2011. This change was made upon approval by the lab, in order to accommodate the schedule of the sampling technician. Additionally, due to the high cost of the PAH assay, and the findings of PAH concentrations three orders of magnitude lower than the other NMHCs, PAH sampling was discontinued when drilling on the well pad of interest ended (after March 29, 2011).

The samples from the Summa Canisters and the DNPH Cartridges were analyzed by Atmospheric Analysis & Consulting, Inc., Ventura, CA, a National Environmental Laboratory Accreditation Conference approved air quality analytical laboratory. The Filter/PUF analyses were conducted by American Environmental Testing Laboratory, Inc., Burbank, CA. Quality control data including duplicate and spike recoveries was provided in all laboratory reports. Chemicals analyzed in more than one assay are reported as follows: for hexane, toluene, heptane, benzene, and cyclohexane, TO-12 values were used instead of TO-15; and for acetone, TO-15 values were used instead of TO-11A.

All test values were reported by the laboratories without problems, with the exception of one Summa Canister sample with a pressure problem, and six DNPH Cartridge samples—two with equipment problems and four with visible water contamination. The results of all tests with reported problems were omitted from analysis, resulting in 48 samples reported for VOCs, 21 for PAHs, and 43 for carbonyls.

**Analyses**

Means, ranges, and standard deviations are presented for all chemicals detected at least once. Means were calculated by summing the values for each chemical and dividing by the number of detects for that chemical. Mean, standard deviation, and range values are reported in parts-per-billion (ppbv) or parts-per-trillion (pptv) volume. Conversions from parts-per-billion carbon and $ng/m^3$ were conducted as necessary to arrive at this common reporting unit (AAC 2012b). Sample detection values greater than one standard deviation above the mean for each chemical were defined as spikes. Because of the exploratory nature of the study and the relatively small data set, values for non-detects were not imputed, no data transformations were performed, and statistical tests of significance were not conducted.

**RESULTS**

Chemicals that were tested but never detected (non-detects) are presented in Table 1, along with the Method Reporting Limit (MRL). Shown in Table 2 are basic descriptive statistics for all the VOCs and carbonyls detected at least once during the sampling period, in order of the percent of detections. Among the VOCs, four chemicals were detected in every sample: methane, ethane, propane, and toluene. Chemicals with the highest mean values across the sampling period include (in order of mean value): methane, methylene chloride, ethane, methanol, ethanol, acetone, and propane. Regarding the carbonyls, formaldehyde and acetaldehyde were detected in every sample. The highest values were for crotonaldehyde and formaldehyde. Also shown in Table 2 are the numbers of times each chemical spiked during the sampling period.

Shown in Table 3 are the results for the PAHs, which were sampled from November 2, 2010, to March 29, 2011. Naphthalene was the only PAH detected in every sample and it was also found at the highest concentration among the PAHs detected.

**Related Events on the Well Pad**

Pertinent events on the pad (*e.g.*, start dates for drilling and hydraulic fracturing) are shown in Figure 1. Dates are included for the well pad of interest (Pad #1) as well as for the two pads that were developed during the latter half of sampling (Pads #2 and #3). The percent and number of chemicals detected on each date of sampling is also shown in Figure 1. Percents were calculated by dividing the number of chemicals detected on a particular date by the total number of chemicals analyzed on that day, not including chemicals that were never detected during the study. The number and percent of detections were generally higher during development of Pad #1 than Pads #2-3. The most chemical detections occurred during the first four months of drilling, at a time when only one fracturing event occurred, which did not change the pattern of detections.

The number of spikes on each date of sampling is shown in Figure 2, presented separately by type of compound (VOC, PAH, carbonyl). By far the most spikes occurred during drilling of Pad #1, particularly between mid-December and mid-January. The carbonyls spiked on and around March 15, 2011. There were also spikes beginning in July, 2011, when drilling of Pad #3 began.

## DISCUSSION

The data in this study show that air sampling near natural gas operations reveals numerous chemicals in the air, many associated with natural gas operations. Some of the highest concentrations in the study were from methane, ethane, propane, and other alkanes that have been sourced to natural gas operations (Baker *et al.* 2008; Gilman *et al.* 2012). In contrast we found very low levels of chemicals such as ethene and other alkenes that are more likely to come from urban road-based pollution (Baker *et al.* 2008; Gilman *et al.* 2012). Acetylene, which is only formed from combustion, was found at low concentrations and in only four samples. Isoprene, which arises primarily from vegetation, was only detected in one sample throughout the study, attesting to the semi-arid landscape of the sampling site (Baker *et al.* 2008; Jobson *et al.* 1994). The chemicals reported in this exploratory study cannot, however, be causally connected to natural gas operations.

Air Resource Specialists, Inc. provides quarterly weather reports from Parachute, Colorado, which is 7.4 miles (11.9 km) southwest of the sampling site (Air Resource Specialists, Inc. 2011a, 2011b, 2011c, 2011d). Wind rose data show that the predominant wind directions throughout the year are from the NE and SW, which is aligned with the topography of the valley along the Colorado River Corridor. During all four quarters of the study year the wind blew from the ESE (from the well pad toward the sampling site) 2–3% of the time, independent of the time of year. There was no correlation between detected emissions (which varied by quarter and were highest in the winter) and wind direction.

Calm winds, however, (wind under 1 mph) were greatest during times when detections were highest. For example, in the fourth quarter of 2010, winds were calm 10.9% of the time, and in the first quarter of 2011 they were calm 8.1% of the time. During the second and third quarters of 2011, when air sampling detections were lower, calm winds were reported 3.5% and 1.8% of the time, respectively. Because of the rugged topography of the area under study it is subject to air inversions, particularly in winter, which trap air at ground level and tend to increase air pollution from local sources (Sexton and Westberg *et al.* 1984). The phenomena of air inversions may explain the higher readings during December and January than in other months.

There was a great deal of variability across sampling dates in the numbers and concentrations of chemicals detected. Notably, the highest percentage of detections occurred during the initial drilling phase, prior to hydraulic fracturing on the well pad. This is not surprising, considering the numerous opportunities for release of NMHCs during drilling. On a typical well pad, when the raw natural gas surfaces it is piped to a glycol dehydrator (heater treater) on the pad where it is heated to evaporate off the water, which then condenses and is stored on the pad in tanks marked "produced water". During the heating process numerous NMHCs are vented while others are piped to a condensate tank on the pad. NMHCs also escape when the glycol in the dehydrator is being regenerated. Transferring of fluids from the produced water and condensate tanks to tanker trucks is another opportunity for the release of NMHCs. Next, the gas goes to a compressor station where is prepped and sent on to a processing plant where the BTEXs (benzene, toluene, ethylbenzene, and xylene), and other NMHCs, some of which are liquids at low temperatures are removed. A number of volatile chemicals, such as benzene, toluene, xylenes and others, have economic value and are captured and used to make diverse products such as plastics, glass, construction material, pesticides, detergents, cosmetics, and pharmaceuticals, and in the U.S. they are added to gasoline.

For well pad #1 in the present study, after all the wells were completed and hooked into the national supply line, according to the COGCC the well pad produced 487,652 Mcf (thousand cubic feet) of raw natural gas during June, 2011 (COGCC 2012b). Using the USEPA estimate of

17.8% NMHCs, that calculates to 2,893 Mcf per day of NMHCs potentially released into the air while the pad is producing, although not all the NMHCs are released on-site.

Methylene chloride stood out due to the extremely high concentrations in some of the samples, including one reading of 1730 ppbv, and three other readings more than 563 ppbv (the cutoff value for spikes) during the period of well development. In contrast, after activity on the pad came to an end and the wells went into production, the highest level of methylene chloride detected was 10.6 ppb. Methylene chloride is not a natural component in raw gas, and is predominantly used as a solvent (USEPA 2000). As far as we are aware, it is not a component in drilling or fracturing fluids. It does not appear on two extensive lists of more than 750 chemicals that companies admit they use during either operation (Colborn *et al.* 2011; US House of Representatives Committee on Energy and Commerce Minority Staff 2011) and it does not appear on the voluntary fracturing chemical disclosure registry (FracFocus 2012) for the well pad of interest in this study. However, residents and gas field workers have reported that methylene chloride is stored on well pads for cleaning purposes. Raw gas in the region under study also contains commercially valuable levels of a mixture of alkanes referred to as paraffin wax that becomes solid at ambient temperatures. As the raw gas escapes on the pad, this slippery material could build up on equipment, requiring cleaning. Given that methylene chloride was found in such high concentrations in air samples in the present study, its source and potential exposure scenarios should be explored with respect to exposure of individuals working on the pads and living nearby.

Regarding the PAHs, although concentrations found in this study appear low, they may have clinical significance. Several studies have been published by the Columbia Center for Children's Environmental Health in which pregnant women in urban settings wore personal air monitors that measured their level of exposure to eight PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene). In 2006, Perera *et al.* demonstrated that among children in New York City, those who were prenatally exposed to eight PAHs with a summed concentration greater than 4.16 ng/m$^3$ had lower mental development scores at age three. In 2009, Perera *et al.* reported lower IQ scores among 5-year olds with prenatal exposure greater than 2.26 ng/m$^3$. In a similar study in Krakow, Poland, Edwards *et al.* (2010) found decreased IQ scores among 5-year olds prenatally exposed to PAHs greater than 17.96 ng/m$^3$. In the present study, the summed composite of the same eight PAHs was 15.5 ng/m$^3$. There are many sources of variability when comparing personal air monitoring and ambient air sampling results. For example, not all eight PAHs summed above were detected in every one of our samples. Nonetheless, these findings suggest that the concentrations of PAHs in rural neighborhoods near natural gas operations deserve further investigation, regardless of the source.

The concentrations of the carbonyls were lowest during the time when the VOCs and PAHs were spiking, but spiked later when the other chemicals did not. Many carbonyls, such as formaldehyde and acetaldehyde, are formed from the reaction of VOCs with nitrogen oxide and sunlight, and thus have peak seasons, which may have accounted for the spikes (Ho *et al.* 2002; National Research Council 1981). Carbonyls are also used as solvents and are associated with diesel emissions (ATSDR 1999; Mitran *et al.* 1997). It is possible that solvents were needed following the accident that occurred when a drilling contractor was removing drill cuttings from the mud tanks (COGCC 2011), which coincided with the time the carbonyls spiked in March.

In order to identify potential hazards associated with the chemicals detected during development of the well pad of interest, a rigorous literature search was conducted. Thirty-five chemicals were found to affect the brain/nervous system, 33 the liver/metabolism, and 30 the endocrine system, which includes reproductive and developmental effects. The categories with the next highest numbers of effects were the immune system (28), cardiovascular/blood (27), and the sensory and respiratory systems (25 each). Eight chemicals had health effects in all 12 categories. There were also several chemicals for which no health effect data could be found. The categories of health effects for each chemical are presented in Table 4, which is supported by Supplemental Material available from the authors that contains a complete list of 400 references. It should be mentioned that laboratory studies typically measure exposure to one chemical at a time, while real-life conditions entail exposure to several volatile chemicals at once, with interactions that cannot be predicted.

The health effects found in the literature are relevant as indicators of potential hazards associated with the chemicals detected in the air samples. They do not address the issue of exposure. The concentrations at which these chemicals were detected in the air are far less than U.S. government safety standards such as NIOSH Recommended Exposure Limits and OSHA Permissible Exposure Limits (NIOSH 1992; OSHA 1993). However, government standards are typically based on the exposure of a grown man encountering relatively high concentrations of a chemical over a brief time period, for example, during occupational exposure. Consequently, such standards may not apply to exposure scenarios faced by individuals (including pregnant women, children, and the elderly) experiencing chronic, sporadic, low-level exposure, 24 hours a day 7 days a week in natural gas neighborhoods. Safety standards also do not account for the kinds of effects found from low-level exposure to endocrine disrupting chemicals (Vandenberg *et al.* 2012), which can be particularly harmful during prenatal development and childhood.

Lessons can be learned from the results of this simple exploratory investigation into air quality in a rural neighborhood interspersed with natural gas operations. In retrospect, we regret not having continued sampling PAHs throughout the entire year. It was not until we began searching the literature for health effects of the chemicals that we discovered the developmental effects of extremely low levels of PAHs. In addition, our study would have benefited from more baseline samples. Unfortunately, there was no way to know exactly when drilling would start and we were only alerted when the drill rig was being installed. If we were to sample again, we would rotate sampling every six days and at varied times around the clock. Most importantly, we would record meteorological data on-site throughout each sampling period. In rural mountainous areas, where local topography varies greatly, public sources of weather data may not be applicable for air quality research.

While natural gas development and production continues to spread across the land it is moving closer to homes, schools, and places of business. At the same time more and more raw gas will be released into the atmosphere on a steady, daily basis. In order to determine how to reduce human exposure for both those who work on the well pads and those living nearby, systematic air quality monitoring of natural gas operations must become a regular part of permitting requirements. It is apparent from what is presented in this paper that the NMHCs need far more attention not only because of their potential immediate and long term chronic health effects, but also for their secondary indirect health and environmental impacts as precursors to ozone.

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**Table 1.** Chemicals not detected in air samples in western Colorado from July, 2010 to October, 2011.

| Chemical | CAS# | Reporting limit[a] |
|---|---|---|
| 1,1,1-trichloroethane | 71-55-6 | 0.5 ppbv |
| 1,1,2,2-tetrachloroethane | 79-34-5 | 0.5 ppbv |
| 1,1,2-trichloro-1,2,2-trifluoroethane | 76-13-1 | 0.5 ppbv |
| 1,1,2-trichloroethane | 79-00-5 | 0.5 ppbv |
| 1,1-dichloroethane | 75-34-3 | 0.5 ppbv |
| 1,1-dichloroethene | 75-35-4 | 1 ppbv |
| 1,2,3-trimethylbenzene | 526-73-8 | 1 ppbv |
| 1,2,4-trichlorobenzene | 120-82-1 | 0.5 ppbv |
| 1,2-dibromoethane | 106-93-4 | 0.5 ppbv |
| 1,2-dichloro-1,1,2,2-tetrafluoroethane | 76-14-2 | 0.5 ppbv |
| 1,2-dichlorobenzene | 95-50-1 | 0.5 ppbv |
| 1,2-dichloroethane | 107-06-2 | 0.5 ppbv |
| 1,2-dichloropropane | 78-87-5 | 0.5 ppbv |
| 1,3,5-trimethylbenzene | 108-67-8 | 1 ppbc |
| 1,3-butadiene | 106-99-0 | 0.5 ppbv |
| 1,3-dichlorobenzene | 541-73-1 | 0.5 ppbv |
| 1,4-dichlorobenzene | 106-46-7 | 0.5 ppbv |
| 1,4-dioxane | 123-91-1 | 0.5 ppbv |
| 1-butene | 106-98-9 | 1 ppbc |
| 1-hexene | 592-41-6 | 1 ppbc |
| 1-pentene | 109-67-1 | 1 ppbc |
| 2,2,4-trimethylpentane | 540-84-1 | 1 ppbc |
| 2,2-dimethylbutane | 75-83-2 | 1 ppbc |
| 2,3,4-trimethylpentane | 565-75-3 | 1 ppbc |
| 2,3-dimethylpentane | 565-59-3 | 1 ppbc |
| 2,4-dimethylpentane | 108-08-7 | 1 ppbc |
| 2-hexanone | 591-78-6 | 0.5 ppbv |
| 4-ethyltoluene | 622-96-8 | 0.5 ppbv |
| acenaphthene | 83-32-9 | 2 ng/m$^3$ (pql) |
| acrolein | 107-02-8 | 0.025 µg/ml |
| acrylonitrile | 107-13-1 | 1 ppbv |
| allyl chloride | 107-05-1 | 0.5 ppbv |
| anthracene | 120-12-7 | 2 ng/m$^3$ (pql) |
| benzyl chloride | 100-44-7 | 0.5 ppbv |
| bromodichloromethane | 75-27-4 | 0.5 ppbv |
| bromoform | 75-25-2 | 0.5 ppbv |
| bromomethane | 74-83-9 | 0.5 ppbv |
| carbon disulfide | 75-15-0 | 0.5 ppbv |
| carbon tetrachloride | 56-23-5 | 0.5 ppbv |
| chlorobenzene | 108-90-7 | 0.5 ppbv |
| chlorodifluoromethane | 75-45-6 | 0.5 ppbv |

**Table 1.** (cont.)

| Chemical | CAS# | Reporting limit[a] |
|---|---|---|
| chloroethane | 75-00-3 | 0.5 ppbv |
| chloroform | 67-66-3 | 0.5 ppbv |
| chloromethane | 74-87-3 | 0.5 ppbv |
| cis-1,2-dichloroethylene | 156-59-2 | 0.5 ppbv |
| cis-1,3-dichloropropene | 10061-01-5 | 0.5 ppbv |
| cis-2-butene | 590-18-1 | 1 ppbc |
| cis-2-pentene | 627-20-3 | 1 ppbc |
| dibromochloromethane | 124-48-1 | 0.5 ppbv |
| dichlorodifluoromethane | 75-71-8 | 0.5 ppbv |
| dichlorofluoromethane | 75-43-4 | 0.5 ppbv |
| ethyl acetate | 141-78-6 | 0.5 ppbv |
| fluoranthene | 206-44-0 | 2 $ng/m^3$ (pql) |
| hexachlorobutadiene | 87-68-3 | 0.5 ppbv |
| isooctane | 540-84-1 | 0.5 ppbv |
| isopropyl alcohol | 67-63-0 | 2 ppbv |
| m-diethylbenzene | 141-93-5 | 1 ppbc |
| methyl isobutyl ketone (MIBK) | 108-10-1 | 0.5 ppbv |
| methyl tert-butyl ether | 1634-04-4 | 0.5 ppbv |
| m-ethyltoluene | 620-14-4 | 1 ppbc |
| m-tolualdehyde | 620-23-5 | 0.025 μg/ml |
| n-propylbenzene | 103-65-1 | 1 ppbc |
| n-undecane | 1120-21-4 | 1 ppbc |
| o-ethyltoluene | 611-14-3 | 1 ppbc |
| o-xylene | 95-47-6 | 1 ppbc |
| p-diethylbenzene | 105-05-5 | 1 ppbc |
| propylene oxide | 75-56-9 | 1 ppbv |
| pyrene | 129-00-0 | 2 $ng/m^3$ (pql) |
| t-1,3-dichloropropene | 10061-02-6 | 0.5 ppbv |
| tetrachloroethene | 127-18-4 | 0.5 ppbv |
| trans-1,2-dichloroethylene | 156-60-5 | 0.5 ppbv |
| trans-2-butene | 624-64-6 | 1 ppbc |
| trans-2-pentene | 646-04-8 | 1 ppbc |
| trichloroethene | 79-01-6 | 0.5 ppbv |
| trichlorofluoromethane | 75-69-4 | 0.5 ppbv |
| valeraldehyde | 110-62-3 | 0.025 μg/ml |
| vinyl acetate | 108-05-4 | 1 ppbv |
| vinyl bromide | 593-60-2 | 0.5 ppbv |
| vinyl chloride | 75-01-4 | 0.5 ppbv |

[a]Reporting limit is mrl (method reporting limit) unless pql (practical quantification limit) is specified.

**Table 2.** Volatile chemicals detected in air samples in western Colorado from July, 2010 to October, 2011.

| Chemical name | CAS # | *n* Detects | % Detects | Mean ppbv | Range ppbv | Std Dev ppbv | *n* Spikes |
|---|---|---|---|---|---|---|---|
| **VOCs** | | | | | | | |
| methane | 74-82-8 | 48 | 100 | 2472.9 | 1600.0-5500.0 | 867.3 | 6 |
| ethane | 74-84-0 | 48 | 100 | 24.4 | 3.6-118.0 | 23.7 | 5 |
| propane | 74-98-6 | 48 | 100 | 9.3 | 1.1-46.7 | 9.0 | 7 |
| toluene | 108-88-3 | 48 | 100 | 1.2 | 0.4-4.3 | 0.9 | 4 |
| isopentane | 78-78-4 | 43 | 90 | 1.8 | 0.4-7.3 | 1.3 | 6 |
| n-butane | 106-97-8 | 42 | 88 | 3.2 | 0.8-14.0 | 2.6 | 4 |
| isobutane | 75-28-5 | 42 | 88 | 2.9 | 0.6-13.5 | 2.5 | 4 |
| acetone | 67-64-1 | 41 | 85 | 9.5 | 3.4-28.3 | 6.2 | 6 |
| n-pentane | 109-66-0 | 40 | 83 | 1.5 | 0.4-5.6 | 1.0 | 5 |
| n-hexane | 110-54-3 | 38 | 79 | 0.9 | 0.3-3.0 | 0.6 | 4 |
| methylcyclohexane | 108-87-2 | 36 | 75 | 0.9 | 0.3-3.1 | 0.6 | 4 |
| methylene chloride | 75-09-2 | 35 | 73 | 206.2 | 2.7-1730.0 | 357.4 | 4 |
| m/p-xylenes | 108-38-3/ 106-42-3 | 29 | 60 | 0.4 | 0.2-0.7 | 0.2 | 6 |
| 2-methylpentane | 107-83-5 | 27 | 56 | 0.8 | 0.3-2.2 | 0.4 | 3 |
| n-heptane | 142-82-5 | 22 | 46 | 0.6 | 0.3-1.4 | 0.3 | 3 |
| 3-methylpentane | 96-14-0 | 21 | 44 | 0.8 | 0.3-2.0 | 0.4 | 3 |
| benzene | 71-43-2 | 21 | 44 | 0.5 | 0.3-1.1 | 0.2 | 3 |
| methanol | 67-56-1 | 19 | 40 | 18.3 | 12.1-30.6 | 5.6 | 4 |
| methylcyclopentane | 96-37-7 | 18 | 38 | 0.6 | 0.3-1.3 | 0.3 | 3 |
| cyclohexane | 110-82-7 | 17 | 35 | 0.6 | 0.3-1.6 | 0.4 | 2 |
| n-octane | 509-84-7 | 15 | 31 | 0.4 | 0.2-0.8 | 0.2 | 3 |
| 3-methylhexane | 589-34-4 | 12 | 25 | 0.5 | 0.3-1.1 | 0.3 | 1 |
| 2-butanone (mek) | 78-93-3 | 10 | 21 | 3.4 | 2.3-5.1 | 1.0 | 2 |
| 2-methylhexane | 591-76-4 | 9 | 19 | 0.4 | 0.2-0.7 | 0.2 | 2 |
| ethylene | 74-85-1 | 8 | 17 | 1.2 | 0.8-1.8 | 0.4 | 1 |
| acetylene | 2122-48-7 | 4 | 8 | 1.4 | 0.9-2.4 | 0.7 | 1 |
| isoprene | 78-79-5 | 4 | 8 | 0.6 | 0.4-0.7 | 0.2 | 0 |
| n-nonane | 111-84-2 | 4 | 8 | 0.2 | 0.2-0.3 | 0.0 | 1 |
| 2,3-dimethylbutane | 79-29-8 | 3 | 6 | 0.4 | 0.4-0.5 | 0.1 | 1 |
| ethanol | 64-17-5 | 3 | 6 | 11.4 | 3.2-19.4 | 8.1 | 0 |
| 2-methylheptane | 592-27-8 | 3 | 6 | 0.3 | 0.3 | 0.0 | 0 |
| 1,2,4-trimethylbenzene | 95-63-6 | 2 | 4 | na | 0.2-0.3 | na | 0 |
| tetrahydrofuran | 109-99-9 | 1 | 2 | na | 2.1 | na | 0 |
| styrene | 100-42-5 | 1 | 2 | na | 0.9 | na | 0 |
| ethylbenzene | 100-41-4 | 1 | 2 | na | 0.7 | na | 0 |
| cyclopentane | 287-92-3 | 1 | 2 | na | 0.4 | na | 0 |
| 3-methylheptane | 589-81-1 | 1 | 2 | na | 0.3 | na | 0 |



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**Table 2.** (cont.)

| Chemical name | CAS # | *n* Detects | % Detects | Mean ppbv | Range ppbv | Std Dev ppbv | *n* Spikes |
|---|---|---|---|---|---|---|---|
| isopropylbenzene | 98-82-8 | 1 | 2 | na | 0.3 | na | 0 |
| n-dodecane | 112-40-3 | 1 | 2 | na | 0.3 | na | 0 |
| **Carbonyls** | | | | | | | |
| formaldehyde | 50-00-0 | 43 | 100 | 1.0 | 0.3-2.4 | 0.5 | 6 |
| acetaldehyde | 75-07-0 | 43 | 100 | 0.6 | 0.3-1.8 | 0.3 | 4 |
| crotonaldehyde | 123-73-9 | 42 | 98 | 1.3 | 0.1-3.0 | 0.8 | 8 |
| mek & butyraldehyde | 78-93-3/ 123-72-8 | 37 | 86 | 0.2 | 0.0-0.4 | 0.1 | 7 |
| hexaldehyde | 66-25-1 | 9 | 21 | 0.1 | 0.1-0.2 | 0 | 2 |
| propionaldehyde | 123-38-6 | 6 | 14 | 0.1 | 0.1-0.2 | 0 | 1 |
| benzaldehyde | 100-52-7 | 5 | 12 | 0.1 | 0.1 | 0 | 1 |
| methacrolein | 78-85-3 | 5 | 12 | 0.1 | 0.1 | 0 | 1 |

na = not applicable. Statistics were not calculated for chemicals in which there were fewer than three detections.

**Table 3.** PAHs detected in air samples in western Colorado from October, 2010 to March, 2011.

| Chemical name | CAS # | *n* Detects | % Detects | Mean pptv | Range pptv | Std Dev pptv | *n* Spikes |
|---|---|---|---|---|---|---|---|
| naphthalene | 91-20-3 | 21 | 100 | 3.01 | 0.81-6.08 | 1.44 | 4 |
| phenanthrene | 85-01-8 | 16 | 76 | 0.36 | 0.21-0.61 | 0.14 | 4 |
| fluorene | 86-73-7 | 11 | 52 | 0.20 | 0.15-0.32 | 0.06 | 2 |
| indeno(1,2,3-cd)pyrene | 193-39-5 | 8 | 38 | 0.18 | 0.09-0.49 | 0.13 | 1 |
| benzo(g,h,i)perylene | 191-24-2 | 7 | 33 | 0.22 | 0.09-0.45 | 0.13 | 1 |
| dibenzo(a,h)anthracene | 53-70-3 | 7 | 33 | 0.20 | 0.11-0.51 | 0.15 | 1 |
| benzo(a)pyrene | 50-32-8 | 5 | 24 | 0.21 | 0.13-0.36 | 0.09 | 1 |
| benzo(b)fluoranthene | 205-99-2 | 5 | 24 | 0.20 | 0.13-0.26 | 0.05 | 1 |
| benzo(k)fluoranthene | 207-08-9 | 5 | 24 | 0.18 | 0.13-0.25 | 0.05 | 1 |
| benzo(a)anthracene | 56-55-3 | 2 | 10 | na | 0.13-0.16 | na | 0 |
| chrysene | 218-01-9 | 2 | 10 | na | 0.12-0.16 | na | 0 |
| acenaphthylene | 208-96-8 | 1 | 5 | na | 0.20 | na | 0 |

na = not applicable. Statistics were not calculated for chemicals in which there were fewer than three detections.

**Table 4.** Health effects[a] of chemicals detected in air samples collected in western Colorado.

| Chemical Name | Sens | Resp | Gastr | Brain/ Nerv | Imm -une | Kidn | Card/ Bld | Canc/ Tum | Geno -toxic | Endo | Liver / Met | Othr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,2,4-trimethylbenzene | X | X | X | X | X | X | X | X | X | X | X | X |
| 2,3-dimethylbutane | | | | | | | | | | | | |
| 2-butanone (mek) | | | | X | | X | | | | X | X | |
| 2-methylheptane | | | | | | | | | | | | |
| 2-methylhexane | | | | | | | | | | | | |
| 2-methylpentane | | | | X | | | | | | | | |
| 3-methylheptane | | | | | | | | | | | | |
| 3-methylhexane | | | | | | | | | | | | |
| 3-methylpentane | | | | X | | | | | | | | |
| acenaphthylene | | | | | | | | | | X | X | X |
| acetaldehyde | X | X | X | X | X | X | X | X | X | X | X | X |
| acetone | X | X | X | X | X | X | X | | | X | X | X |
| acetylene | | | | | | | | | | | | |
| benzaldehyde | X | X | X | X | X | X | X | | X | X | X | X |
| benzene | X | X | | X | X | | X | X | X | X | X | X |
| benzo(a)anthracene | X | X | | | | | | X | X | | X | X |
| benzo(a)pyrene | X | X | X | X | X | X | X | X | X | X | X | X |
| benzo(b)fluoranthene | | X | | | X | X | | X | X | X | X | X |
| benzo(g,h,i)perylene | | | | | | | | | X | | | |
| benzo(k)fluoranthene | | | | | X | | X | X | X | X | X | |
| butyraldehyde | | | | X | | | | | | | | |
| chrysene | | X | | | X | X | X | X | X | X | X | X |
| crotonaldehyde | | X | X | X | X | X | X | X | X | X | X | X |
| cyclohexane | | | | X | | X | | X | | | X | |
| cyclopentane | | | | X | | | | | | | | |
| dibenzo(a,h)anthracene | X | X | X | X | X | X | X | X | X | X | X | X |
| ethane | | | | | | | | | | | | |
| ethanol | X | X | X | X | | | X | X | | X | X | X |
| ethylene | | | | | | | | | | | X | X |
| fluorene | X | | | X | X | X | X | | | | X | X |
| formaldehyde | X | X | X | X | X | X | X | X | X | X | X | X |
| hexaldehyde | X | | | X | X | | X | | X | X | | X |
| indeno(1,2,3-cd)pyrene | | X | | X | X | | | X | X | X | X | |
| isobutane | | | | | | | | | | | | |
| isopentane | | | | | | | | | | | | |
| isoprene | X | X | X | X | X | X | X | X | X | X | X | X |
| methacrolein | X | X | | | | | | | | | | |
| methane | | | | | | | | | | | | |
| methylcyclohexane | | | | | | | | | | | | |
| methylcyclopentane | | | | X | | | | | | | | |
| methylene chloride | X | X | X | X | X | X | X | X | X | X | X | X |
| m-xylene | X | X | | X | X | X | X | | | X | X | |
| naphthalene | X | X | X | X | X | X | X | X | X | X | X | X |
| n-butane | | | | X | | | X | | | | | X |

**Table 4.** (cont.)

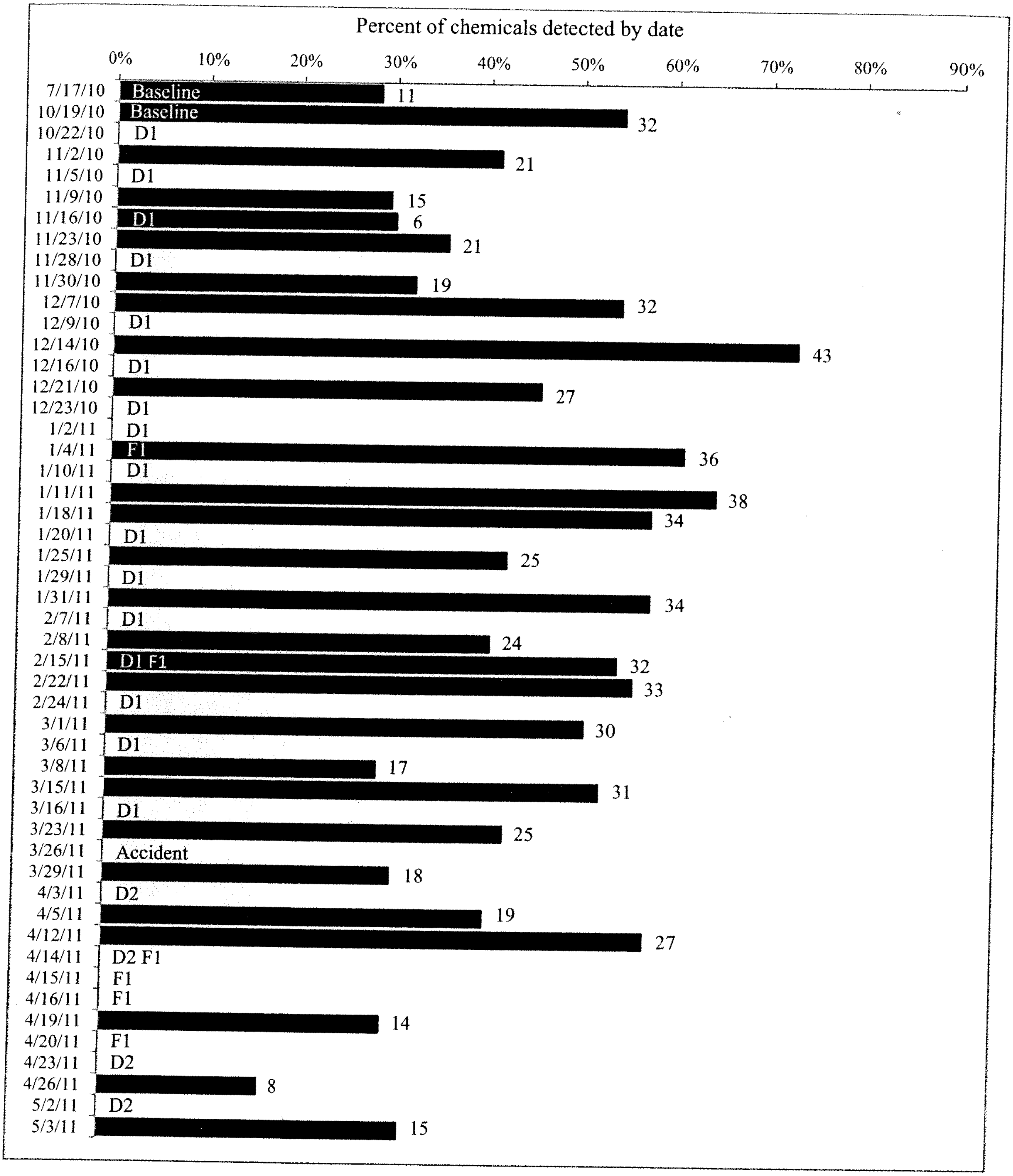
| Chemical Name | Sens | Resp | Gastr | Brain/ Nerv | Imm -une | Kidn | Card/ Bld | Canc/ Tum | Geno -toxic | Endo | Liver /Met | Othr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| n-decane | X | X | | X | X | | | | | | | X |
| n-heptane | X | | | X | | | X | | X | X | X | |
| n-hexane | | | | X | X | | X | | | X | X | |
| n-nonane | X | | | X | X | X | X | | | X | X | X |
| n-octane | X | X | | X | X | X | X | | | X | X | X |
| n-pentane | | | | | | | | | | | | |
| phenanthrene | X | X | | X | X | | X | | | X | X | X |
| propane | | | | | | | | | | | | |
| propionaldehyde | | | | | X | | | | X | | | X |
| propylene | X | X | | X | X | X | | | | X | X | |
| p-xylene | X | X | | X | | X | X | | X | X | X | X |
| tetrahydrofuran | | | X | X | X | X | X | X | X | X | X | X |
| toluene | X | X | X | X | X | X | X | | X | X | X | X |
| Total | 25 | 25 | 14 | 35 | 28 | 23 | 27 | 18 | 23 | 30 | 33 | 29 |

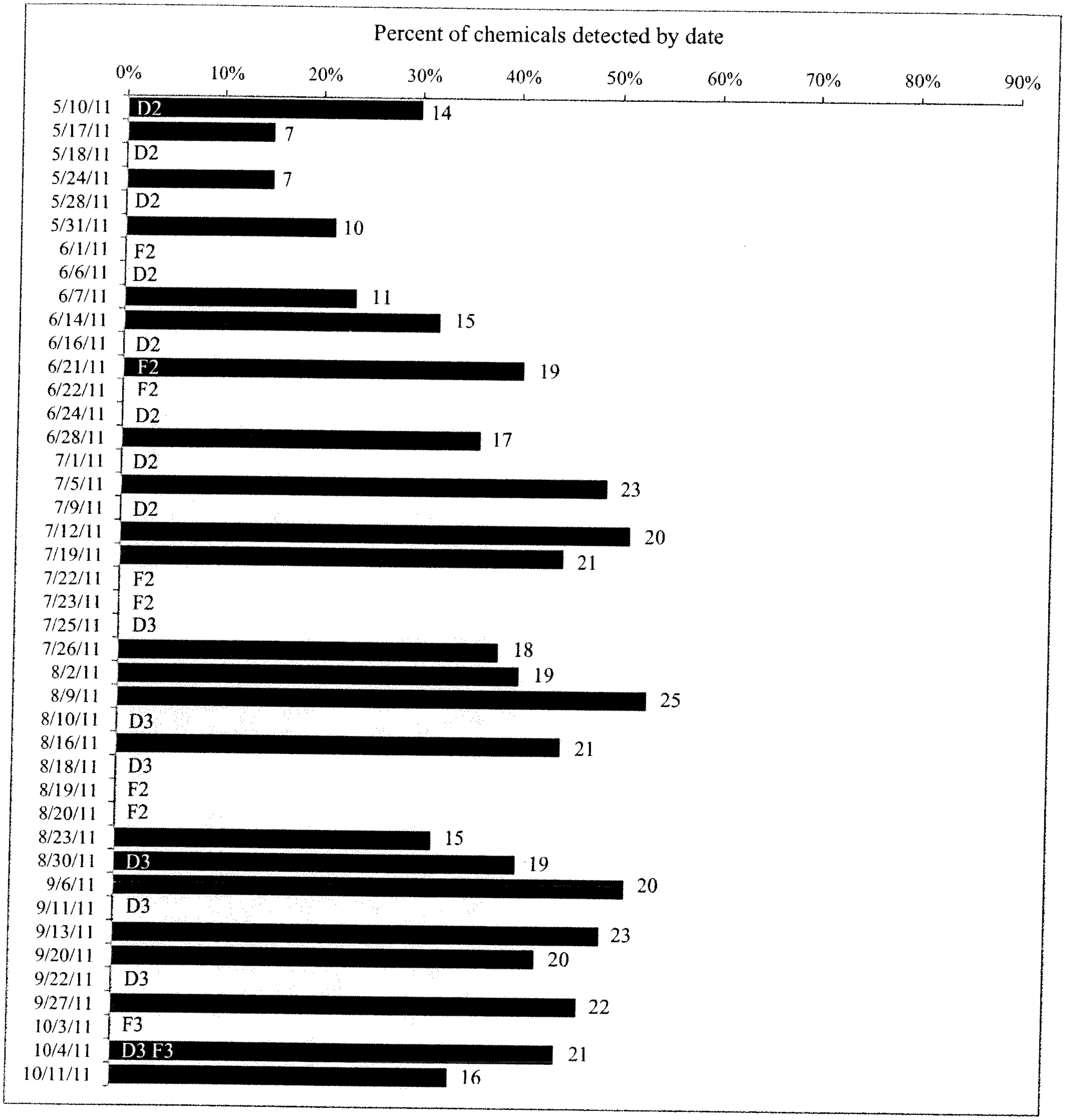
[a]Sens = skin/eye/sensory organ; Resp = respiratory; Gastr = gastrointestinal; Brain/Nerv = brain/nervous system; Immune = immune system; Kidn = kidney; Card/Bld = cardiovascular/blood; Canc /Tum = cancer/ tumorigen; Genotoxic = genotoxic; Endo = endocrine system; Liver/Met = liver/metabolic; Othr = other.

**Figure 1.** Percent and number[a] of chemicals detected in air samples collected in western Colorado from July, 2010 to October, 2011, and drilling/fracturing events, by date.

**Figure 2.** Number of chemical spikes[a] from air samples collected in western Colorado from November, 2010 to October, 2011, by compound type and date of sampling event.

Figure 1.


Percent of chemicals detected by date
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
7/17/10 Baseline 11
10/19/10 Baseline 32
10/22/10 D1
11/2/10 21
11/5/10 D1
11/9/10 15
11/16/10 D1 6
11/23/10 21
11/28/10 D1
11/30/10 19
12/7/10 32
12/9/10 D1
12/14/10 43
12/16/10 D1
12/21/10 27
12/23/10 D1
1/2/11 D1
1/4/11 F1 36
1/10/11 D1
1/11/11 38
1/18/11 34
1/20/11 D1
1/25/11 25
1/29/11 D1
1/31/11 34
2/7/11 D1
2/8/11 24
2/15/11 D1 F1 32
2/22/11 33
2/24/11 D1
3/1/11 30
3/6/11 D1
3/8/11 17
3/15/11 31
3/16/11 D1
3/23/11 25
3/26/11 Accident
3/29/11 18
4/3/11 D2
4/5/11 19
4/12/11 27
4/14/11 D2 F1
4/15/11 F1
4/16/11 F1
4/19/11 14
4/20/11 F1
4/23/11 D2
4/26/11 8
5/2/11 D2
5/3/11 15



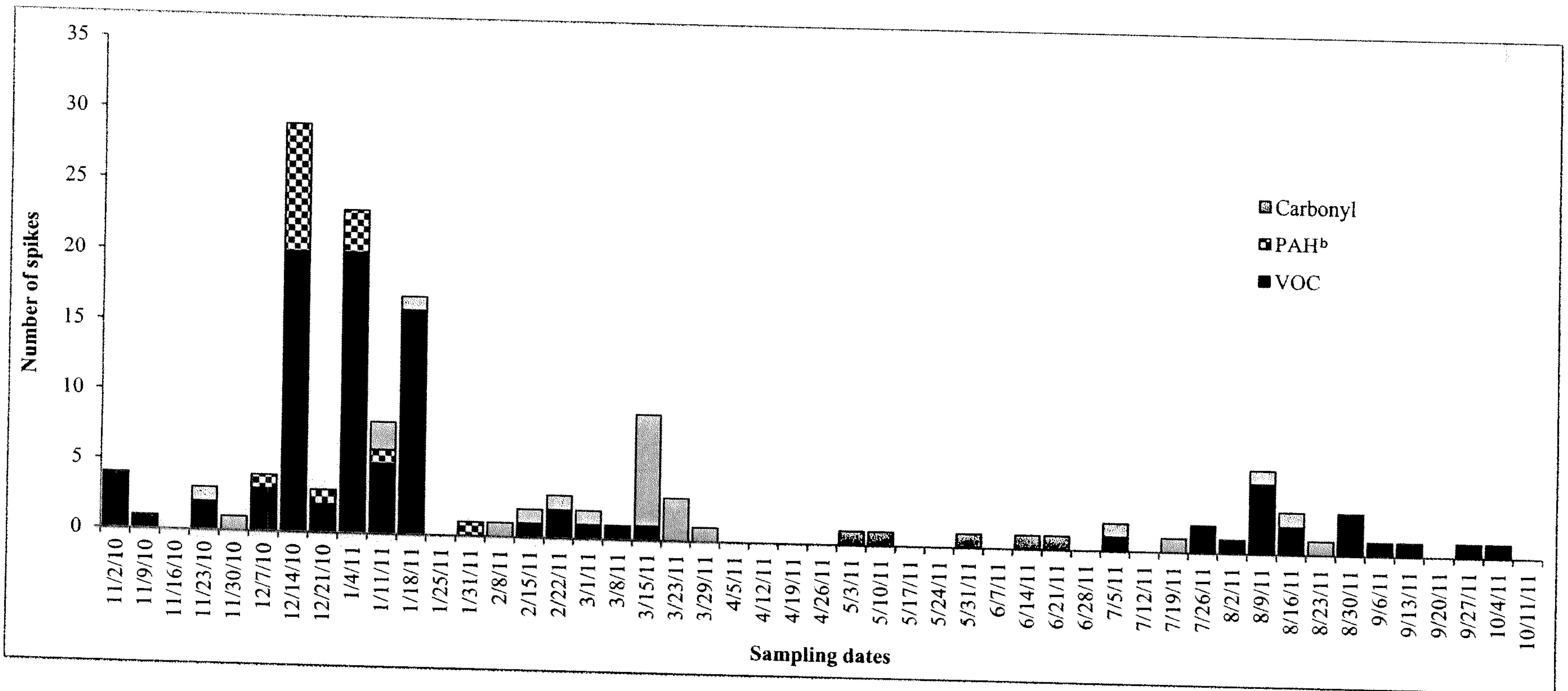

[a] The number of chemicals detected is shown at the end of each bar.

D1 FI: Drilling and fracturing events during development of Pad #1.

D2 F2: Drilling and fracturing events during development of Pad #2.

D3 F3: Drilling and fracturing events during development of Pad #3.

Figure 2.




[a] A spike is a detected chemical level that is at least one standard deviation above the mean.

[b] PAHs were sampled from 11/2/10 to 3/29/11.

022598

# WATERLESS FRACKING: NOT YET A JUSTIFIABLE ALTERNATIVE TO HYDRAULIC FRACTURING

Glenn Selker (grs38@pitt.edu)

## INTRODUCTION: LIQUID PETROLEUM GAS VS. WATER

In the past decade advances in technology have caused an industrial boom in the area of extracting natural gas from shale, a layer of non-permeable rock. Many gas companies have been successfully using a common process called hydraulic fracturing, also called fracking, but negative aspects of this method have caused innovators, such as GASFRAC Energy Services Inc., to develop an alternative approach to fracking. Commonly called waterless fracking, this method uses liquid petroleum gas (LPG) as the fracking fluid instead of water. In this article, we will explore the possibility that waterless fracking could be a viable method of extracting natural gas from shale. Evidence reveals that waterless fracking may be more productive and more environmentally friendly than hydraulic fracturing. Unfortunately, there are some ethical roadblocks to the implementation of waterless fracking, one of which is the risk to workers safety due to explosions. Thus, I cannot whole-heartedly support waterless fracking until it becomes a safer and more fully developed technology. It is clear that situations with ethical conflicts, in this case protecting the environment and protecting workers, commonly occur in engineering. To be well prepared, freshman engineering students will benefit greatly from examining engineering codes of ethics and examining their applications to specific engineering technologies.

I have chosen this topic since it is a local issue that directly affects me and many other small town residents. In fact, my neighborhood association of homes in Washington County, Pennsylvania, decided not to give gas companies access to the gas and mineral rights for our property because of the possibility of damage to our water resources and property. This issue should interest not just me, but the entire engineering community because it is concerned with the equitable and practical use of natural resources and with designing and implementing processes and machinery used in fracking. Without responsibly engineered methods of obtaining natural gas from shale, vast amounts of natural gas resources in our country will lie untapped.

## COMPARING LPG TO WATER: REASONS WHY TO USE LPG

Certain characteristics of liquid petroleum gas make it function as well as or better than water as a fracking fluid and lead to reduced costs. Also, waterless fracking does not contaminate water resources like hydraulic fracturing.

### Fracking Basics

Before we can cover the specific problems with hydraulic fracturing and the benefits of using liquid petroleum gas, we need to briefly examine the basic process used to fracture shale wells. In her analysis of the fracking process and its effects on water resources, Hannah Coman states that the depth of the shale layer "can range from slightly less than 1,000 feet to greater than 8,000 feet deep" [1]. The gas company drills a vertical shaft down to this level and may choose to drill horizontally at this point. Then it blasts that shaft with "50,000 to 5 million gallons of water" that has been mixed with various additives, causing the walls of the well to crack and release natural gas [1]. Flowback water is the remainder of the fracking fluid contaminated with minerals and other particulate matter from inside the well as well as additives that were initially present. Waterless fracking pumps liquid petroleum gas, mostly propane, with additives down the well instead; no flowback water is involved in this process.

### Higher Well Productivity

One of the big profitability issues for gas companies is maximizing the amount of gas released from their wells. Evidence suggests that waterless fracking can increase the gas yield of shale wells and, therefore, increase profitability. According to Adam Currie, a journalist focused on marine fuels and oil, fracking with liquid petroleum gas may cause significantly greater amounts of gas to flow to the surface. In one case, a GASFRAC well fractured with liquid petroleum gas produced almost three hundred percent the volume normally resulting from fracking using water [2]. Tory Aardvark, a conservative political blogger and climate realist, explains that when water used in fracking can partially clog the cracks in the shale, but liquid petroleum gas does not create any such obstruction [3]. Thus, more gas is free to flow to the surface. Scott Jenkins, a member of the National Research Council Committee on Sedimentation Control in Strategic Harbors and Waterways and Technical Advisory Committee of the San Diego Regional Water Quality Control Board, further explains this increased well productivity: "LPG's solubility with natural gas and miscibility with oil from the formation, keep the shale pore openings clear and allow higher well productivity" [4]. Because natural gas and LPG mix better than natural gas and water, the natural gas flows up the shaft with greater ease when gas companies fracture their wells with liquid petroleum gas. Larger yields from gas wells clearly increase the economic feasibility of using liquid petroleum gas as a fracking fluid.

### Flowback Perils Negated by Using LPG

According to the American Society of Mechanical Engineers Code of Ethics, "Engineers shall concern themselves with the impact of their plans and designs on the environment" [5]. Waterless fracking has a significantly lower impact on the environment because it does not create any flowback water. According to Coman, "A few of the chemicals commonly found in [hydraulic] fracturing fluid are hydrochloric acid, ethylene glycol, ammonium persulfate, citric acid, potassium chloride, potassium carbonate, and isopropanol." [1]. Tens of thousands of gallons of mixtures of these compounds are added to the fracking fluid. When these compounds return to the surface, they can cause serious detriment to water supplies and affect other parts of the environment and human health.

According to Robert W. Howarth of the Department of Ecology and Evolutionary Biology, Cornell University and Terry Engelder of the School of Civil and Environmental Engineering at Cornell University, "In New York and Pennsylvania…there has been contamination of the Ohio River with barium, strontium and bromides from municipal wastewater treatment plants receiving fracking wastes" [6]. This contamination not only damages aquatic ecosystems but also sources of drinking water, which is hazardous to human health. In its Code of Ethics, the National Society of Professional Engineers declares, "Engineers shall hold paramount the safety, health, and welfare of the public" [7]. Waterless fracking appears to be the more ethical choice in the light of this statement and potential detriment to human health associated with flowback water from hydraulic fracturing.

We cannot simply stop our evaluation here, however. The American Society of Civil Engineers Code of Ethics states that "Engineers shall include all relevant and pertinent information in such reports, statements, or testimony" [8]. As an engineer to be, I must include in my discussion the negative aspects of waterless fracking. Before I do, I need to discuss some more ways that waterless fracking can cut certain costs associated with hydraulic fracturing, which will actually set the stage for further ethical discussion.

### Reduced Costs Associated with Waterless Fracking

Waterless fracking's lack of flowback water has benefits outside the environmental and human health sphere: It reduces operational costs significantly. Waterless fracking eliminates the need to purify flowback water and also the cost of purifying that water and transporting the flowback water for treatment or storage. These transportation costs alone are very expensive. According to Keith Schaefer, editor and publisher of the *Oil & Gas Investments Bulletin*, "The disposal costs for water in both the Marcellus Shale in the northeast US and in Texas are sometimes as much as $10/barrel—making water costs on a well $1-$2 million or more" [9]. According to the GASFRAC website, "Because propane liquid is half the specific gravity of water, there is reduced trucking to the site and no trucking to transport post stimulation - which can reduce truck traffic by up to 90%" [10]. Clearly, using LPG as a fracking fluid will save millions of dollars that would be spent on costly trucking and water treatment.

Although waterless fracking can reduce some costs significantly, hydraulic fracturing is still less expensive for the gas companies. For operators using waterless fracking, this can potentially create the mindset that they have to cut costs wherever possible to make up the difference in profitability. If safety procedures and mechanisms are reduced or eliminated to cut costs, the results could be disastrous for the health and safety of workers, which would be a clear ethical violation. As we will see, these workers are already working in a dangerous environment.

## THE DOWNSIDE TO WATERLESS FRACKING: EXPLOSIONS

Before we can decide whether waterless fracking is an ethical choice, we need to consider the negative aspects of waterless fracking. While there are several downsides to fracking with liquid petroleum gas, the one most relative to our ethics discussion is the likelihood of the propane in liquid petroleum gas to explode and harm workers.

### Intrinsic Combustibility

While waterless fracking may impact the environment less than hydraulic fracturing, it creates greater health risk for workers. In the Gibsons Material Safety Data Sheet on propane, the first line of the Hazards Identification section states, "Danger! This product is extremely flammable!" [11]. Propane is also explosive, and unfortunately, GASFRAC has found this out the hard way with its waterless fracking operations. Shaun Polczer, a journalist reporting on environmental issues in Canada, recorded that "A [GASFRAC] work site explosion on the weekend injured three workers" [12]. He went on to cite a Raymond James analyst, Andrew Bradford, who states, "Incidents such as this are relatively common across many oilfield service lines" [12]. This is an alarming statement, suggesting that we should expect more explosions!

The Catskill Mountainkeeper website reports on another 2011 GASFRAC explosion and a 2012 fire not resulting in explosion: "The second, a flash fire, injured about a dozen workers...In a third incident, GASFRAC Energy Services had to shut down the company for 2 weeks in January 2012 while they investigated a fire at a well site" [13]. These three incidents must not be viewed as insignificant. Right now hydraulic fracturing, which does not have the risk of explosion, is the commonly used fracking process. Waterless fracking is not widely used, but if it were to become commonly accepted, I believe that we would see a significant increase in the number of explosions in the fracking industry and a large increase in worker injuries in this field.

So far we have seen that waterless fracking looks like an environmentally responsible way to access important natural resources, at least relative to hydraulic fracking. This is in accordance with the clause of the National Society of Professional Engineers Code of Ethics that states, "Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations" [7]. It is interesting to note how the American Society of Civil Engineers defines sustainable development in its code of ethics: "The process of applying natural, human, and economic resources to enhance the safety, welfare, and quality of life for all society while maintaining the availability of the remaining natural resources" [8].What I find interesting is that this definition includes responsible use of human resources, the workers, and states that "the safety...of all society" should be taken into consideration. Clearly, protecting the environment alone is not enough to justify using waterless fracking; waterless fracking must uphold the safety of the workers involved, who are currently being put in danger. Thus, I conclude that waterless fracking needs further development before it can ethically be implemented on a wider basis. If engineers are to "hold paramount the safety, health, and welfare of the public," then they need to find a way to ensure that waterless fracking is safe for workers before it can become commonly accepted.

## IMPORTANCE OF ETHICS ANALYSIS TO FRESHMAN ENGINEERS

The fracking we have examined is one situation involving engineers that requires us to evaluate ethics from more than one perspective. We must consider that it is important to protect the environment, but it is more important to protect human lives. It is safe to assume that this ethical complexity is common in engineering; otherwise, each of the professional engineering societies would not have thought it necessary to write and update their own codes of ethics.

The National Society of Professional Engineers Code of Ethics states that "Engineering is a learned profession" [9]. This implies that engineers must not only be learned in technical areas, but also in applying ethics to their areas of technical competence. It is clear from the NSPE, Civil Engineering, Mechanical Engineering, and Chemical Engineering codes of ethics, which I have read, that making correct ethical judgments is a fundamental aspect of being an engineer. Why, then, would freshman engineering students not need to be exposed to engineering codes of ethics and their practical applications? It takes time to develop the skill to make sound judgments when ethics are involved, and engineers must benefit from learning about engineering ethics from the beginning of their education. This writing assignment is clearly an important part of our engineering education because it exposes us to codes of ethics and how they apply to a real-life engineering problem.

Furthermore, being able to articulate evaluations based on research is an integral part of being an engineer. According to the Society for Mining, Metallurgy, and Explorations Code of Ethics, which is composed of geologists, engineers and geoscientists, "[Members] shall contribute to the public discussion on scientific and technological matters in the member's area of competence" [14]. This certainly includes the discussion of ethics with regard to the application of technology. Therefore, researching and discussing engineering codes of ethics and how they apply to a specific topic as required by a freshman engineering curriculum will certainly benefit any engineering student.

## CONCLUSION

Because waterless fracking does not produce flowback water, it is has a lower impact on the environment and water resources than hydraulic fracturing does. From an ethical standpoint, this is a major benefit. Unfortunately, waterless fracking poses a serious risk to workers' health due to the combustibility of the propane in LPG. Based on the emphasis which engineering codes of ethics put on safety, I have concluded that waterless fracking needs to be further developed before it can be considered ethical to use. We must realize that preserving human life and safety is more important than preserving the environment. If engineers are successful in designing waterless fracking processes to ensure the workers' safety, waterless fracking could solve the quandary of accessing natural gas from shale while protecting vital water resources. This would benefit many communities, including my own, because their natural gas resources will be accessible, while their water resources are protected. However, since this ethical dilemma still exists, it is extremely important to educate engineers about how to apply engineering ethics to real life situations such this. This is a process that takes time and should start in the freshman year of engineering school, so that future engineers can be adequately prepared to tackle the problems that lie ahead.

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# WATERLESS FRACKING: NOT YET A JUSTIFIABLE ALTERNATIVE TO HYDRAULIC FRACTURING

Glenn Selker (grs38@pitt.edu)

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## COMPARING LPG TO WATER: REASONS WHY TO USE LPG

Certain characteristics of liquid petroleum gas make it function as well as or better than water as a fracking fluid and lead to reduced costs. Also, waterless fracking does not contaminate water resources like hydraulic fracturing.

### Fracking Basics

Before we can cover the specific problems with hydraulic fracturing and the benefits of using liquid petroleum gas, we need to briefly examine the basic process used to fracture shale wells. In her analysis of the fracking process and its effects on water resources, Hannah Coman states that the depth of the shale layer "can range from slightly less than 1,000 feet to greater than 8,000 feet deep" [1]. The gas company drills a vertical shaft down to this level and may choose to drill horizontally at this point. Then it blasts that shaft with "50,000 to 5 million gallons of water" that has been mixed with various additives, causing the walls of the well to crack and release natural gas [1]. Flowback water is the remainder of the fracking fluid contaminated with minerals and other particulate matter from inside the well as well as additives that were initially present. Waterless fracking pumps liquid petroleum gas, mostly propane, with additives down the well instead; no flowback water is involved in this process.

### Higher Well Productivity

One of the big profitability issues for gas companies is maximizing the amount of gas released from their wells. Evidence suggests that waterless fracking can increase the gas yield of shale wells and, therefore, increase profitability. According to Adam Currie, a journalist focused on marine fuels and oil, fracking with liquid petroleum gas may cause significantly greater amounts of gas to flow to the surface. In one case, a GASFRAC well fractured with liquid petroleum gas produced almost three hundred percent the volume normally resulting from fracking using water [2]. Tory Aardvark, a conservative political blogger and climate realist, explains that when water used in fracking can partially clog the cracks in the shale, but liquid petroleum gas does not create any such obstruction [3]. Thus, more gas is free to flow to the surface. Scott Jenkins, a member of the National Research Council Committee on Sedimentation Control in Strategic Harbors and Waterways and Technical Advisory Committee of the San Diego Regional Water Quality Control Board, further explains this increased well productivity: "LPG's solubility with natural gas and miscibility with oil from the formation, keep the shale pore openings clear and allow higher well productivity" [4]. Because natural gas and LPG mix better than natural gas and water, the natural gas flows up the shaft with greater ease when gas companies fracture their wells with liquid petroleum gas. Larger yields from gas wells clearly increase the economic feasibility of using liquid petroleum gas as a fracking fluid.

### Flowback Perils Negated by Using LPG

According to the American Society of Mechanical Engineers Code of Ethics, "Engineers shall concern themselves with the impact of their plans and designs on the environment" [5]. Waterless fracking has a significantly lower impact on the environment because it does not create any flowback water. According to Coman, "A few of the chemicals commonly found in [hydraulic] fracturing fluid are hydrochloric acid, ethylene glycol, ammonium persulfate, citric acid, potassium chloride, potassium carbonate, and isopropanol." [1]. Tens of thousands of gallons of mixtures of these compounds are added to the fracking fluid. When these compounds return to the surface, they can cause serious detriment to water supplies and affect other parts of the environment and human health.

According to Robert W. Howarth of the Department of Ecology and Evolutionary Biology, Cornell University and Terry Engelder of the School of Civil and Environmental Engineering at Cornell University, "In New York and Pennsylvania…there has been contamination of the Ohio River with barium, strontium and bromides from municipal wastewater treatment plants receiving fracking wastes" [6]. This contamination not only damages aquatic ecosystems but also sources of drinking water, which is hazardous to human health. In its Code of Ethics, the National Society of Professional Engineers declares, "Engineers shall hold paramount the safety, health, and welfare of the public" [7]. Waterless fracking appears to be the more ethical choice in the light of this statement and potential detriment to human health associated with flowback water from hydraulic fracturing.

We cannot simply stop our evaluation here, however. The American Society of Civil Engineers Code of Ethics states that "Engineers shall include all relevant and pertinent information in such reports, statements, or testimony" [8]. As an engineer to be, I must include in my discussion the negative aspects of waterless fracking. Before I do, I need to discuss some more ways that waterless fracking can cut certain costs associated with hydraulic fracturing, which will actually set the stage for further ethical discussion.

### Reduced Costs Associated with Waterless Fracking

Waterless fracking's lack of flowback water has benefits outside the environmental and human health sphere: It reduces operational costs significantly. Waterless fracking eliminates the need to purify flowback water and also the cost of purifying that water and transporting the flowback water for treatment or storage. These transportation costs alone are very expensive. According to Keith Schaefer, editor and publisher of the *Oil & Gas Investments Bulletin*, "The disposal costs for water in both the Marcellus Shale in the northeast US and in Texas are sometimes as much as $10/barrel—making water costs on a well $1-$2 million or more" [9]. According to the GASFRAC website, "Because propane liquid is half the specific gravity of water, there is reduced trucking to the site and no trucking to transport post stimulation - which can reduce truck traffic by up to 90%" [10]. Clearly, using LPG as a fracking fluid will save millions of dollars that would be spent on costly trucking and water treatment.

Although waterless fracking can reduce some costs significantly, hydraulic fracturing is still less expensive for the gas companies. For operators using waterless fracking, this can potentially create the mindset that they have to cut costs wherever possible to make up the difference in profitability. If safety procedures and mechanisms are reduced or eliminated to cut costs, the results could be disastrous for the health and safety of workers, which would be a clear ethical violation. As we will see, these workers are already working in a dangerous environment.

## THE DOWNSIDE TO WATERLESS FRACKING: EXPLOSIONS

Before we can decide whether waterless fracking is an ethical choice, we need to consider the negative aspects of waterless fracking. While there are several downsides to fracking with liquid petroleum gas, the one most relative to our ethics discussion is the likelihood of the propane in liquid petroleum gas to explode and harm workers.

### Intrinsic Combustibility

While waterless fracking may impact the environment less than hydraulic fracturing, it creates greater health risk for workers. In the Gibsons Material Safety Data Sheet on propane, the first line of the Hazards Identification section states, "Danger! This product is extremely flammable!" [11]. Propane is also explosive, and unfortunately, GASFRAC has found this out the hard way with its waterless fracking operations. Shaun Polczer, a journalist reporting on environmental issues in Canada, recorded that "A [GASFRAC] work site explosion on the weekend injured three workers" [12]. He went on to cite a Raymond James analyst, Andrew Bradford, who states, "Incidents such as this are relatively common across many oilfield service lines" [12]. This is an alarming statement, suggesting that we should expect more explosions!

The Catskill Mountainkeeper website reports on another 2011 GASFRAC explosion and a 2012 fire not resulting in explosion: "The second, a flash fire, injured about a dozen workers...In a third incident, GASFRAC Energy Services had to shut down the company for 2 weeks in January 2012 while they investigated a fire at a well site" [13]. These three incidents must not be viewed as insignificant. Right now hydraulic fracturing, which does not have the risk of explosion, is the commonly used fracking process. Waterless fracking is not widely used, but if it were to become commonly accepted, I believe that we would see a significant increase in the number of explosions in the fracking industry and a large increase in worker injuries in this field.

So far we have seen that waterless fracking looks like an environmentally responsible way to access important natural resources, at least relative to hydraulic fracking. This is in accordance with the clause of the National Society of Professional Engineers Code of Ethics that states, "Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations" [7]. It is interesting to note how the American Society of Civil Engineers defines sustainable development in its code of ethics: "The process of applying natural, human, and economic resources to enhance the safety, welfare, and quality of life for all society while maintaining the availability of the remaining natural resources" [8].What I find interesting is that this definition includes responsible use of human resources, the workers, and states that "the safety...of all society" should be taken into consideration. Clearly, protecting the environment alone is not enough to justify using waterless fracking; waterless fracking must uphold the safety of the workers involved, who are currently being put in danger. Thus, I conclude that waterless fracking needs further development before it can ethically be implemented on a wider basis. If engineers are to "hold paramount the safety, health, and welfare of the public," then they need to find a way to ensure that waterless fracking is safe for workers before it can become commonly accepted.

## IMPORTANCE OF ETHICS ANALYSIS TO FRESHMAN ENGINEERS

The fracking we have examined is one situation involving engineers that requires us to evaluate ethics from more than one perspective. We must consider that it is important to protect the environment, but it is more important to protect human lives. It is safe to assume that this ethical complexity is common in engineering; otherwise, each of the professional engineering societies would not have thought it necessary to write and update their own codes of ethics.

The National Society of Professional Engineers Code of Ethics states that "Engineering is a learned profession" [9]. This implies that engineers must not only be learned in technical areas, but also in applying ethics to their areas of technical competence. It is clear from the NSPE, Civil Engineering, Mechanical Engineering, and Chemical Engineering codes of ethics, which I have read, that making correct ethical judgments is a fundamental aspect of being an engineer. Why, then, would freshman engineering students not need to be exposed to engineering codes of ethics and their practical applications? It takes time to develop the skill to make sound judgments when ethics are involved, and engineers must benefit from learning about engineering ethics from the beginning of their education. This writing assignment is clearly an important part of our engineering education because it exposes us to codes of ethics and how they apply to a real-life engineering problem.

Furthermore, being able to articulate evaluations based on research is an integral part of being an engineer. According to the Society for Mining, Metallurgy, and Explorations Code of Ethics, which is composed of geologists, engineers and geoscientists, "[Members] shall contribute to the public discussion on scientific and technological matters in the member's area of competence" [14]. This certainly includes the discussion of ethics with regard to the application of technology. Therefore, researching and discussing engineering codes of ethics and how they apply to a specific topic as required by a freshman engineering curriculum will certainly benefit any engineering student.

## CONCLUSION

Because waterless fracking does not produce flowback water, it is has a lower impact on the environment and water resources than hydraulic fracturing does. From an ethical standpoint, this is a major benefit. Unfortunately, waterless fracking poses a serious risk to workers' health due to the combustibility of the propane in LPG. Based on the emphasis which engineering codes of ethics put on safety, I have concluded that waterless fracking needs to be further developed before it can be considered ethical to use. We must realize that preserving human life and safety is more important than preserving the environment. If engineers are successful in designing waterless fracking processes to ensure the workers' safety, waterless fracking could solve the quandary of accessing natural gas from shale while protecting vital water resources. This would benefit many communities, including my own, because their natural gas resources will be accessible, while their water resources are protected. However, since this ethical dilemma still exists, it is extremely important to educate engineers about how to apply engineering ethics to real life situations such this. This is a process that takes time and should start in the freshman year of engineering school, so that future engineers can be adequately prepared to tackle the problems that lie ahead.

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# Fracking Exposes Workers to High Levels of Silica and Other Health Hazards



05/22/2012 Ja-Rei Wang



If you work in the hydraulic fracturing industry—better known as "fracking"—you may be exposed to high levels of crystalline silica, putting you at risk of developing silicosis, lung cancer and other debilitating diseases, according to a letter sent today from the AFL-CIO, Mine Workers (UMWA (http://www.umwa.org/) ) and the United Steelworkers (USW) (http://www.usw.org/) to the top federal safety agencies.

The letter highlights a recent two-year National Institute for Occupational Safety and Health (NIOSH) assessment, which found that, among those exposed, 79 percent of samples for silica exceeded the NIOSH Recommended Exposure Limits.

Silica sand is a major component of the fracking process. The sand is mixed with large volumes of water and chemical additives and injected under high pressure by drilling into shale rock. Massive quantities of sand are used and workers are at risk of high levels of exposure during multiple points of the fracking process.

In addition to the health hazards, workers in the oil and gas extraction industries face high rates of fatal occupational injuries. Between 2003 and 2009, there were 27.5 deaths per 100,000 workers, a rate more than seven times higher than the fatality rate for all U.S. workers.

As the fracking industry continues to rapidly grow, and as more workers enter the field with little experience or knowledge about the potential hazards in this industry, it is vital the government, companies and unions work together to ensure workers have the work safety and health knowledge, training and protection they need.

The letter urges the Occupational Safety and Health Administration (OSHA), NIOSH and the Mine Safety and Health Administration to take immediate action and issue a joint "hazard alert" that identifies the occupational safety and health hazards in the fracking industry, with a special focus on silica exposures. It also recommends OSHA to take immediate steps to initiate rule making on a new silica standard that includes requirements for exposure monitoring and medical surveillance and NIOSH to expand its field work in the fracking industry to include medical surveillance of workers.

Click here (http://www.aflcio.org/content/download/28091/347761/version/1/file/safetyhealth_05222012.pdf) for the full letter.

Tagged under:
fracking, Mine Safety and Health Administration, Mine Workers, MSHA, National Institute for Occupational Safety and Health, NIOSH, Occupational Safety and Health Administration, OSHA, safety and health, UMWA, United Steelworkers, USW

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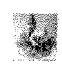

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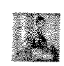

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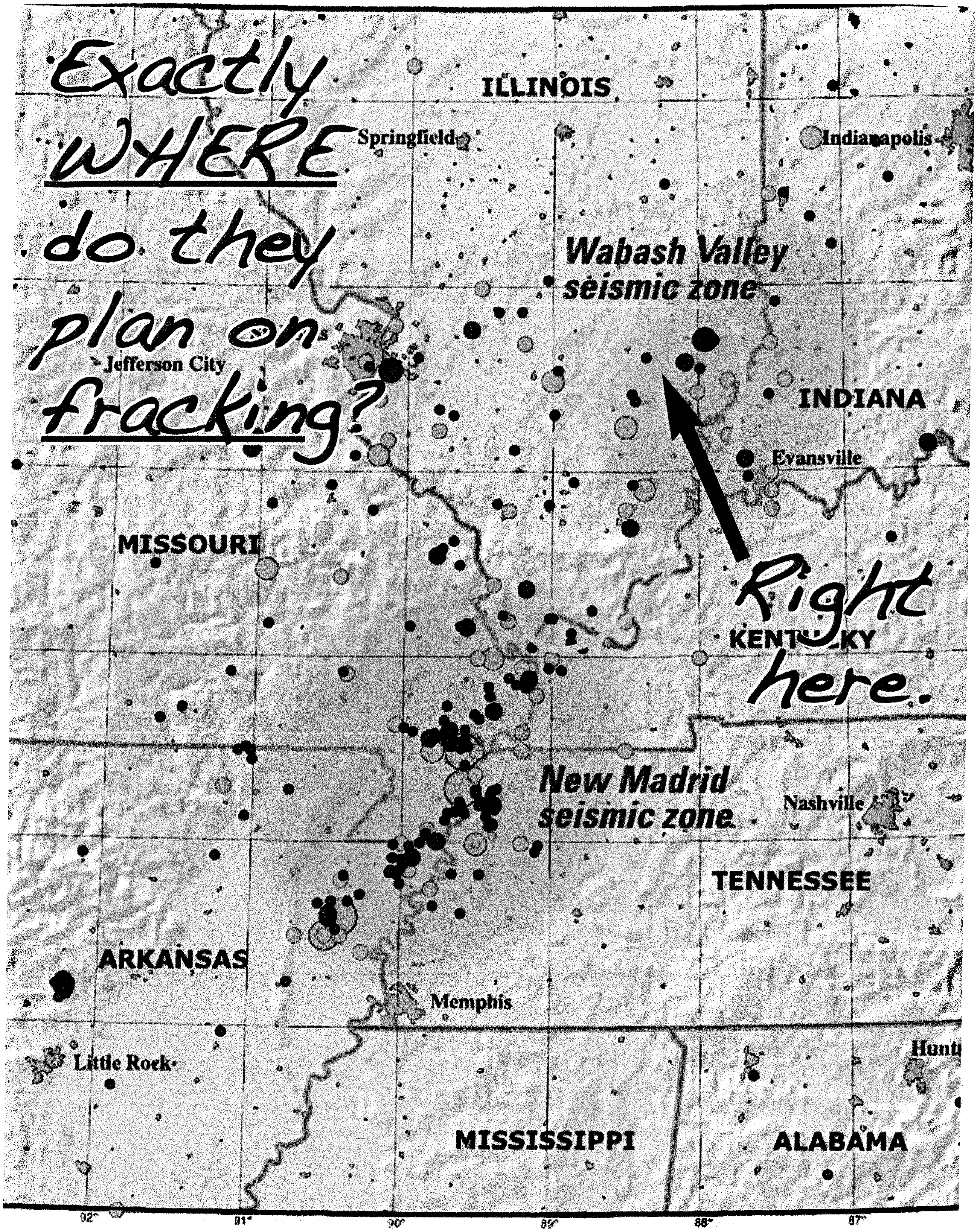


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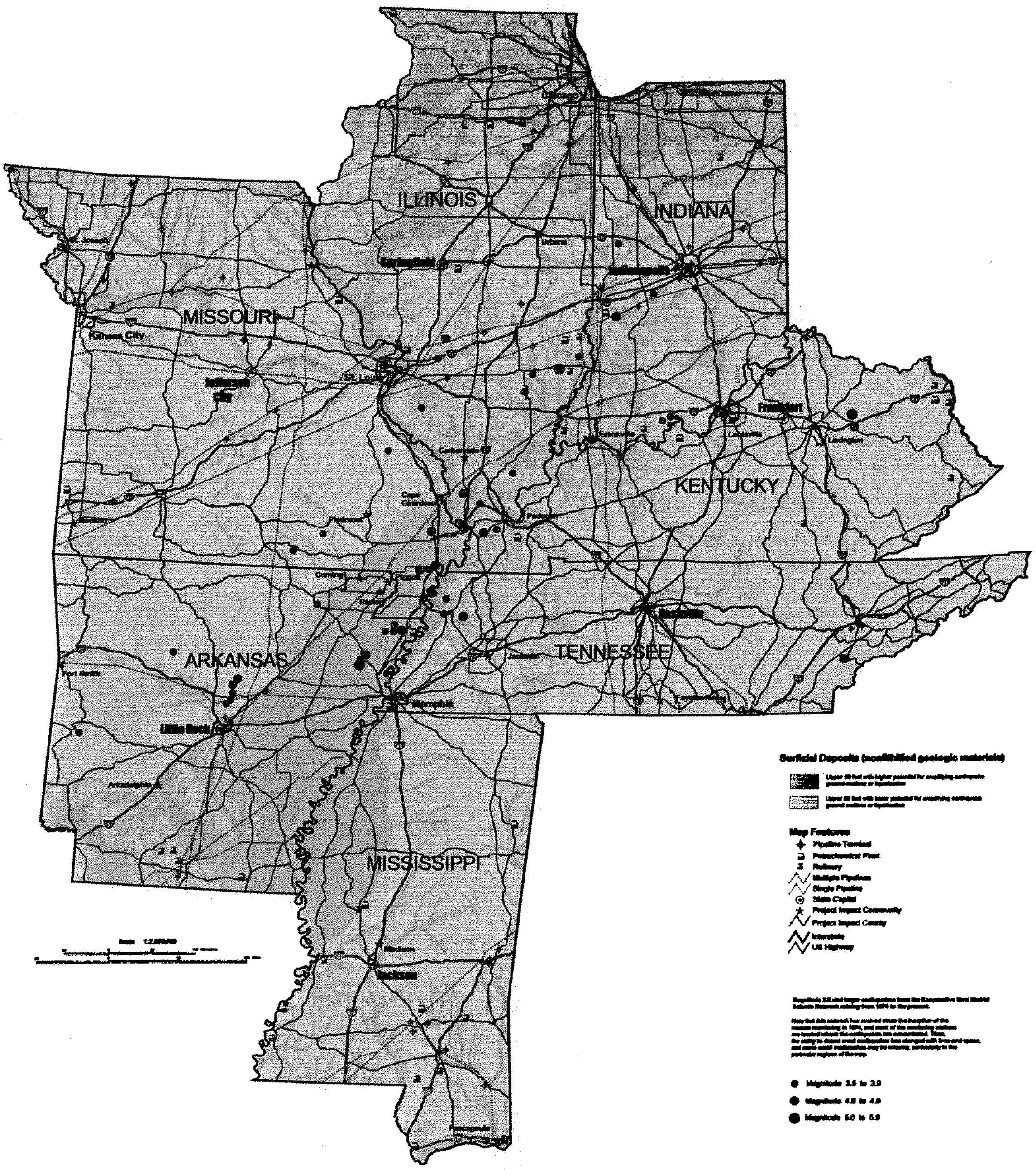
# Soil Amplification/Liquefaction Potential Map

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William V. Bush, Arkansas Geological Commission
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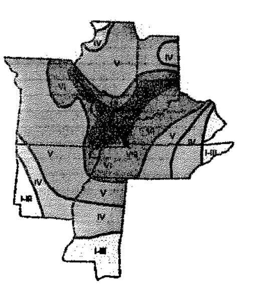
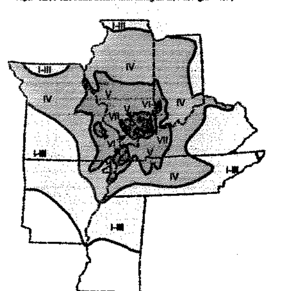
Missouri Department of Natural Resources, Division of Geology and Land Survey
S. Cragin Knox, Mississippi Department of Environmental Quality, Office of Geology


Map Features

- Pipeline Terminal
- Petrochemical Plant
- Refinery
- Multiple Pipelines
- Single Pipeline
- State Capital
- Project Impact Community
- Project Impact County
- Interstate
- US Highway

- Magnitude 3.5 to 3.9
- Magnitude 4.0 to 4.9
- Magnitude 5.0 to 5.9




# Soil Amplification/ Liquefaction Potential Map

Showing Areas of Relative Potential for Shaking and/or Liquefaction from Earthquakes

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# Soil Amplification/Liquefaction Potential Map


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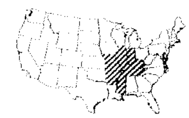

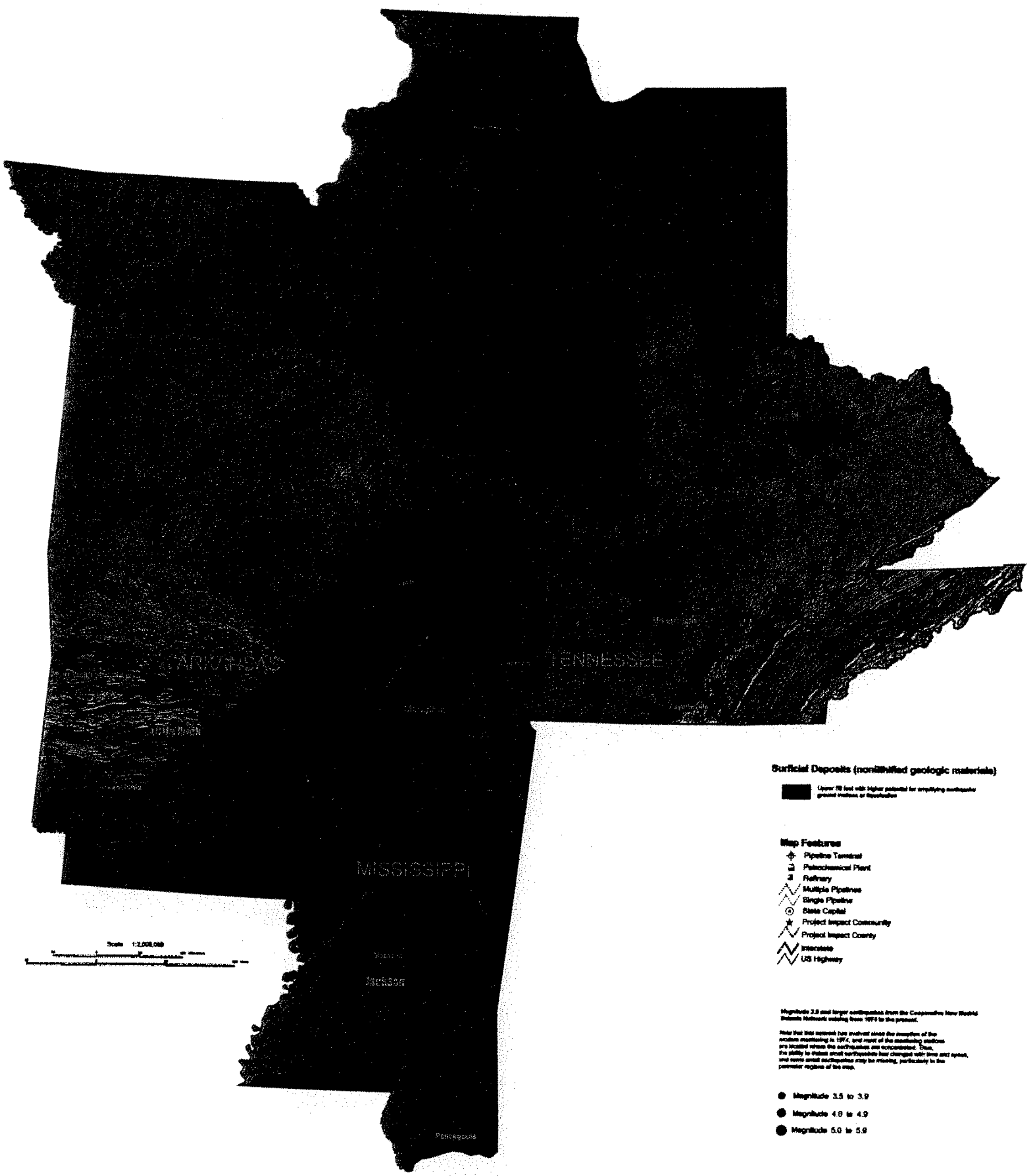


Scale 1:2,000,000

**Amplification/Liquefaction Hazard Map**

This map shows areas of higher and lower potential for amplification of earthquake ground motion by nonlithified geologic materials (soils) or for liquefaction of these soils. [illegible]

Earthquakes in the Central United States have wide regional effects [illegible]

[illegible]

**Features on the Map**

On this map, yellow indicates where the upper 50 feet of NGM (soils) is considered likely to amplify earthquake ground motion or to undergo liquefaction during an earthquake. [illegible]

This map also shows the location of earthquakes of magnitude 3.5 and higher. [illegible]

**Central United States Earthquake Consortium**

The Central United States Earthquake Consortium (CUSEC) is an organization of emergency managers from states that fall within the New Madrid and Wabash Valley Seismic Zones. [illegible]

This map is a second version of our first product completed under the program. A map scale of 1:2,000,000 [illegible]

For further information contact:

[illegible]

**Surficial Deposits (nonlithified geologic materials)**

Upper 50 feet with higher potential for amplifying earthquake ground motions or liquefaction

**Map Features**

- Pipeline Terminal
- Petrochemical Plant
- Refinery
- Multiple Pipelines
- Single Pipeline
- State Capital
- Project Impact Community
- Project Impact County
- Interstate
- US Highway

Magnitude 3.5 and larger earthquakes from the Cooperative New Madrid Seismic Network catalog from 1974 to the present.

Note that this network has evolved since the inception of the modern monitoring in 1974, and most of the monitoring stations are located where the earthquakes are concentrated. Thus, the ability to detect small earthquakes has changed with time and space, and some small earthquakes may be missing, particularly in the perimeter regions of the map.

- Magnitude 3.5 to 3.9
- Magnitude 4.0 to 4.9
- Magnitude 5.0 to 5.9


Map Unit Interpretations by:

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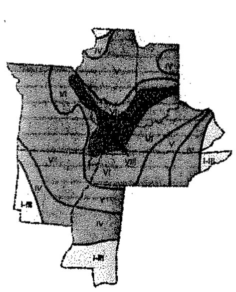
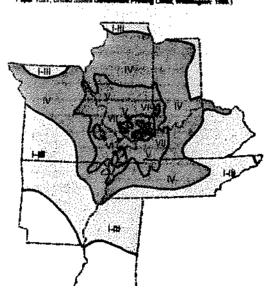
Isoseismal map for the Charleston, Missouri earthquake of October 31, 1895. Isoseismals are based on intensity estimates from data (Hopper, M.G., and S.T. Algermissen, 1980, An Evaluation of the Effects of the October 31, 1895, Charleston, Missouri, Earthquake: U.S. Geological Survey, Open-File Report 80-778, 43p.)



Isoseismal map for the Southern Illinois earthquake of November 9, 1968. Isoseismals are based on intensity estimates from data. (Abridged from Seismicity of the United States, 1568-1989 (Revised), by Carl W. Stover and Jerry L. Coffman, U.S. Geological Survey Professional Paper 1527, United States Government Printing Office, Washington: 1993.)



The following gives damage descriptions for the Modified Mercalli Intensity Scale.

| Intensity | Description of Effects |
| --- | --- |
| I. | Not felt except by a very few under especially favorable conditions. |
| II. | Felt only by a few persons at rest, especially on upper floors of buildings. |
| III. | Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to passing of a truck. Duration estimated. |
| IV. | Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. |
| V. | Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop. |
| VI. | Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Slight damage. |
| VII. | Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. |
| VIII. | Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. |
| IX. | Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings with partial collapse. Buildings shifted off foundation. |
| X. | Some well-built wooden structures destroyed; most masonry and frame structures destroyed, also their foundations. Rails bent. |
| XI. | Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. |
| XII. | Damage total. Lines of sight and level are distorted. Objects thrown into the air. |

# Soil Amplification/ Liquefaction Potential Map

Showing Areas of Relative Potential for Shaking and/or Liquefaction from Earthquakes

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# EVALUATING SUSTAINABILITY OF PROJECTED WATER DEMANDS UNDER FUTURE CLIMATE CHANGE SCENARIOS


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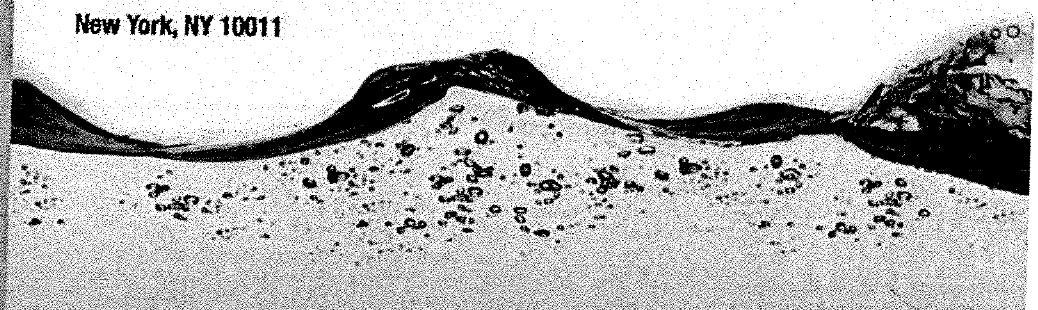

July 2010

TETRA TECH

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# Executive Summary

Climate change will impact water supplies, exacerbating existing pressures on water resources caused by population and economic growth. Given the combination of these stressors, the sustainability of water resources in future decades is a concern in many parts of the world. This study presents an integration of water withdrawal projections and future estimates of renewable water supply across the United States to assess future water availability in the face of a changing climate. The water demand projections in this work are based on business-as-usual trends in growth, particularly of population and energy demand, and renewable water supply projections are based on the average results of an ensemble of sixteen established climate models. The analysis is performed using annual water use data at the U.S. county level, and using global climate model outputs for temperature and precipitation, both projected 20-40 years into the future. The analysis provides a national-scale evaluation of the results of changing water demand and supply, and helps identify regions that are most susceptible to climate change.

As part of this analysis, a water supply sustainiability index comprised of five attributes of water use and growth was developed, and used to compare impacts across regions. We found that, under the business-as-usual scenario of demand growth, water supplies in 70% of counties in the U.S. may be at risk to climate change, and approximately one-third of counties may be at high or extreme risk. The geographic extent of potential risk to water supplies is greatly increased when climate change is considered (Figure ES-1). This calculation indicates the increase in risk that affected counties face that water demand will outstrip supplies, if no other remedial actions are taken. To be clear, it is not intended as a prediction that water shortages will occur, but rather where they are more likely to occur. As a result, the pressure on public officials and water users to creatively manage demand and supply—through greater efficiency and realignment among competing uses, and by water recycling and creation of new supplies through treatment—will be greatest in these regions. In addition to developing national-scale maps of potential climate impacts, this work serves as a starting point for more detailed analysis, either at more local scales, or by consideration of specific sectors of the economy that are directly dependent on sustainable water resources.

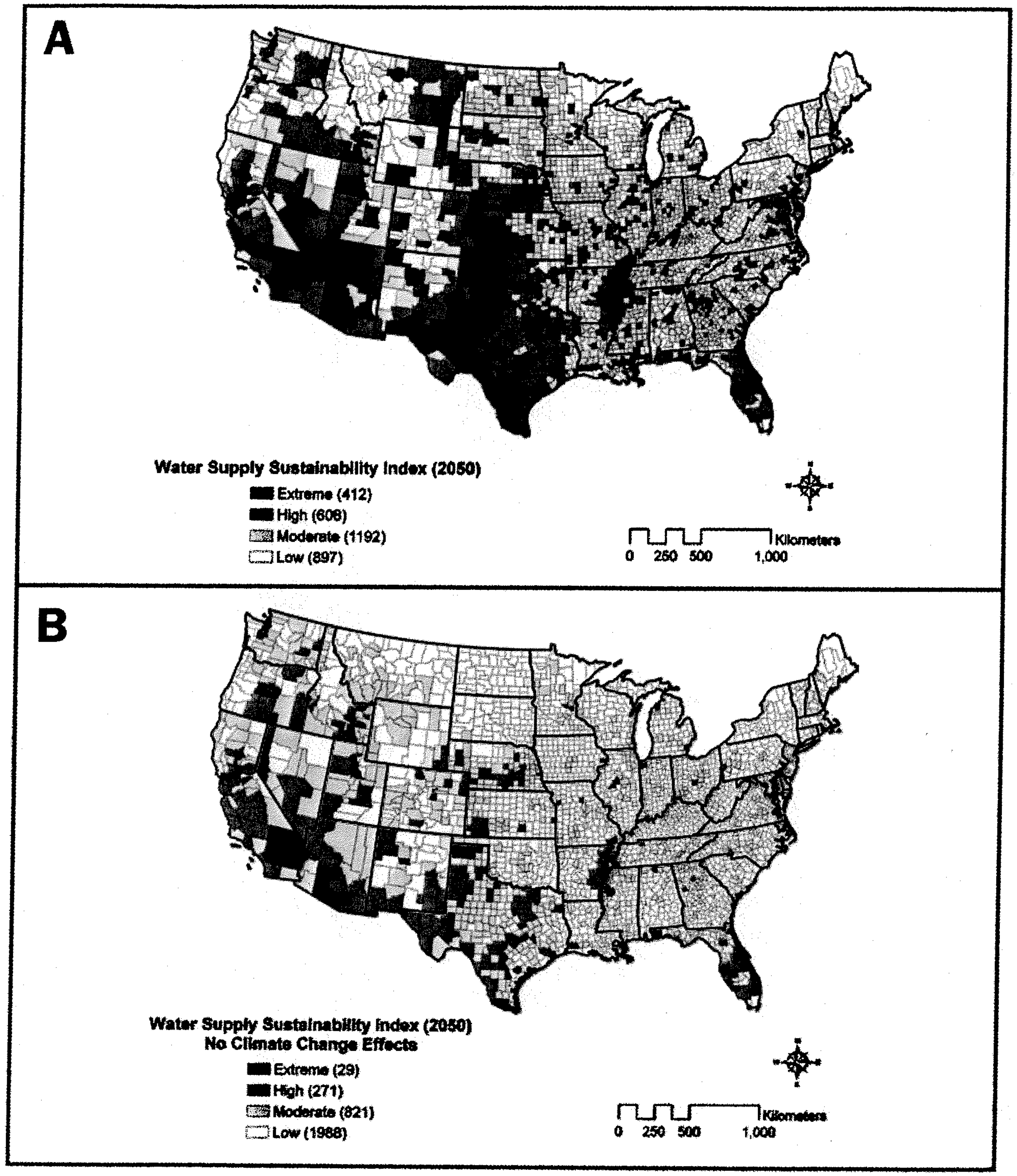


Figure ES-1. Water Supply Sustainability Index in 2050, (a) with available precipitation computed using projected climate change, and (b) with available precipitation corresponding to 20th century conditions, i.e., 1934-2000. The risks to water sustainability are classified into four categories from Extreme to Low. The numbers in parentheses are the numbers of counties in each category.



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# Introduction

Human needs for water continue to grow with increasing population, primarily for direct consumption, but also secondarily for energy production, and agricultural, commercial, and industrial activities. The sustainability of water resources, defined as the maintenance of natural water resources in adequate quantity and with suitable quality for human use and for aquatic ecosystems, is adversely impacted by these increasing demands. Over the coming decades, climate change, caused by the buildup of heat-trapping greenhouse gases in the atmosphere, is expected to be another stressor on water resources. Climate change impacts on water resources through changing precipitation, snowmelt, and other processes related to warming temperature, have been identified in previous work (Gleick, 1989; Hurd et al., 1999; Jacobs et al., 2001; Bates et al., 2008; Brekke et al., 2009a). For example, as temperatures increase, more water is evaporated, and less runs off into rivers and reservoirs. Previous work has identified areas of the globe where atmosphere-ocean general circulation models (AOGCMs or GCMs, also known as "global climate models") project changes in temperature and precipitation as a result of changing concentrations of heat trapping greenhouse gases in the atmosphere (Christensen et al., 2007; Intergovernmental Panel on Climate Change, IPCC, 2007). Projected future precipitation changes are variable over regional scales. Unlike temperature—which all climate models agree will increase—precipitation is projected to both increase and decrease across different regions over the 21st century. How-[redacted]due [redacted] use [redacted]ease [redacted]ing in greater evapotranspiration. Synthesis reports for the United States have also been prepared that provide an overview of the hydrologic changes that might be expected due to climate change, which include continuing increases in extreme precipitation, intensification of droughts, acceleration of snowmelt, increased evaporation, and other effects, resulting in impacts to infrastructure, water availability, and aquatic ecosystems (National Science and Technology Council, 2008; Brekke et al., 2009a; U.S. Global Change Research Program, 2009). This study adds to this general body of knowledge by providing quantitative and region-specific information on the impacts of climate change to water availability and to future water supplies versus projections of demand across the United States.

This work is an analysis of future business-as-usual water demand as it relates to renewable water availability at the national scale across the United States, under scenarios that consider potential changes in precipitation and temperature in 2030 and 2050 as projected by GCMs. The extent of climate change over this time frame is less severe than end-of-21st century projections, however, this time frame was chosen because it is within the time horizon of most major infrastructure planning activities, especially infrastructure related to water resources and energy production (e.g., Brekke, et al., 2009b). [redacted] there is a time lag between greenhouse gas emissions and climate change impacts, this is also with-[redacted]

For the purpose of this analysis, we project future water withdrawals under scenarios of continued population growth and associated municipal/domestic water, electricity and cooling water demands, focusing on freshwater withdrawals from groundwater and surface water sources. Water demand projections are based on five-yearly water use surveys reported by the U.S. Geological Survey, most recently for 2005 (USGS; Kenney et al., 2009). Population projections are based on Cen-



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sus Bureau estimates (U.S. Census Bureau, 2008), and electricity production estimates are from the Department of Energy (EIA, 2009). Using these values, and making assumptions on water use per capita and water use per unit of electricity generated, we estimate future water demand growth as a result of additional domestic supply and electricity generation. Future water demand projected using this approach is a business-as-usual type of scenario, and does not specifically represent future enhancements in water use efficiency in these sectors, and does not consider changes in the rates of use that might be related to climate change. Thus, future thermoelectric cooling demand is based on water use rates typical of generating plants being developed today, and future municipal demand is based on per capita water use rates in 2005 combined with future populations. The goal of such an analysis is to represent future conditions that might be expected if water use practices continue along their present trajectory. This is a somewhat artificial scenario, in that water use efficiency is not static and has continued to improve; the needs of a larger population and economy are being met mostly through total withdrawals at national aggregate levels that have remained flat over past two decades, although there are regions where withdrawals are higher and others where they are lower over this period. However, by highlighting discrepancies between potential future demand and future supply using the business-as-usual scenario, we focus attention on areas where there are likely to be the greatest pressures to improve management of surface water and groundwater resources. This could occur by management of demand growth, realignment in water use among competing uses, greater water recycling, and creation of new supplies through treatment. The past paradigm where new demands could be simply met by greater withdrawals from natural systems, with no consideration of impacts to sustainability, is unlikely to be considered as plausible in water resources development in most regions (Gleick, 1998).

Projected future withdrawals are related to a simple measure of renewable water production, or "available precipitation," which is calculated under current and future temperature and precipitation scenarios (Roy et al., 2005). In a given region, precipitation as rain or snow is the main source of renewable water. Some of the precipitation is lost to the atmosphere by evaporation or through transpiration by plants (these two processes are usually lumped together and termed evapotranspiration). The remainder percolates into the ground and is stored as groundwater or moves as runoff into surface water bodies. For the purpose of this analysis, we consider that precipitation that is not lost to evapotranspiration (termed available precipitation) can be used for other purposes, and is an approximate measure of available renewable water in a region. We calculate this as the precipitation minus potential evapotranspiration (PET) for each month, and then sum the net values for the entire year. For months where the PET exceeds precipitation, the net addition to the available water for that month is zero, to avoid counting unavailable water. PET can be thought of as an index that corresponds to the maximum evapotranspirative loss that might occur from land; in this work it is computed using a relatively simple method that can be applied over current and future conditions and across broad geographic scales.

Relating future demand and available precipitation provides an initial estimate of water supply sustainability across the nation—resolved at the county-level, the best available resolution for water use information—and helps identify areas most likely to be affected by climate change (Roy et al. 2004, 2005). Although the maps produced in this work display significant local-scale complexity, the underlying analysis is intended to be relatively simple and provide a basis for more focused regional studies where appropriate. This document summarizes the assumptions associated with the analysis relating to water demand projections, future climate, and water availability, and presents the results as a series of maps.

The remainder of this report is organized in the following manner. We first present the key elements of the methodology used, including the estimation of water demand in the future, climate projections from GCMs, the estimation of available precipitation, and the development of an index to composite multiple facets of water use. We then present the results as a series of maps for 2050, followed by the principal conclusions of this work. An appendix includes a set of maps for 2030.

# Methodology

## Water Use Data in the United States

The most comprehensive data on water use in the U.S. are collected every five years by the USGS as part of the National Water Use Information Program. These surveys were first conducted in 1950, and the most recent survey that is available is for 2005 (Kenny et al., 2009). This data gathering effort generally obtains information on surface water and groundwater withdrawals and consumptive use, and identifies use by six major categories: public and domestic water supply, commercial, industrial, mining, irrigation, and thermoelectric cooling for electric generation (including fossil-fuel and nuclear power generation). The type of water withdrawn, either fresh water or saline water, and the source, either surface or groundwater, is also reported. The most recent water use surveys also estimated livestock and aquaculture use, although these are relatively minor. In the terminology of the USGS, all these uses these are termed "offstream" uses, as opposed to "instream" uses for hydroelectric power generation (USGS, 1998). Instream uses for non-human, environmental purposes, such as flows for maintaining aquatic ecosystems, are not cataloged by the USGS. This analysis is primarily focused on offstream freshwater use.

On a national aggregate basis, Figure 1(a) shows the offstream withdrawal of freshwater for each of the major categories described above for the 2005 water use survey, as well as the trends in total freshwater withdrawal from 1950-2005 (Figure 1b). Electric generation, specifically thermoelectric cooling water and irrigation withdrawals are the dominant components of the total fresh water withdrawal nationwide (40% and 36%, respectively), followed by public and domestic water supply (14%). Although thermoelectric cooling use is a major fraction of the withdrawal, most of this use is not consumptive. In the 1995 water use survey, for example (USGS, 1998), where consumptive use was last reported, thermoelectric cooling was a relatively modest fraction of the total consumptive use (3%), and irrigation the most significant consumptive user of water (82%). Trends in freshwater withdrawal from surface and

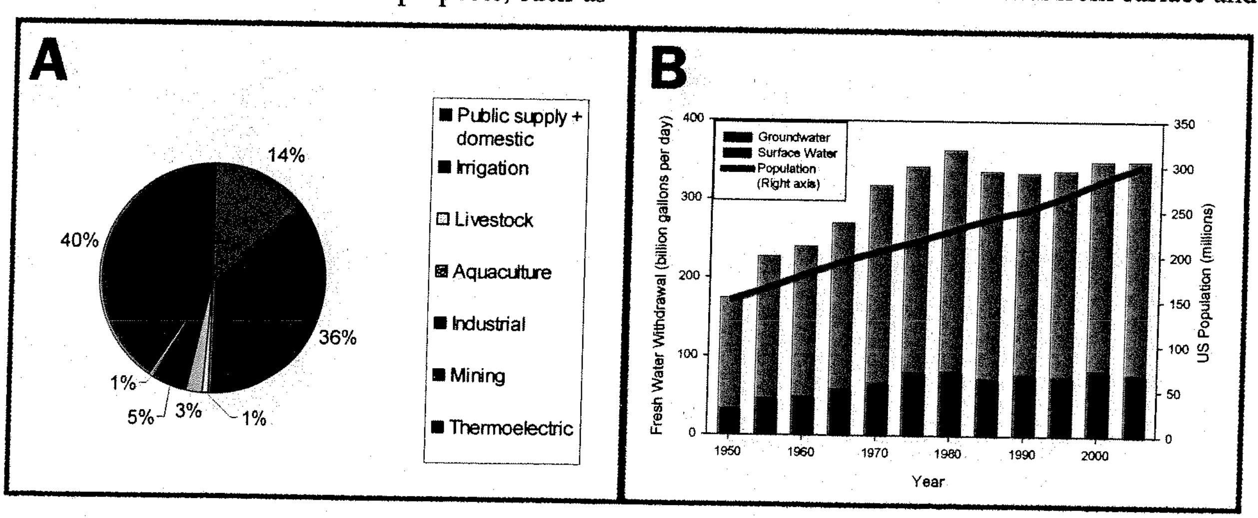


Figure 1. (a) Water use by sectors in 2005 (Source: Kenny et al., 2009), and (b) trends in total freshwater withdrawal (1950-2005).

groundwater sources provide interesting insight into the future development of water resources in the United States (Figure 1b): as population has continued to grow, total water withdrawals have remained relatively flat. The two sectors using the most water, thermoelectric generation and agriculture, have both increased their efficiency of water use over the last two to three decades, such that increased electricity generation and food production have been obtained without the use of additional water supplies. Water used instream for hydroelectric generation is not considered in this analysis and is assumed to not directly affect offstream uses.

The 2005 water use survey data at the county level (Kenny et al., 2009) forms the baseline for this analysis. Total freshwater withdrawals reported in the 2005 survey are shown in Figure 2 where the volumes of freshwater withdrawn are normalized to the county area and shown in inches per year. The withdrawals associated with thermoelectric cooling and irrigation are shown in Figure 3. There are clear geographic variations in the major sectors associated with freshwater withdrawal: irrigation withdrawals occur largely in the western states, whereas large thermoelectric withdrawals are in the eastern states and clustered near the major rivers, such as the Ohio and Mississippi River basins, and the Great Lakes. These data are shown in the units reported by USGS, i.e., in million gallons per day or mgd, for each county.

## Water Demand In 2030 and 2050

Any projection of future use is based on assumptions in the growth or decrease in demand in each of the major sectors of water use, which depend on uncertain demographic and economic forces. For the purpose of this analysis, as noted above, business-as-usual projections of future water demand were made. It was further assumed that growth occurs only for domestic supply and for thermoelectric cooling. Water use for irrigation, livestock, aquaculture and mining was assumed to remain at the same levels as in 2005.

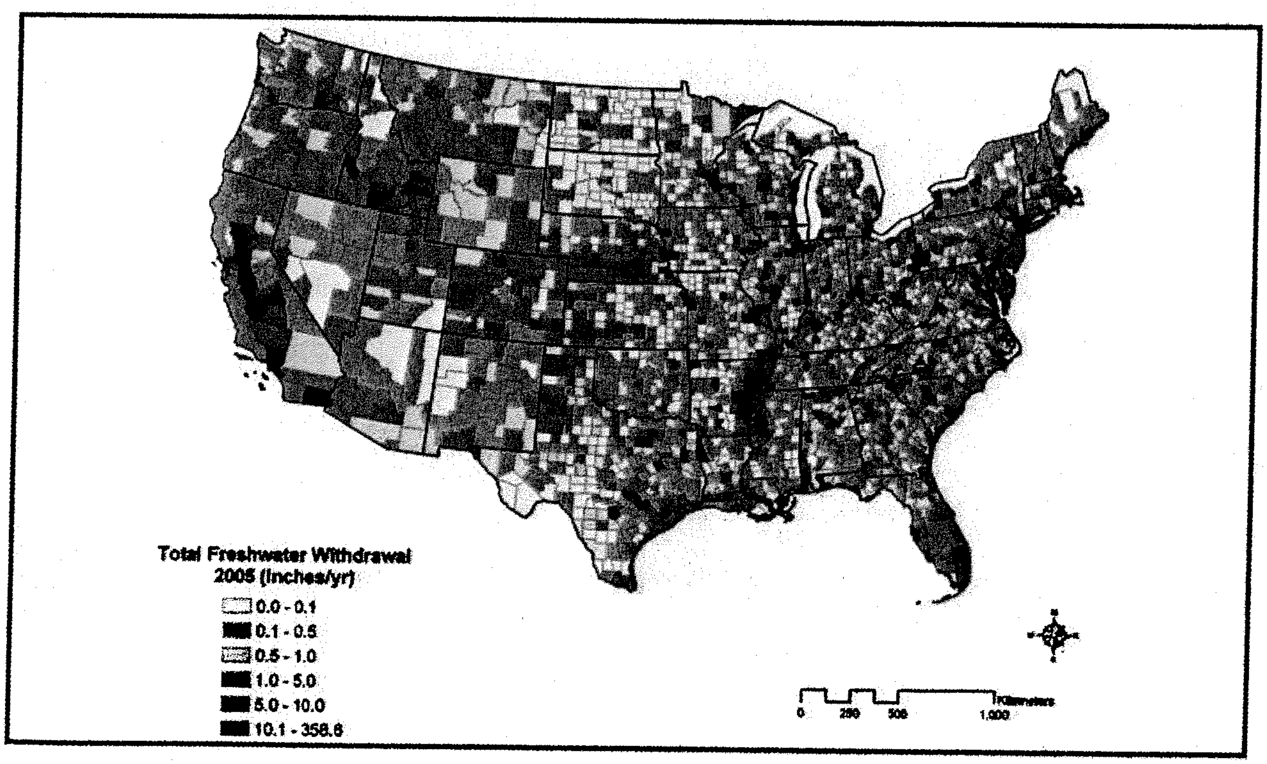


Figure 2. Total freshwater withdrawal in 2005 at the county level (Kenny et al., 2009). The specific sectors considered in the USGS water use survey include thermoelectric cooling, irrigation, public supply, industrial, commercial, livestock, aquaculture, and mining water use. Total volumes of water withdrawal in mgd are normalized to county area and reported in inches for direct comparison with precipitation and related climatic variables.

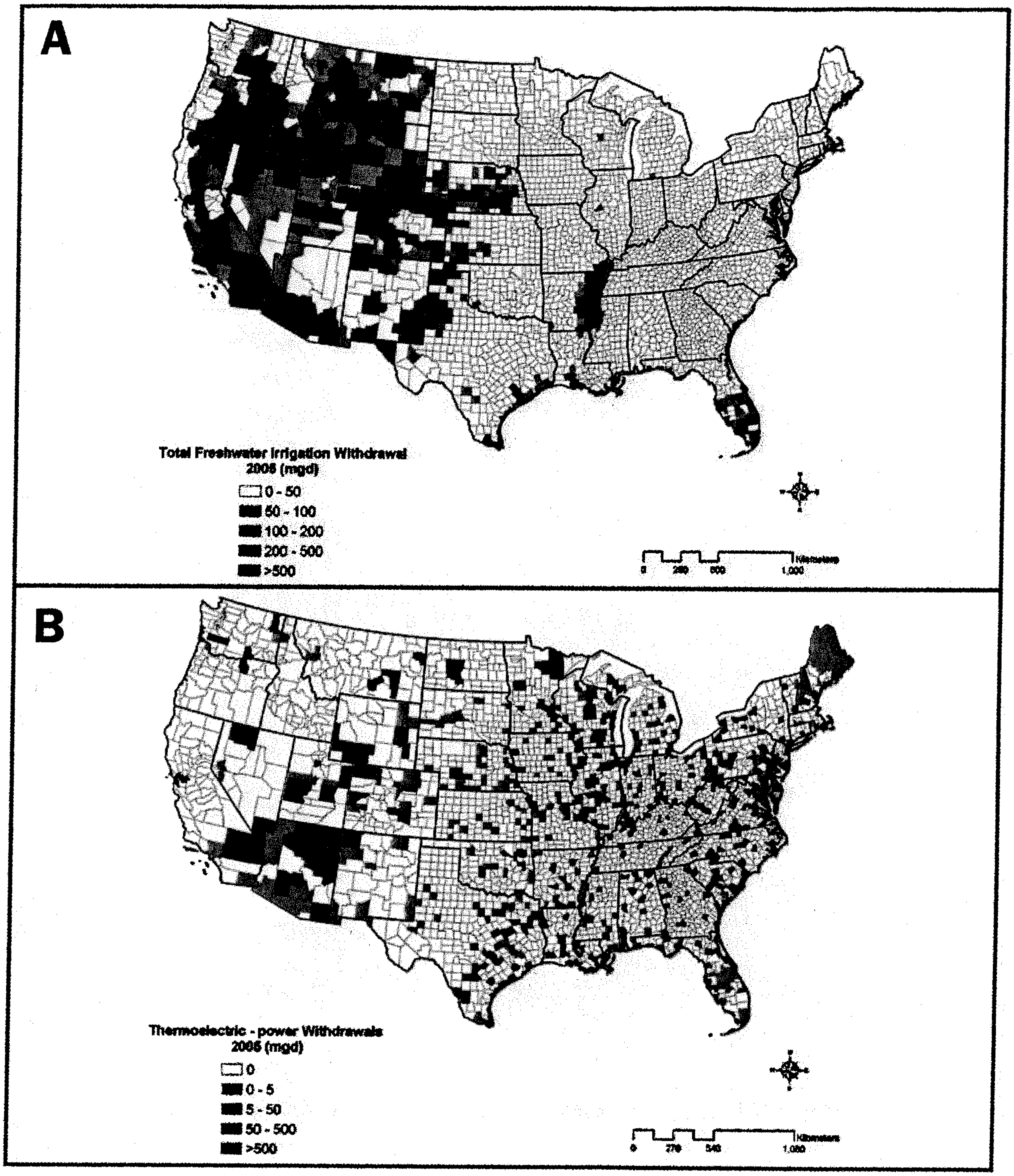


Figure 3. Withdrawals associated with irrigation and thermoelectric cooling, reported in units of mgd by the USGS (Kenny et al., 2009).

Municipal water demand was projected based on estimated future population and with current levels of per capita water use, similar to approaches used in prior analysis (Roy et al. 2003; 2005). Thermoelectric water use was projected based on new power generation and water withdrawal per unit generation at levels typical in modern power plants. New electricity generation demand estimates until 2030 were obtained from the Energy Information Administration (EIA), and extrapolated linearly to 2050. The EIA estimates are based on a model of the energy-economic system of the U.S., and also include projections of fuel type used for electricity generation (Annual Energy Outlook, EIA, 2009). Until 2030, EIA projections show the continued dominance of fossil and nuclear fuel sources in the electricity supply mix. For the purpose of this analysis, it assumed that future generation will have cooling water needs at a value similar to that reported in modern plants with evaporative cooling. These projection approaches are detailed below.

## Population Change Forecast

Total population in 2050 was projected for the U.S. by the Census Bureau (CB). Population in the U.S. in 2050 is projected to increase by 48.8%, from 282.1 million in 2000 to 419.9 million (U.S. Census Bureau, 2008). The anticipated increase is relatively linear through this period (Figure 4). Population projections at the state level have also been made by the Census Bureau for the period 2010-2030. Population projections for future years at the county level for the entire U.S. are not readily available. At the county level, total population data are available from the CB for the period of 2000-2008. In previous analysis (Roy et al., 2003; 2005), population growth rates at the county level for the period of 1990-2000 were used to project population for the period of 2000-2025. In this analysis, population change rates for the period of 2000-2008 were used to project future populations for the period of 2008-2050. The projected population at the county level was aggregated to the state level and compared to data from CB for the period of 2010-2030. Projected population at the state level at five year intervals compared well to projections by the CB ($r^2 > 0.99$), with the largest discrepancy in projections occurring in Florida. Projected total population in the U.S. using the county-by-county

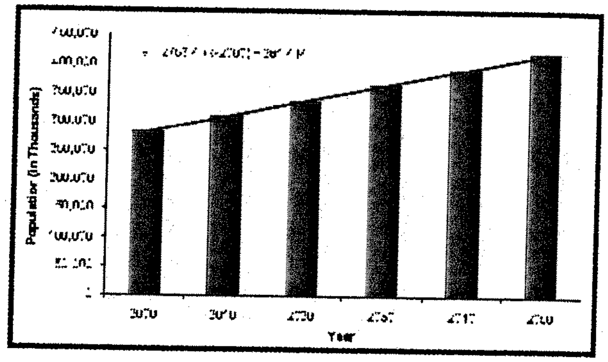

Figure 4. Projected U.S. total population for the period of 2000-2050 by U.S. Census Bureau.

method for 2050 is 419.0 million, which compares well to the CB national projection of 419.9 million. The county-level population projection approach was therefore used for this analysis, and for subsequent estimates of water use.

## Municipal Water Demand Projection

Total freshwater demand for the municipal sector (including domestic supply) was projected based on population in 2030 and 2050 and per capita water use in 2000. The per capita water use is derived as the total fresh water withdrawal from public supply and domestic water use, divided by total population served. Per capita municipal water use varies through the country, and at the state level, varies from 54 gallons per capita per day to 187 gallons per capita per day (Kenny et al., 2009), with consistently higher values in the more arid parts of the country. In forecasting future municipal water demand in a given county, the per capita water use was assumed to remain at the 2005 levels, i.e., no change in per capita rates were assumed to occur as a result of climate change. Total municipal water demand is projected to increase by 32.8% in 2030 and by 54.8% in 2050 from 2005 levels.

## Total Power Generation Forecast

To estimate the total power generation over 2006-2050, electric generation projected by the EIA for the period of 2006-2030 at the Energy Market Module (EMM) Regions was used (EIA, 2009). The projected electric generation is largest in the Southeastern Electric Reliability Council Region (excluding Florida) and the East Central Area Reliability Coordination Agreement Region (Figure 5). When forecasting the energy demand, the EIA assumes for

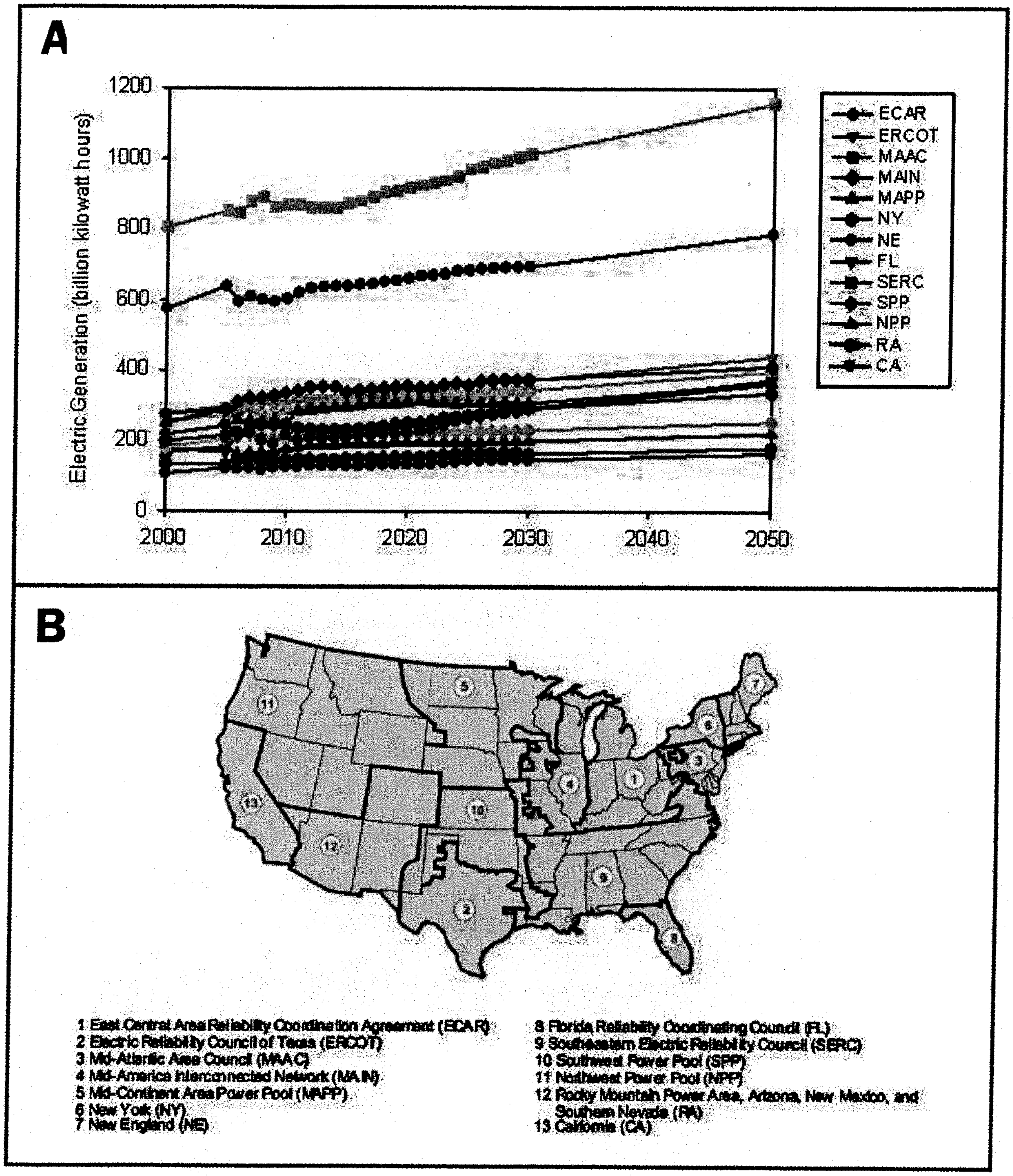


Figure 5. Projected electricity generation by EMM regions in the U.S. for the period of 2006-2050 (Source: EIA, 2009). EIA projections cover the period to 2030. These were linearly extrapolated to 2050 for the purpose of this analysis.

its reference case that growth in the world economy and fuel demand will recover by 2010, and that this growth will continue through the rest of the projection period (EIA, 2009). To extend the projections by EIA to 2050, the growth estimated for the period of 2010-2030 was extrapolated forward.

The projected thermoelectric generation in 2050 at the EMM region was first converted to the state level by applying percent changes for the period of 2005 to 2050. The percent changes were then applied to counties with existing thermoelectric generation in proportion to the level of current generation, i.e., the new generation was allocated to counties only with existing generation. This approach assumes that new thermoelectric generation, by virtue of proximity to existing transmission infrastructure or population centers, will be largely focused on areas with existing generation. Over a medium-term horizon, two to four decades, this is a reasonable starting assumption, although over a longer term, it may not hold, as the mix of generation, the population distribution, and transmission infrastructure may change.

## Projecting Thermoelectric Water Withdrawal

In projecting water withdrawal due to increases in power generation, water withdrawal per unit of electricity generation was assumed to be 500 gallons/Megawatt-hour, a mid-point range in a recent DOE analysis of water use in modern closed-loop cooling power plants where values ranged from 226-1,100 gallons/Megawatt-hour (Feeley et al., 2008). This analysis included coal, natural gas, and nuclear power plants, all which have a need for cooling water. Power plants with closed-loop cooling use water multiple times, typically in cooling towers, before discharge back to the source water body. In closed-loop processes, the total quantity of water withdrawn is significantly lower than once-through cooling power plants (averaging 27,000 gallons/Megawatt-hour; Feeley et al., 2008).

The amount of thermoelectric water use in 2030 and 2050 was calculated as the total thermoelectric freshwater withdrawal in 2005, plus the amount of water withdrawal due to new power generation. The water use per unit power generation of 500 gallons/Megawatt-hour was used based on the assumption that water withdrawal per unit generation in future will be low due to the use of improved cooling technologies (typically the use of closed-loop cooling). Based on increasing generation needs alone, projected water withdrawal for thermoelectric generation for 2030 and 2050 increased by 8.45% and 13.5% from 2005 levels.

## Projecting Total Water Demand in 2030 and 2050

Total water demand from different sectors in 2030 and 2050 can be estimated as total freshwater withdrawal in 2000 plus the projected changes in municipal and thermoelectric sectors. The analysis assumes that changes in irrigation, industrial, commercial, livestock, aquaculture, and mining water uses are less significant, and these were held at 2005 levels. Of these water uses, assumption related to irrigation is the most consequential, and merits further explanation. Irrigation water use was held constant for the following two reasons: (i) Water use for irrigation has remained within a narrow range or has declined marginally over the period 1970-2005, (ii) In the USGS dataset, the irrigation intensity, i.e., water use per unit area, did not show a clear correlation with climatic drivers (such as average precipitation and potential evapotranspiration), and may well be affected by other factors not known at the national scale, such as total water availability and water rights, the crop types being irrigated, and the irrigation practices being used . It is conceivable that irrigation water withdrawals will continue a gradual decline in the coming decades as demand in other sectors increases. However, to be conservative, the irrigation withdrawal values were essentially maintained at 2005 levels.

## Climate Projections

For future climate projections, GCMs are relied upon to provide plausible, physically-based estimates of the climate response to changes in composition of boundary conditions and increasing atmospheric greenhouse gas concentrations. Many GCMs are in current use, developed by different modeling groups throughout the world, and have been included in assessments in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC AR4, 2007). Because of the complexity of processes simulated by GCMs, their results vary, especially when variables such as precipitation are considered. For impact studies, such as this one, there is abundant support in the literature to use an ensemble of multiple models to represent a range of plausible future conditions, rather than to use the results of a single model (e.g., Christensen et al., 2007; Reichler and Kim, 2008; Maurer et al., 2007; Brekke et al., 2008; Pierce et al., 2009). For this study, we follow this trend in recent research and use an ensemble of GCM projections.

The set of 16 GCMs from which we draw our ensemble is shown in Table 1 below. The GCM output for these models, for both the 20th and 21st century simulations, was obtained from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007).

Because the spatial scale of GCM output, typically 200 to 500 km, is too large to characterize climate over smaller areas, we used spatial downscaling to make the data more relevant at the regional scale being considered in this report. For this work we used published statistically downscaled data from the 16 models in Table 1 spanning a 150-year period from 1950 to 2099 (Maurer et al. 2007) downscaled to a 1/8° resolution (resulting in cells of approximately 12 by 12 km). Statistical downscaling uses long sequences of observed climate to establish statistical relationships between large- and fine-scale climate features. These are then applied to future projections to infer the fine-scale response implicit in the large-scale GCM projections. The historical data used for the downscaling is the gridded National Climatic Data Center Cooperative Observer station data, developed as described by Maurer et al. (2002).

For each GCM, outputs using different greenhouse gas emissions scenarios are available, three of which have been used for the standardized model comparisons as part of the CMIP3 work. These are labeled Scenarios A1B, A2, and B1, following the convention of Nakicenovic et al. (2000). Each scenario embodies a different storyline for growth, technology diffusion, and interconnectivity among different regions. Broadly speaking, the three emission scenarios in the CMIP3 work represent a higher (A2), medium (A1B), and lower (B1) rate of emission growth through the 21st century. For the purpose of this analysis the A1B scenario projections for temperature and precipitation were used. Over the time period of interest in this analysis, 2020-2059, the differences between emission scenarios are relatively small, and the selection of one scenario over another would not change the results very much. Greater divergences between scenarios occur by the late 21st century, but this was not evaluated in this study.

To account for year-to-year and decadal variations in projections of temperature and precipitation projected by the GCMs, reflecting longer-term cycles in the underlying oceanic and atmospheric processes, projections for 2030 and 2050 were represented using twenty-year averaging periods about the mid-point years: the average climate for 2020 to 2039 represents 2030, and 2040 to 2059 represents 2050. For the analyses requiring monthly data, the average monthly value across the 20-yr period was used. Thus, for January 2030, we use an average of January values for each of the 20 years from 2020 to 2039. In the descriptions that follow, when we refer to temperature or precipitation from 2030 or 2050, we are referring to the average values over a 20-year period that is centered around 2030 or 2050.

The 1/8° resolution downscaling results in approximately 54,000 grid cells to cover the land area of the 48 conterminous U.S. Because we are also looking at monthly values at each cell over a 20-year period and 16 GCMs, this results in an enormous amount of data. For the purpose of this analysis, the climate data were processed using the Climate Wizard tool (http://ClimateWizard.org, Girvetz et al. 2009). The Climate Wizard tool was used to calculate the median, minimum and maximum of the 16 GCMs at each grid cell for the monthly average temperature and precipitation projected during 2020-2039 and 2040-2059. Similarly, the 20th, 25th, 40th, 60th, 75th, and 80th percentiles were calculated across all 16 GCMs for the projected monthly temperature and precipitation.

## Available Precipitation: Historical Values and Projections for 2030 and 2050

Available precipitation, defined as the difference between precipitation and potential evapotranspiration (PET) for each month of the year (Roy et al. 2005), was computed based on averages of historical data at 344 climate divisions over the period of 1934-2000. Monthly temperature and precipitation data at the climate division level was obtained from the National Oceanic and Atmospheric Administration (http://www.cpc.ncep.noaa.gov/soilmst/index_jh.html; methodology in Huang et al., 1996).

Table 1 - Table of 16 candidate GCMs for use in this study.

| | Modeling Group, Country | IPCC Model I.D. | Primary Reference |
|---|---|---|---|
| 1. | Bjerknes Centre for Climate Research | BCCR-BCM2.0 | [Furevik et al., 2003] |
| 2. | Canadian Centre for Climate Modeling & Analysis | CGCM3.1 (T47) | [Flato and Boer, 2001] |
| 3. | Météo-France / Centre National de Recherches Météorologiques, France | CNRM-CM3 | [Salas-Mélia et al., 2005] |
| 4. | CSIRO Atmospheric Research, Australia | CSIRO-Mk3.0 | [Gordon et al., 2002] |
| 5. | U.S. Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA | GFDL-CM2.0 | [Delworth et al., 2006] |
| 6. | U.S. Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA | GFDL-CM2.1 | [Delworth et al., 2006] |
| 7. | NASA / Goddard Institute for Space Studies, USA | GISS-ER | [Russell et al., 2000] |
| 8. | Institute for Numerical Mathematics, Russia | INM-CM3.0 | [Diansky and Volodin, 2002] |
| 9. | Institut Pierre Simon Laplace, France | IPSL-CM4 | [IPSL, 2005] |
| 10. | Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan | MIROC3.2 (medres) | [K-1 model developers, 2004] |
| 11. | Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA | ECHO-G | [Legutke and Voss, 1999] |
| 12. | Max Planck Institute for Meteorology, Germany | ECHAM5/MPI-OM | [Jungclaus et al., 2006] |
| 13. | Meteorological Research Institute, Japan | MRI-CGCM2.3.2 | [Yukimoto et al., 2001] |
| 14. | National Center for Atmospheric Research, USA | PCM | [Washington et al., 2000] |
| 15. | National Center for Atmospheric Research, USA | CCSM3 | [Collins et al., 2006] |
| 16. | Hadley Centre for Climate Prediction and Research / Met Office, UK | UKMO-HadCM3 | [Gordon et al., 2000] |

The available precipitation in 2030 and 2050 was estimated using a similar approach, except that GCM-downscaled values of precipitation and temperature were used rather than historical values. The ensemble median values of the 16 climate models in Table 1 were used to represent future precipitation and temperature for each month.

## Projecting Evapotranspiration and Available Precipitation in Future Years

In projecting the available precipitation in 2030 and 2050, the 50th percentile from the 16 GCMs in Table 1 was used. For each of years analyzed, the difference between monthly precipitation and potential evapotranspiration (P–PET) over the course of a year was summed to estimate the annual available precipitation. When precipitation is less than potential evapotranspiration for a particular month, the available precipitation of that month was counted as 0. The monthly potential evapotranspiration (PET) was estimated based on projected monthly temperature, using the Hamon equation (Hamon, 1961):

$$E=\frac{2.1H_t^2 e_s}{(T_t+273.2)}$$

E = evaporation, day t (mm/day)

Ht = average number of daylight hours per day during the month in which day t falls

es = saturated vapor pressure at temperature $T_t$ (kPa)

$T_t$ = temperature, day t (°C)

Ht was calculated by using the maximum number of daylight hours on day t.

Saturated vapor pressure es was estimated as:

$$e_s=0.6108\exp\left(\frac{17.27T_t}{237.3+T_t}\right)$$

The Hamon equation is one of several approaches used to estimate potential evapotranspiration, and was used because of its simplicity and relatively modest data requirements. The limited data requirements are an important constraint because we are applying the model across a broad geographic scope and into the future, where additional data (e.g., soil moisture and wind speed) are not easily available. Furthermore, comparisons of multiple PET estimation approaches have demonstrated that the Hamon method is generally preferable for contemporary climate studies (Vorosmarty et al., 1998). A similar cross-comparison of PET estimation methods in the Southeast (Lu et al., 2005), where different techniques were used to compute water budgets for 36 watersheds, identified the Hamon equation as one of three methods suitable for use. For these reasons, future estimates of PET, used to compute the available precipitation, were based on the Hamon equation. PET projections do not consider changing land use as a factor, given the time frame and spatial scale applied in this analysis, changing land use was not variable over time.

## Ratio of Future Water Demand and Available Precipitation

As a metric representing the intensity of water development in a region, the ratio between water demand and available precipitation can be computed. To compute the ratio of future demand and available precipitation, the projected available precipitation at 1/8° scale was aggregated to the county level. The projected water withdrawal in mgd as reported by the USGS was normalized to the county area, and represented in inches for direct comparison to available precipitation. High values of this ratio are indicative of the withdrawal of a large fraction of the available precipitation, and are representative of what is called water resources "development" in a region.

Besides ratios of future water demand and available precipitation, another metric computed was the summer deficit, defined as the available precipitation minus withdrawal in June, July, and August, typically the three warmest months of the year that correspond to increased municipal, thermoelectric cooling, and irrigation demand. The irrigation demand is reported as an annual value, and as noted above, is assumed to remain flat over the time horizon of the analysis on an annual basis. However, during the year, irrigation water is applied to meet the deficit between precipitation and evapotranspiration, and the demand is not constant over the year. In estimating irrigation demand in June, July, and August, it was assumed that irrigation needs are proportional to monthly deficit in available precipitation (P–PET). The summer deficit is an indicator of water shortage on a seasonal basis that must be met through stored sources or groundwater.

## Development of an Index of Water Sustainability and Climate Susceptibility

The water resources literature presents several examples of indices that are used to integrate different measures of water availability and access to human populations (e.g., Loucks and Gladwell, 1999; Vorosmarty et al., 2005). Well known examples include the Water Stress Index defined as the ratio of available river runoff to population in basin, with a level of 1700 $m^3$ per capita per year being defined as the threshold below which a basin may be considered to be water stressed (Falkenmark et al., 1989).

Another simple index is the basic water requirements (BWR) value of 50 liters per capita per day to meet basic human needs (Gleick, 1996, 1998). A multidimensional index in common use is the Water Poverty Index that combines physical and socioeconomic factors and has been used to rank water stress in many regions of the world (Lawrence et al., 2002; Sullivan et al., 2003). Similarly, Hurd et al. (1999) assessed relative regional vulnerability to climate change using a set of unweighted indices representing offstream and instream uses, representing variables such as levels of freshwater withdrawal, groundwater depletion, flood risk, etc.

Several of the published indices were developed to meet different purposes, ranging from human access to clean water or ecosystem health. In the particular context of this study in the United States, where access to water for basic human needs is not a major concern, and where detailed data on water use is readily available through the USGS water use surveys, a more targeted index may be developed that is focused on water supply concerns in coming decades. For this reason, building on past work (Roy et al., 2003, 2004), a water supply sustainability index was developed to evaluate multiple water constraints in a composite index. The index can be computed using historical precipitation (e.g., 1934-2000) or using future projected precipitation for the 21st century from GCMs. Metrics considered in the index include natural available precipitation, the extent of water development already in place, dependence on groundwater, the region's susceptibility to drought, projected increases in water use, and the difference between peak summer demand and available precipitation, a measure of storage requirements. Regardless of the structure of the index used, it is important to emphasize that it is at best an indicator, and a means to summarize information across a broad geographic domain, in this case the lower 48 states of the U.S.. The goal of the index is to present information compactly, and to highlight areas that need further attention, and more refined local-scale analysis (e.g., see case studies in the the West discussed by Anderson and Woosley, 2005).

In compositing the sustainability index for future years, five criteria were used. The risk to water sustainability for counties meeting two of the criteria are classified as "moderate," those meeting three of the criteria are classified as "high," and those meeting four or more are classified as "extreme." Counties meeting fewer than two criteria are considered to have low risk to water sustainability. The criteria are as follows:

1. Extent of development of available renewable water: greater than 25% of available precipitation is used (calculated based on projected water demand and available precipitation in 2050). The larger the fraction of available precipitation that is used to meet human needs, the greater the risk to supply when this quantity changes.

2. Sustainable groundwater use: ratio of groundwater withdrawal to total withdrawal is greater than 25% (based on current groundwater withdrawal). Greater withdrawals may be indicative of unsustainable use of aquifers.

3. Susceptibility to drought: Summer deficit, as described above, is greater than 10 inches, and this water requirement must be met through stored surface water, groundwater withdrawals, or transfers from other basins. In estimating irrigation demand in June, July and August, it was assumed that irrigation needs are proportional to monthly deficit in available precipitation (P– PET).

4. Growth in water demand: The increase of total freshwater withdrawal between 2000 and 2050 is more than 20%. Based on the discussion above, growth in water demand is driven largely by population growth and the need for new thermoelectric generation.

5. Increased need for storage: summer deficit increases more than 1 inch over 2005 and 2050. As noted in item 3 above, the summer deficit is met through stored surface water, groundwater, or transfers from other basins. An increase in the summer deficit means that additional supply must be generated in the dry months through new storage or other means.

# Results

## Projected Precipitation and Temperature Changes by the Climate Models

A plot of projected precipitation changes between 1961-1990 and 2020-2039 (Figure 6) indicates decreases in precipitation in the West and parts of the Gulf states and increases in the Northeast and parts of the Midwest. Projected precipitation changes between 1961-1990 and 2040-2059 indicate similar spatial patterns, although with greater differences from 20th century values: there are decreases in the Gulf states (Texas) of more than 1 inch/yr and increases in the Northeast by 2-4 inches/yr (Figure 7). California stands out as an exception with changes in the Sierra region and parts of the coast moving from a decrease to an increase. A closer scrutiny of the underlying data show limited systematic variation in the precipitation for this region as a result of climate change, and the absolute changes (going from -1 inch to +1-2 inches) are relatively small compared to the total precipitation.

Projected temperature increases between 1961-1990 and 2020-2039 are 0.9 – 1.95 °C, with the highest temperature increases occurring in parts of the Midwest and parts of the western mountain regions (Figure 8). Projected increases in temperature for 2040-2059 are greater and range from 1.5 to 3 °C. The highest temperature increases are in the Midwest and mountain regions of the West (Figure 9).

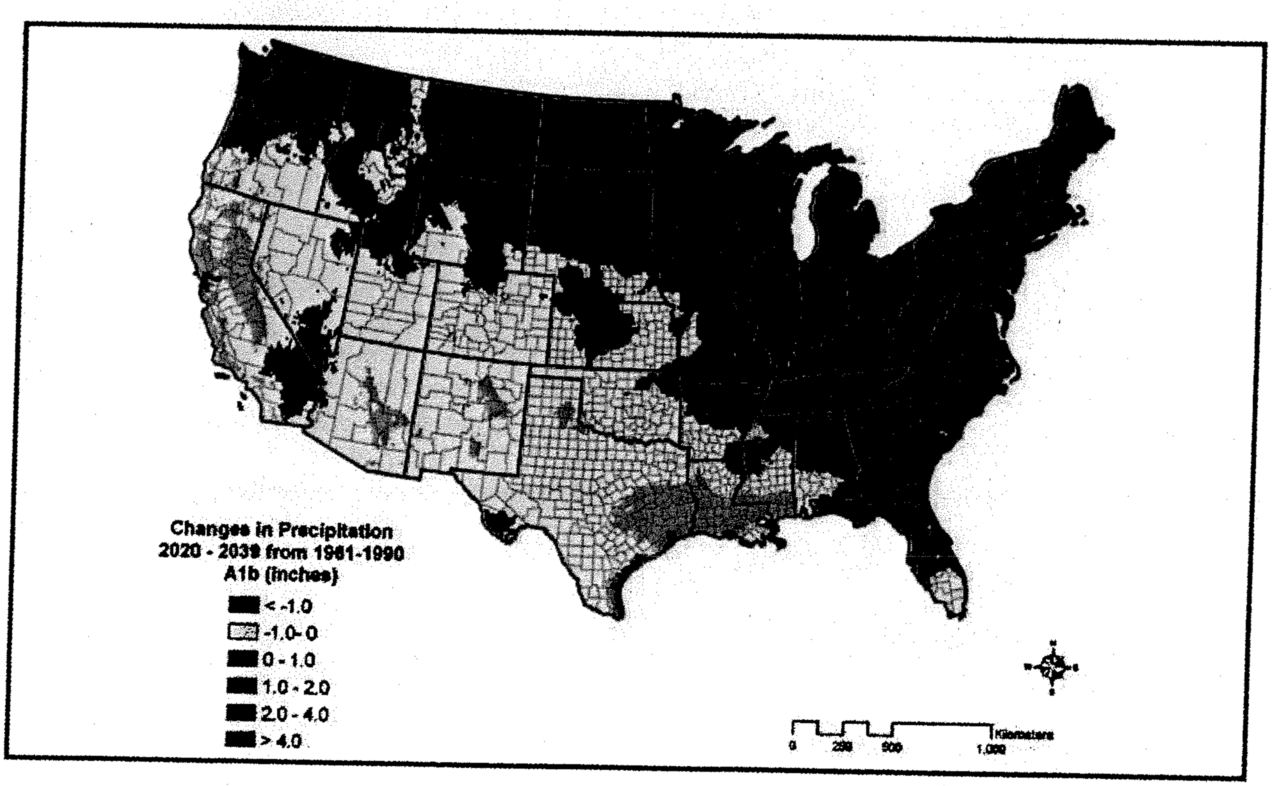


Figure 6. Predicted changes in mean annual precipitation from 1961-1990 to 2020-2039 (median of 20-year means computed from the 16 GCMs in Table 1).

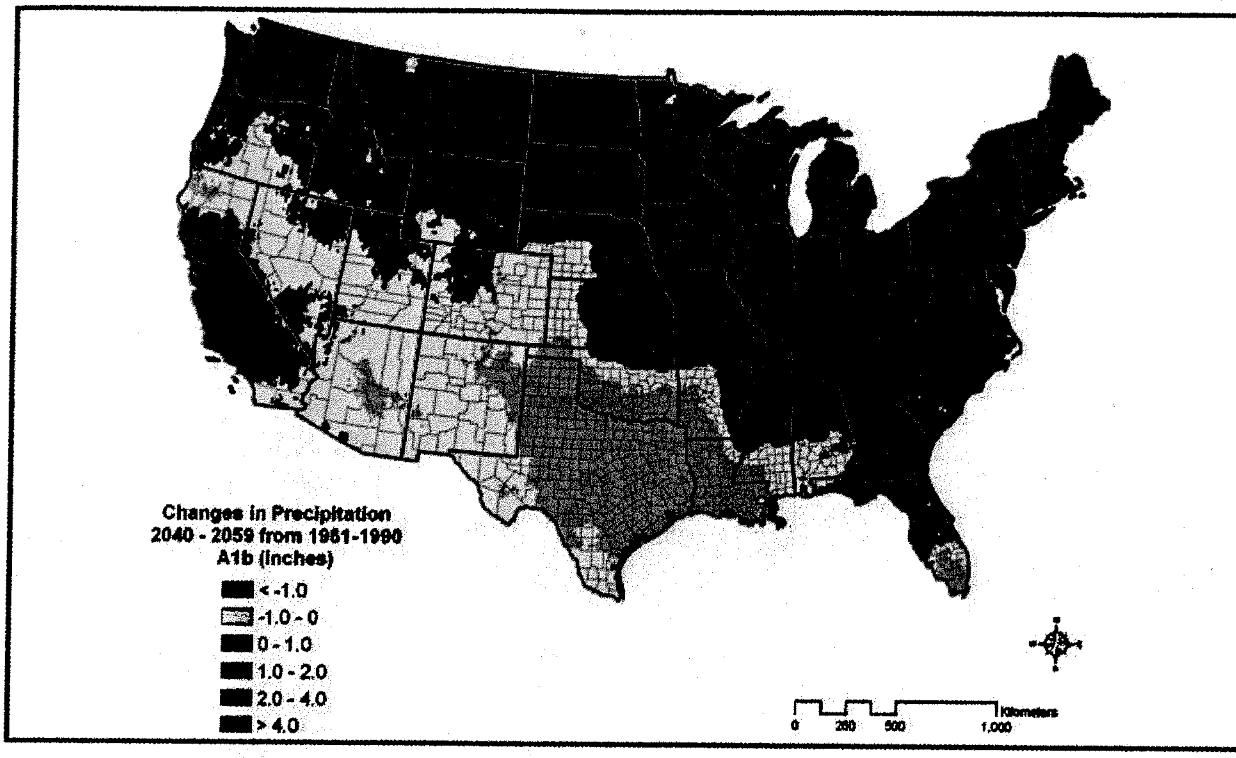


Figure 7. Predicted changes in mean annual precipitation from 1961-1990 to 2040-2059 (median of 20-year means computed from the 16 GCMs in Table 1).

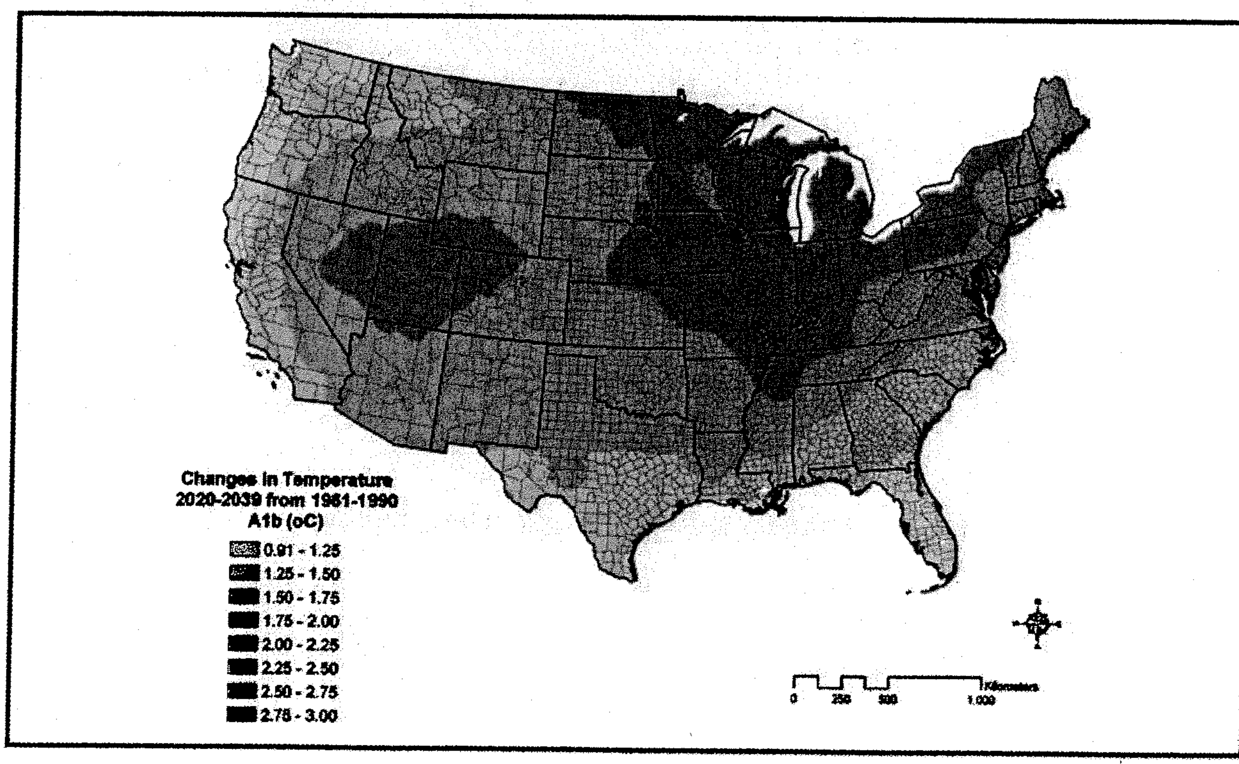


Figure 8. Predicted changes in mean temperature from 1961-1990 to 2020-2039 (median of 20-year means computed from the 16 GCMs in Table 1).



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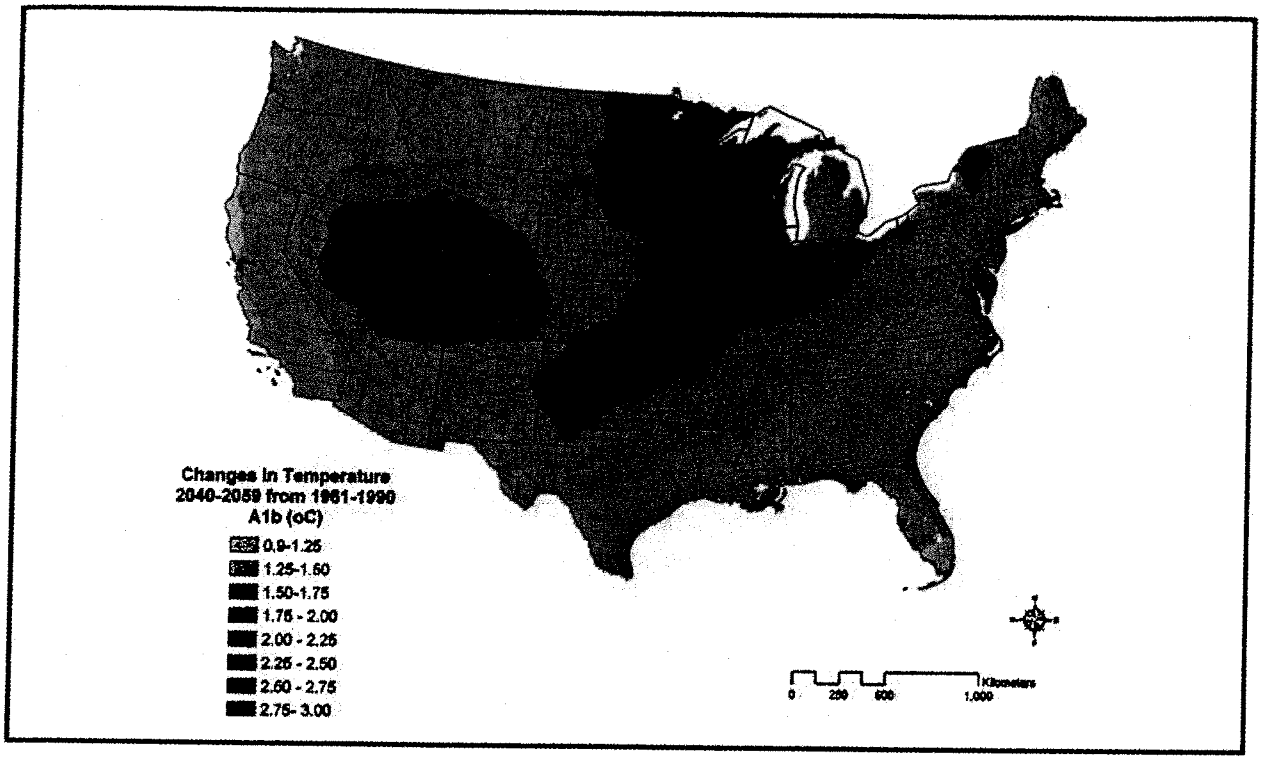


Figure 9. Predicted changes in mean temperature for the period of 1961-1990 to 2040-2059 (median of 20-year means computed from the 16 GCMs in Table 1).

A quantitative measure of the variation in projected precipitation across different GCMs defined as (75th percentile value minus 25th percentile value)/ Median, termed the interquartile ratio, is shown in Figure 10, and was computed using the Climate Wizard tool. Low values of the interquartile ratio at a given location imply that the 16 GCM projections for this location are in general agreement, whereas large values of this ratio suggest greater differences across models. The precipitation trend projected by the GCMs may be considered more certain when the interquartile ratio among models is low. The interquartile ratio shows agreement in precipitation projections for most of the country with the Southwest and the Great Plains being the exceptions. In other words, the 16 models predict future precipitation with greater uncertainty in these regions, a finding that is important because these are also among the most water short and water stressed regions in the country.

## Projected Available Precipitation in 2050

Projected available precipitation (P–PET) in 2050 under the A1b scenario, using the median of 16 GCMs, is shown in Figure 11. Projected changes in total available precipitation for 2050 from the twentieth century records (1934-2000) are shown in Figure 12. Projected available precipitation is less than 2 inches for many areas in the West and more than 15 inches in the Northeast, Northwest, and South Atlantic. Projected decreases in available precipitation from historical records are generally less than 2.5 inches/yr with some regions in Texas and the Mississippi Basin showing more than 5 inches of decrease. Similar maps for 2030 are presented in the appendix.

Changes in available precipitation are a result both of changing precipitation and of changing PET, as a consequence of higher temperatures. In areas

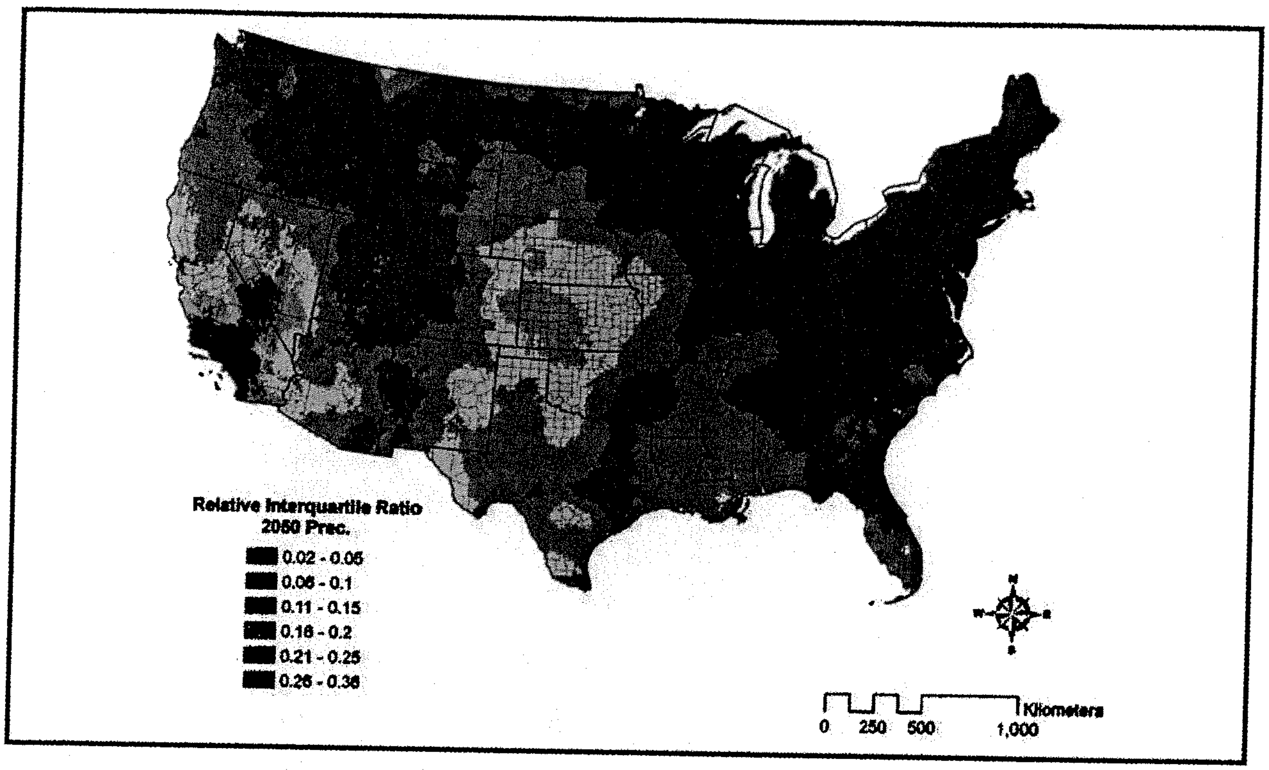


Figure 10. Relative inter quartile ratio (RIQR) for the 2050 precipitation based on analysis of monthly data from 16 GCMs. The RIQR is a quantitative measure of the variation in projected precipitation across different GCMs defined as (75th percentile value -25th percentile value)/Median. Low values of the ratio at a given location imply that the 16 GCM projections for this location are agreement, whereas large values of this ratio suggest differences across models. The RIQR shows agreement in annual precipitation projections for most of the country with the Southwest and the Great Plains being the exceptions. These are among the most water short and water stressed regions in the country.

where both changes are adverse, i.e., higher PET and lower precipitation, the impacts to available precipitation are most significant. Figure 13 shows the projected changes in PET in comparison with changes in precipitation over the 2000-2050 period. The most significant adverse changes are in the central and southwestern regions of the U.S.

The projected available precipitation shows patterns similar to historical precipitation patterns (Roy et al. 2005). The main changes are increases in certain low available precipitation zones (0-5 inches/yr) and decreases in high available precipitation zones (15-25 inches/yr).

## Projected Total Water Demand in 2050

Projected total freshwater withdrawal in 2050 based on changes in municipal and thermo-electric water demand are shown in Figure 14. Projected changes in water demand in 2050 are shown in Figure 15. Similar maps for 2030 are presented in the appendix. Under the business as usual scenario presented here, total water demand is projected to increase by 7.3% in 2030 and by 12.3% in 2050 from 2005 levels.

Total freshwater withdrawals in 2050 are significant in the major agricultural and urban areas

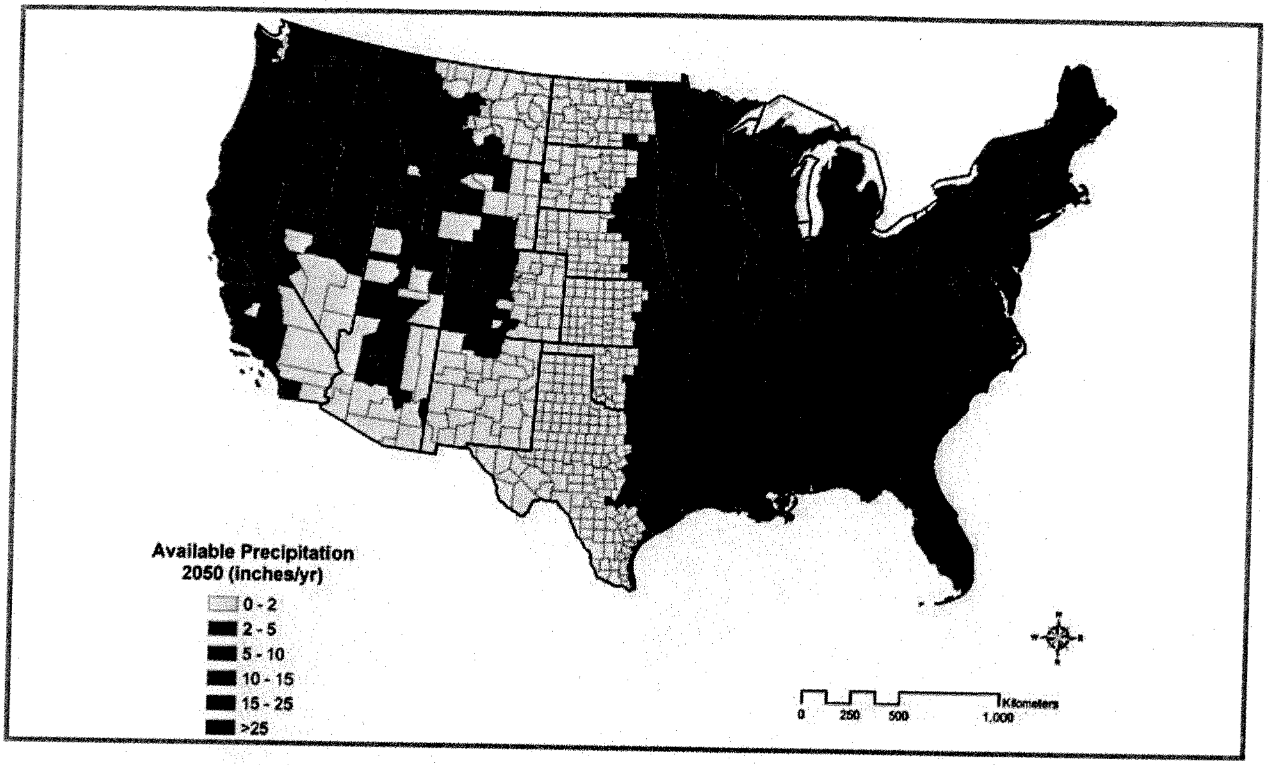


Figure 11. Projected available precipitation in 2050 aggregated to the county level, based on the 50th percentile of projected precipitation by climate models (ensemble of 16 GCMs).

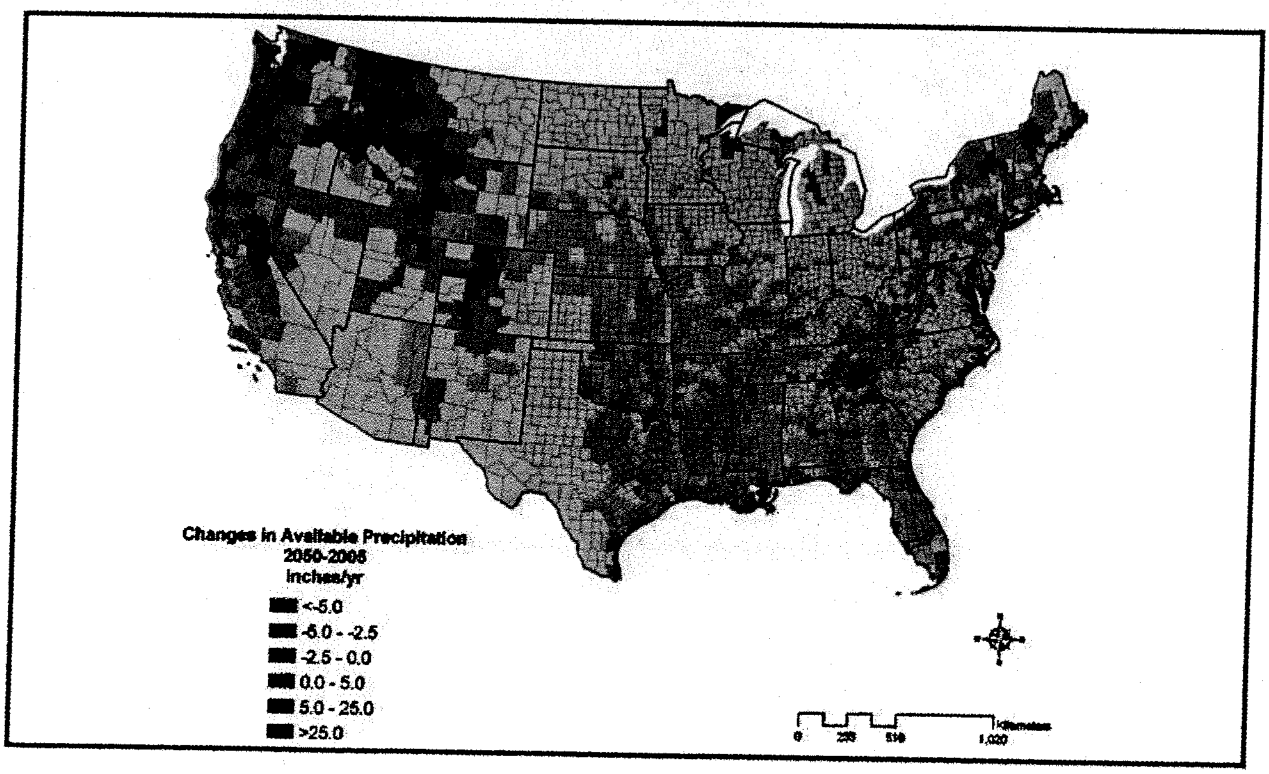


Figure 12. Changes in available precipitation from 2005 to 2050 in inches/yr. 2050 values are based on an ensemble of 16 GCMs and represent conditions between 2040 and 2059.

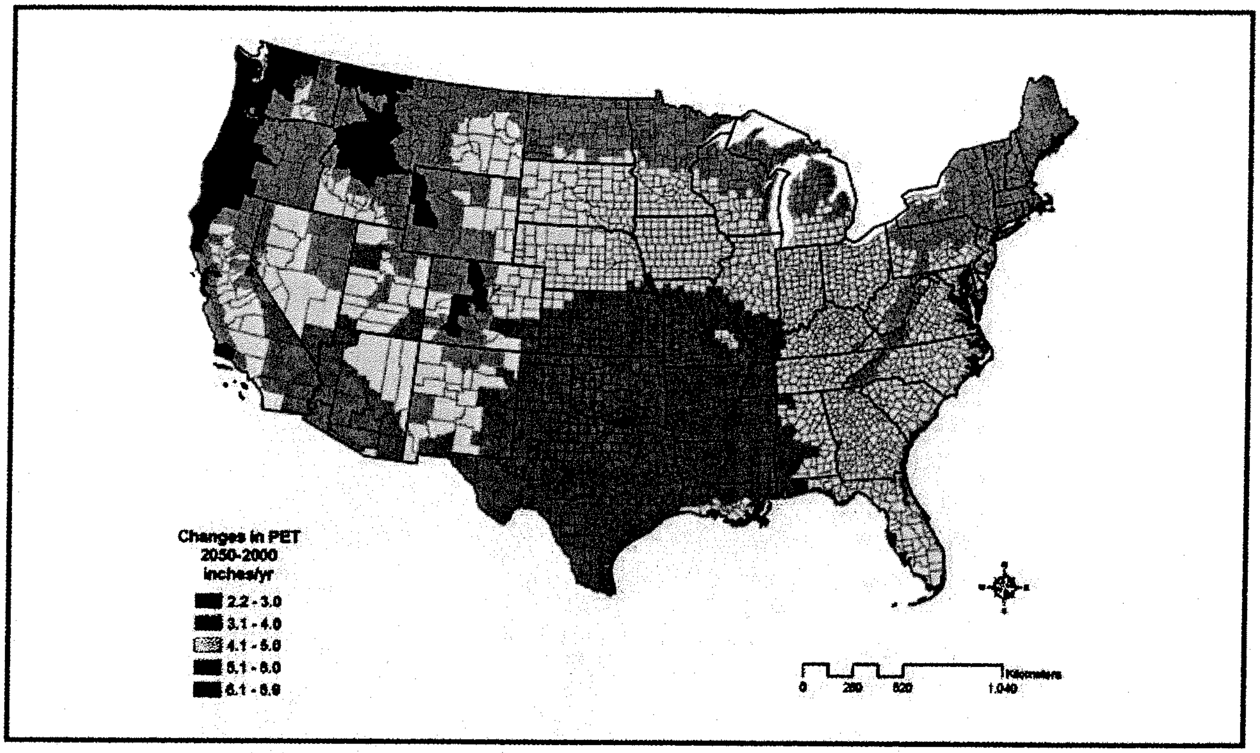


Figure 13. Projected changes in PET during 2000-2050 as a result of projected climate change. The change in PET, estimated using the Hamon equation, largely as a consequence of temperature change, can be compared with the projected change in precipitation (Figure 7).

throughout the nation. Total freshwater withdrawals in 2050 are between 0.2-0.5 inches/yr with some areas in the West showing withdrawals of 1-5 inches. Some areas in California, Texas and the Mississippi River basin show water demand of more than 10 inches/yr. The projected changes in water withdrawal include decreases in the Midwest and increases in some areas in the Southeast, the South, and the West. The projected increases in water demand are 0.1 inches/yr for most regions, with a few areas showing more than 3 inches of increase.

Projected percent changes in total freshwater withdrawal include decreases in the Midwest and some areas in the Northeast. The projected percent increases in water withdrawal are greater than 25% in many areas of the U.S. including the arid Arizona/New Mexico area, the populated areas in the South Atlantic region, Florida, Mississippi River basin, and Washington DC and surrounding regions.

## Projected Ratios of Water Demand and Available Precipitation

The projected total freshwater withdrawal as a percentage of available precipitation for 2050 assuming climate change impacts and for historical precipitation (1934-2000) is shown in Figure 16a and Figure 16b. Similar plots for 2030 are presented in the appendix. These maps can be used to compare directly the location and magnitude of impacts due to climate change. As the maps for the historical precipitation show, there are some regions in the U.S. where withdrawal is larger than renewable supply, indicative of transport by rivers, interbasin transfer by manmade canals or aqueducts, or groundwater mining in excess of recharge. However, the consideration of climate change impacts greatly expands areas where water withdrawal is greater than renewable supply. This is especially the case for much of the western U.S., in particular areas over the Ogallala Aquifer (Central U.S.) and Edwards Aquifer (Texas), and in the Southwest.

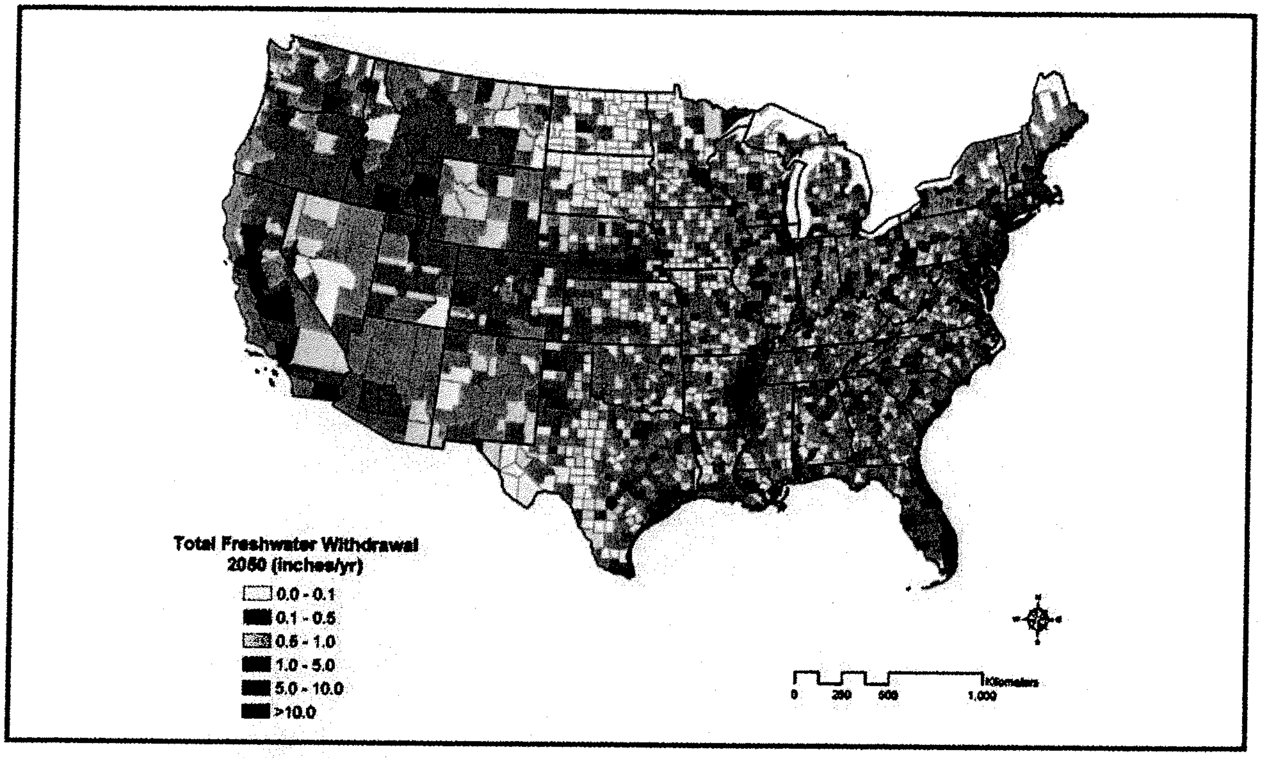


Figure 14. Projected total freshwater withdrawal in 2050 (inches/yr). The 2050 values are based on population growth and increased electric generation capacity, and assuming water use rates for domestic use at 2005 levels, albeit varying by county, and new cooling water use at 500 gallons/ Megawatt-hour. Withdrawals for other sectors are assumed to remain at their 2005 levels.

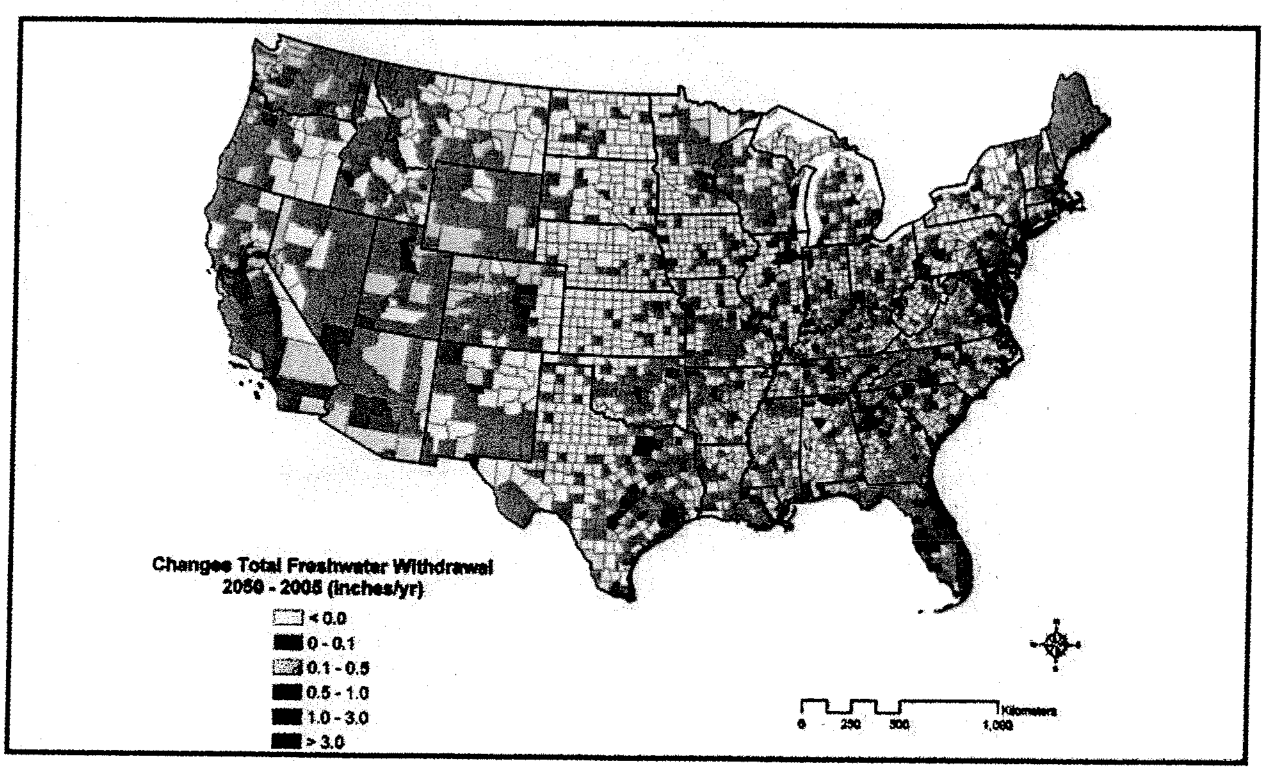


Figure 15. Changes in total freshwater withdrawal from 2005 to 2050 (inches/yr).



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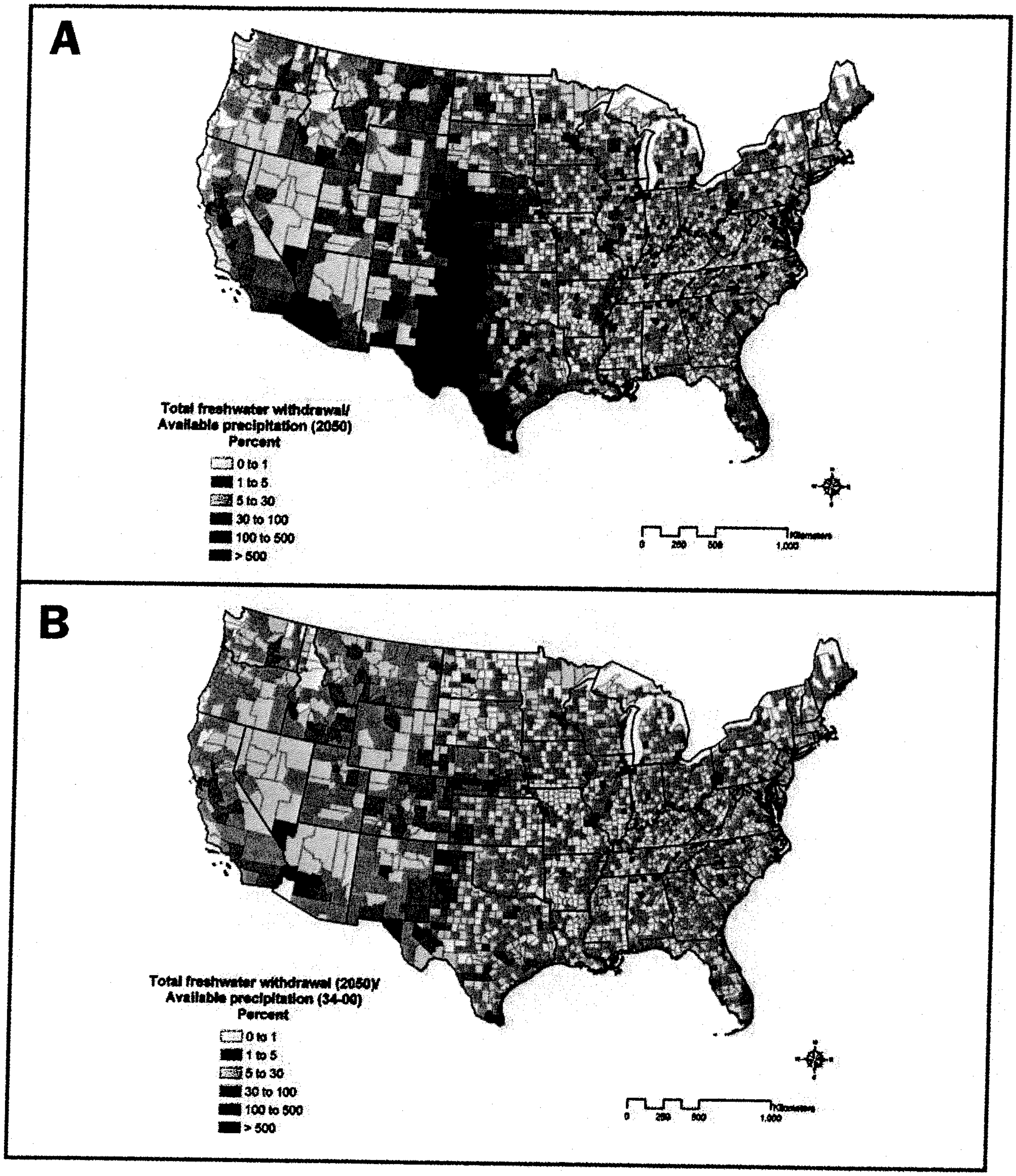


Figure 16. (a) Projected total water withdrawal as percent of available precipitation in 2050. 2050 values are based on an ensemble of 16 GCMs and represent conditions between 2040 and 2059. (b) Projected total freshwater withdrawal in 2050 as percent of historical (1934-2000) total available precipitation.



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The estimated water withdrawal as a percent of available precipitation is generally less than 5% for the majority of the eastern U.S. and less than 30% for the majority of the West. In some arid regions (e.g., Texas and California) and agricultural areas, water withdrawals are estimated to be greater than 100% of the available precipitation. In some regions (e.g., Texas), due to projected changes in precipitation and increases in temperature, projected PET exceeds precipitation, and results in 0 available precipitation.

## Projected Water Sustainability Supply Index

The water supply sustainability index is computed for 2050 demands using GCM-projected available precipitation and using historical available precipitation (Figure 17). The map of the water supply sustainability index suggests several areas that are at high or extreme risk to climate change impacts in 2050. These areas include California, Nevada, Arizona, Texas and part of the Florida. The majority of the Midwest and the South are considered to be at moderate risk, whereas the Northeast and some regions in the Northwest are at low risk of impacts. Without the consideration of climate change in future years, the range of counties with water supply sustainability is far smaller, although many of the same states are affected, including parts of California, Arizona, Nevada, Texas, Arkansas, and Florida. The impacts on the interior, central parts of the U.S. (especially over the Ogallala Aquifer), Texas (over the Edward Aquifer), and much of the Southeast are considerably more amplified in the presence of climate change.

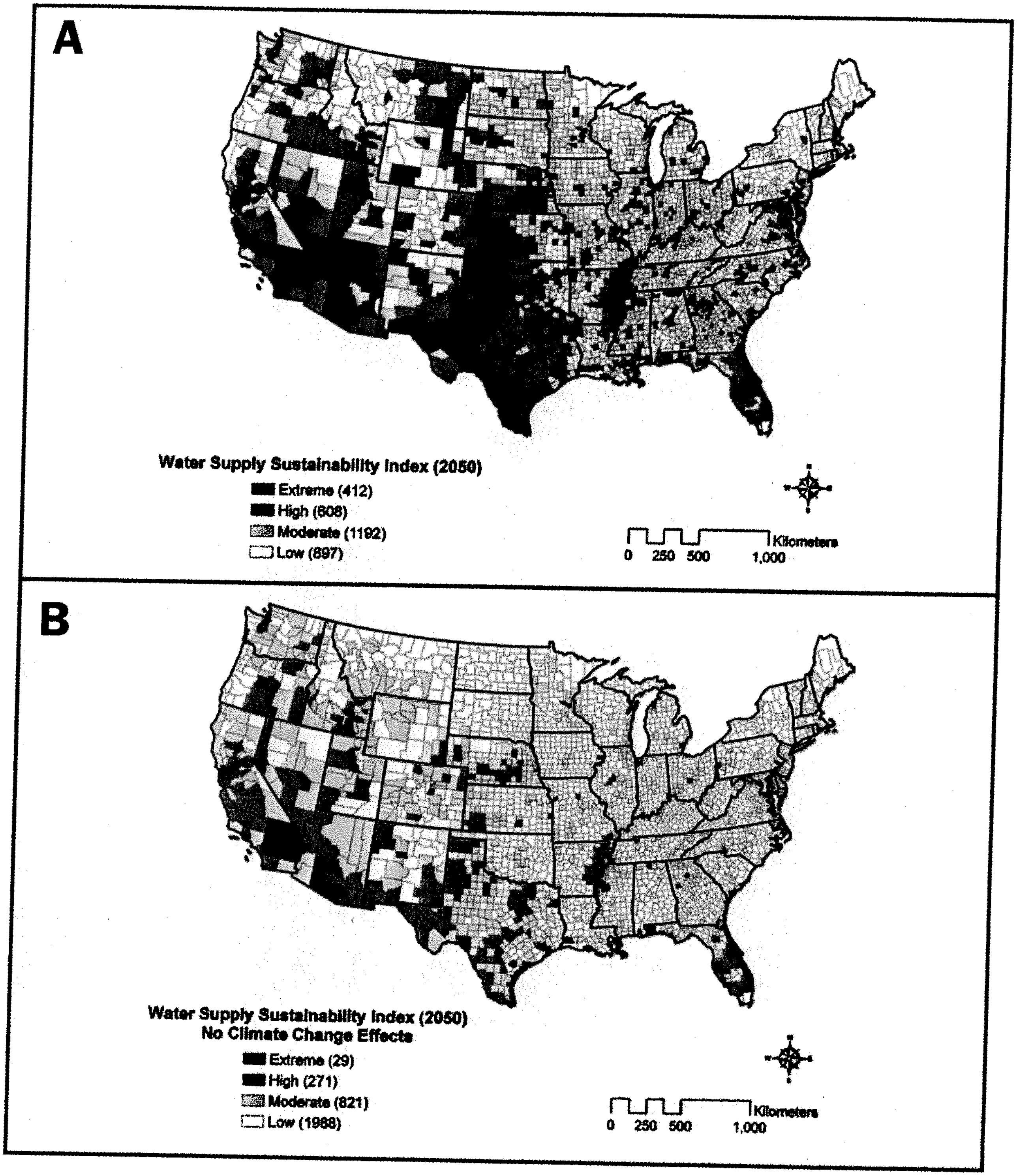


Figure 17. Water Supply Sustainability Index in 2050, (a) with available precipitation computed using projected climate change, and (b) with available precipitation corresponding to 20th century conditions, i.e., 1934-2000. The risks to water sustainability are classified into four categories from Extreme to Low. The numbers in parentheses are the numbers of counties in each category.

# Conclusions

The analysis presented in this work used a combination of publicly available data on current water use and future trends in population and energy demand to estimate future water withdrawal requirements under business as usual conditions, and to relate this to renewable water availability under future climate conditions. Water resources constraints differ from region to region, and include concerns about growth in demand, insufficient storage to tide over low rainfall periods, and overextraction of groundwater. In many regions of the U.S., where some of these constraints are apparent—such as areas in the Southwest, and over the Ogallala and Edwards Aquifers—climate change is one more factor to contend with. To address this multifaceted aspect of water sustainability, an index was developed to help rank the relative risk of different regions from one or more of these factors. Broad scale impacts to water resources that may be anticipated have been addressed in previous work (e.g., Gleick, 1989; Jacobs et al., 2001; Bates et al., 2008). This analysis provides a quantitative and region-specific assessment of the nature of impacts that might be expected across the United States. The maps produced as part of this work are based on fairly straightforward and easily replicable metrics that represent different aspects of water withdrawal and use.

The projected climate changes by 16 GCMs show significant variations in predicted precipitation, although temperature was projected to increase by all climate models. Mean changes in annual precipitation projected by the climate models show decreases in precipitation in many regions of the U.S., including areas that may currently be described as water-short. Projected changes in water demand for the period of 2005 to 2050 are generally at a scale of 0.1 inches, mostly as increases, while projected changes in available precipitation are at a scale of 2.5 inches, often as decreases. Therefore, the higher ratios of water demand as a fraction of available precipitation projected for 2050 are largely a result of changes in available precipitation. The projected changes in available precipitation are due to both changes in precipitation and increased PET. Projected changes in PET due to climate change are generally 4 to 5 inches/yr, with areas in the South showing 5 to 6 inches/yr increases in PET.

From this analysis, it appears highly likely that climate change could have major impacts on the available precipitation and the sustainability of water withdrawals in future years under the business-as-usual scenario. Based on an index compositing multiple metrics, we found that water supplies in 70% of counties in the U.S. may be at some risk to climate change, and approximately one-third of counties may be at high or extreme risk. The geographic extent of potential risk to water supplies is greatly increased when climate change is considered than when 20th century temperature and precipitation are used. This calculation indicates the increase in risk that affected counties face that water demand will outstrip supplies, if no other remedial actions are taken. To be clear, it is not intended as a prediction that water shortages will occur, but rather where they are more likely to occur. As a result, the pressure on public officials and water users to creatively manage demand and supply--through greater efficiency and realignment among competing uses, and by water recycling and creation of new supplies through treatment--will be greatest in these regions.

The maps produced in this work can be used in different ways. They provide a large-scale overview to help assess the extent of water resources impacts that are associated with future climate change, and to identify regions that are most likely to be affected. They are also a starting point for more detailed mechanistic water budget analysis at a localized scale, such as that of a city or water district, or a specific watershed. The metrics computed in this work are for a single business-as-usual scenario on the growth side, albeit one that is plausible. It is expected that more detailed analysis will consider and perhaps identify alternative region-specific growth trajectories that are more likely to be sensitive to anticipated climate change. These analyses can serve as the foundation for developing regional-scale alternatives for adaptation, such as modification of withdrawals, changing water use efficiency in different sectors, creating new supplies through technologies such as desalination, or creating more storage to address potentially greater year-to-year variability in precipitation.

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# Appendix: Maps for 2030

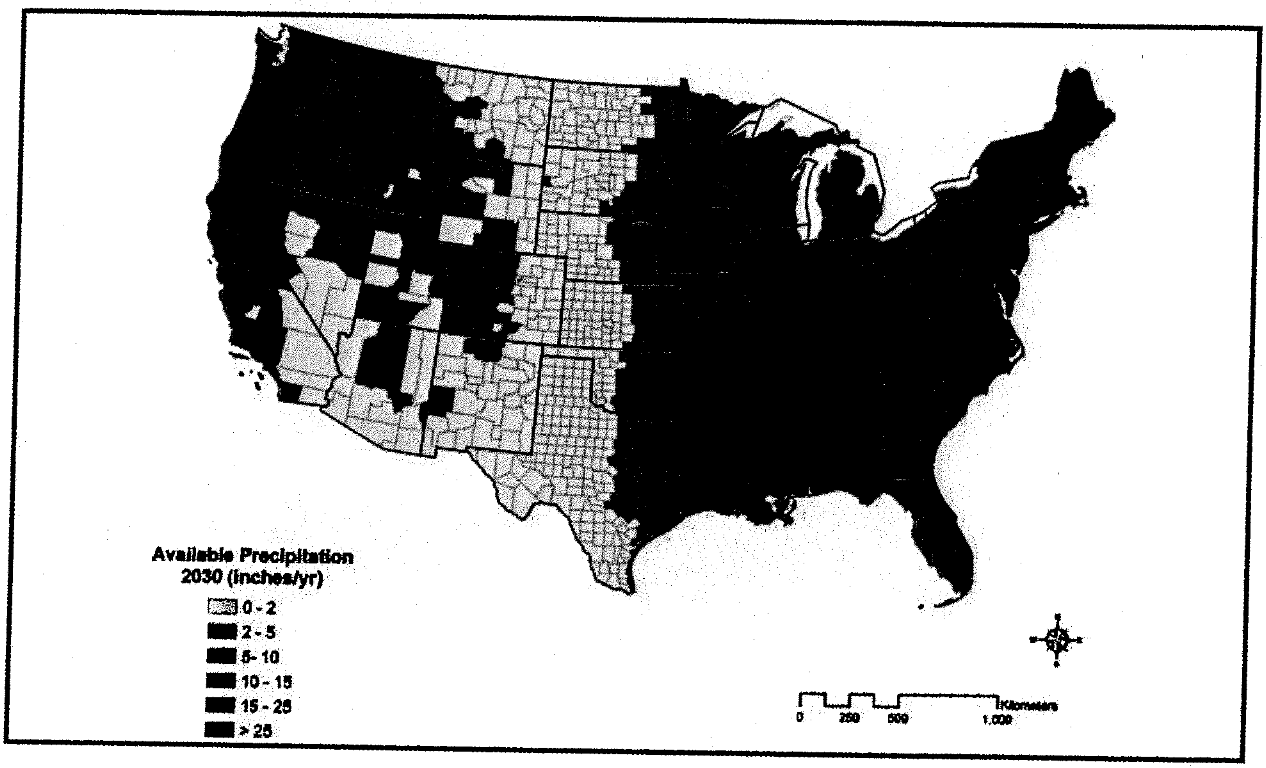


Figure A-1. Projected available precipitation in 2030 aggregated to the county level, based on the 50th percentile of projected precipitation by climate models (ensemble of 16 GCMs).


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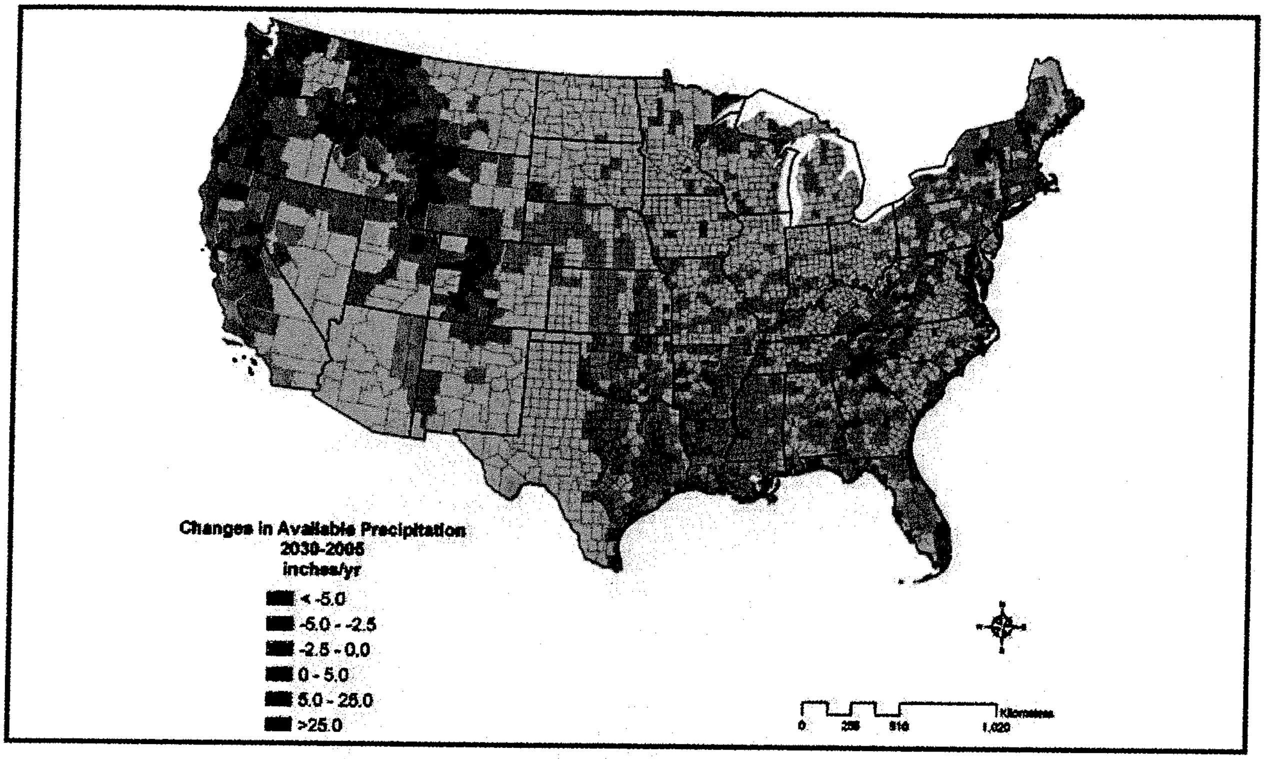


Figure A-2. Changes in available precipitation from 2005 to 2030 in inches/yr. 2030 values are based on an ensemble of 16 GCMs and represent conditions between 2020 and 2039.

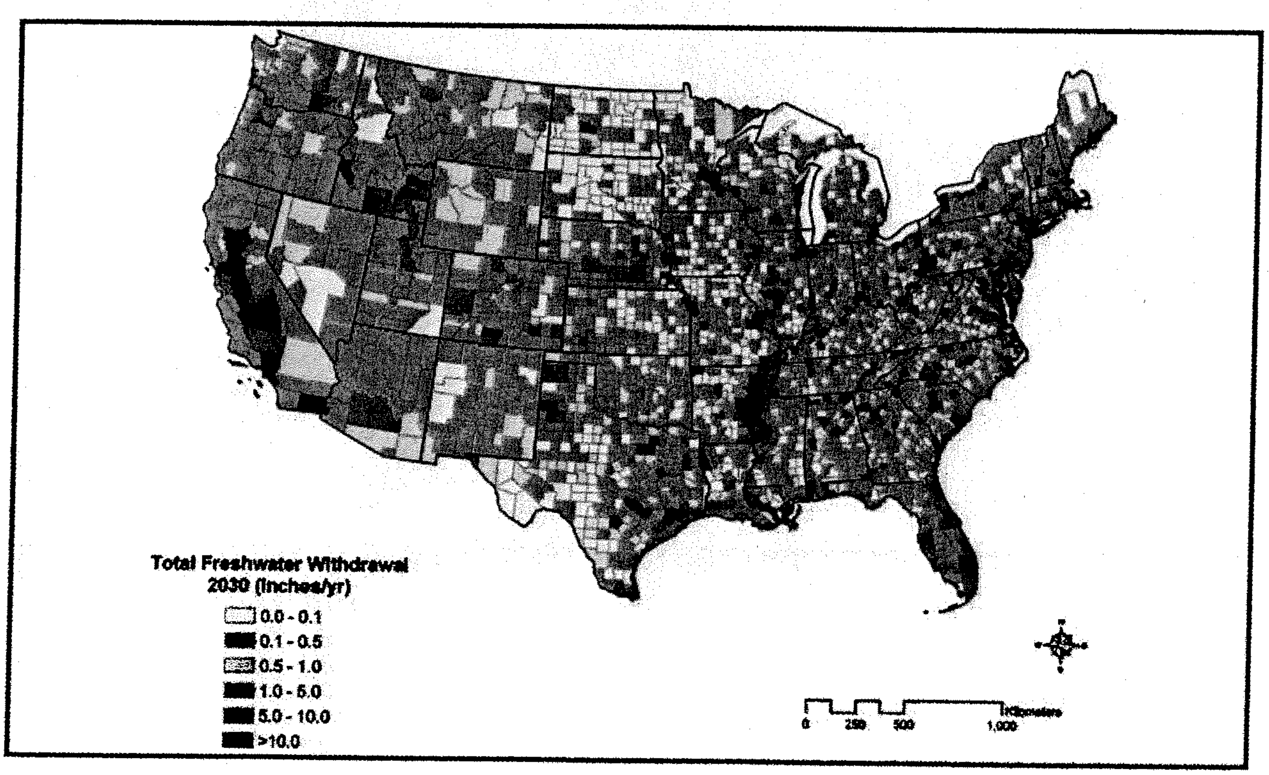


Figure A-3. Projected total freshwater withdrawal in 2030 (inches/yr). The 2030 values are based on population growth and increased electric generation capacity, and assuming water use rates for domestic use at 2005 levels, albeit varying by county, and new cooling water use at 500 gallons/Megawatt-hour. Withdrawals for other sectors are assumed to remain at their 2005 levels.

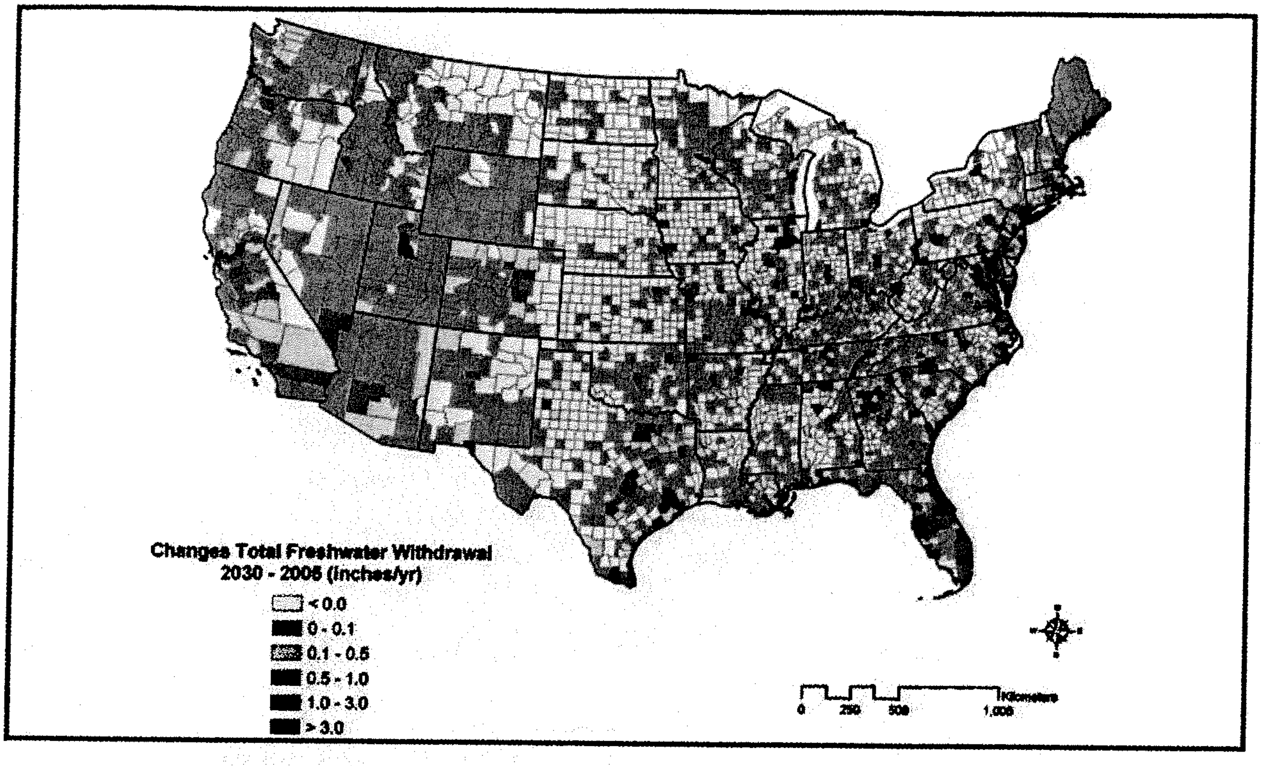


Figure A-4. Changes in total freshwater withdrawal from 2005 to 2030 (inches/yr)

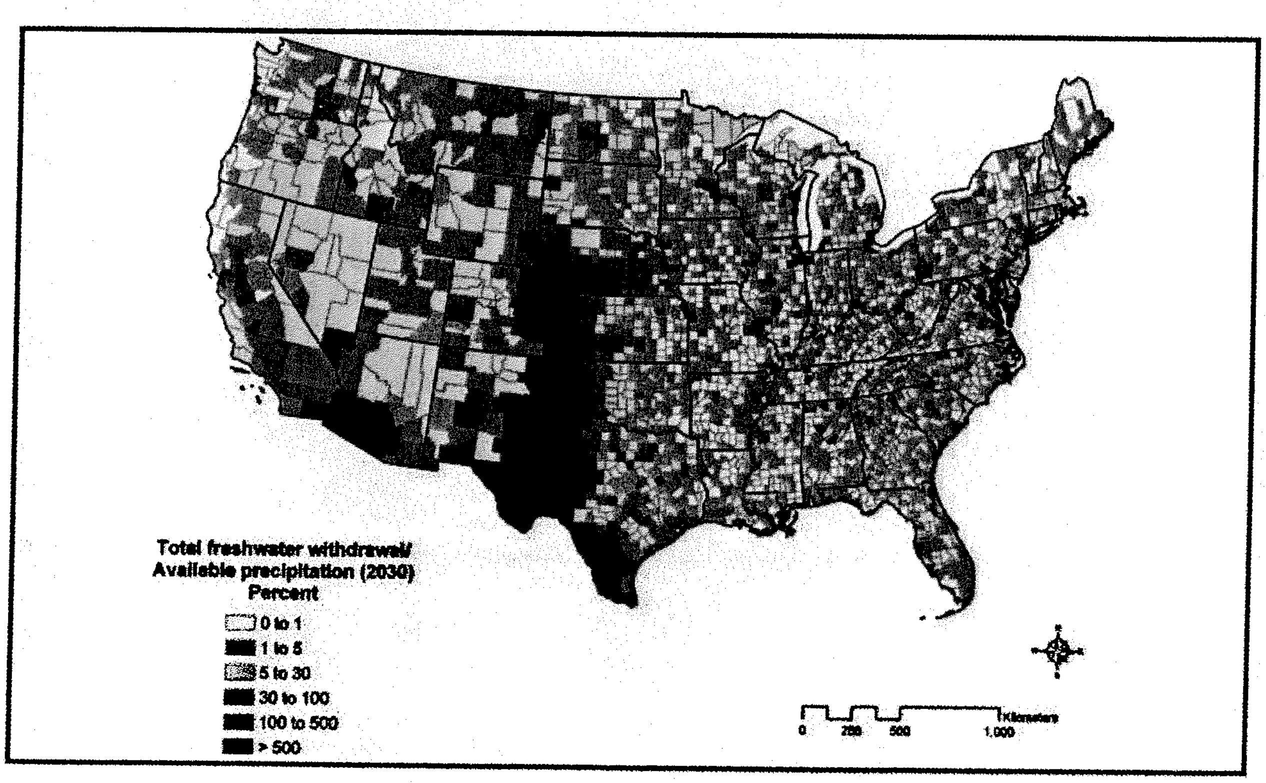


Figure A-5. Projected total water withdrawal as percent of available precipitation in 2030. 2030 values are based on an ensemble of 16 GCMs and represent conditions between 2020 and 2039.

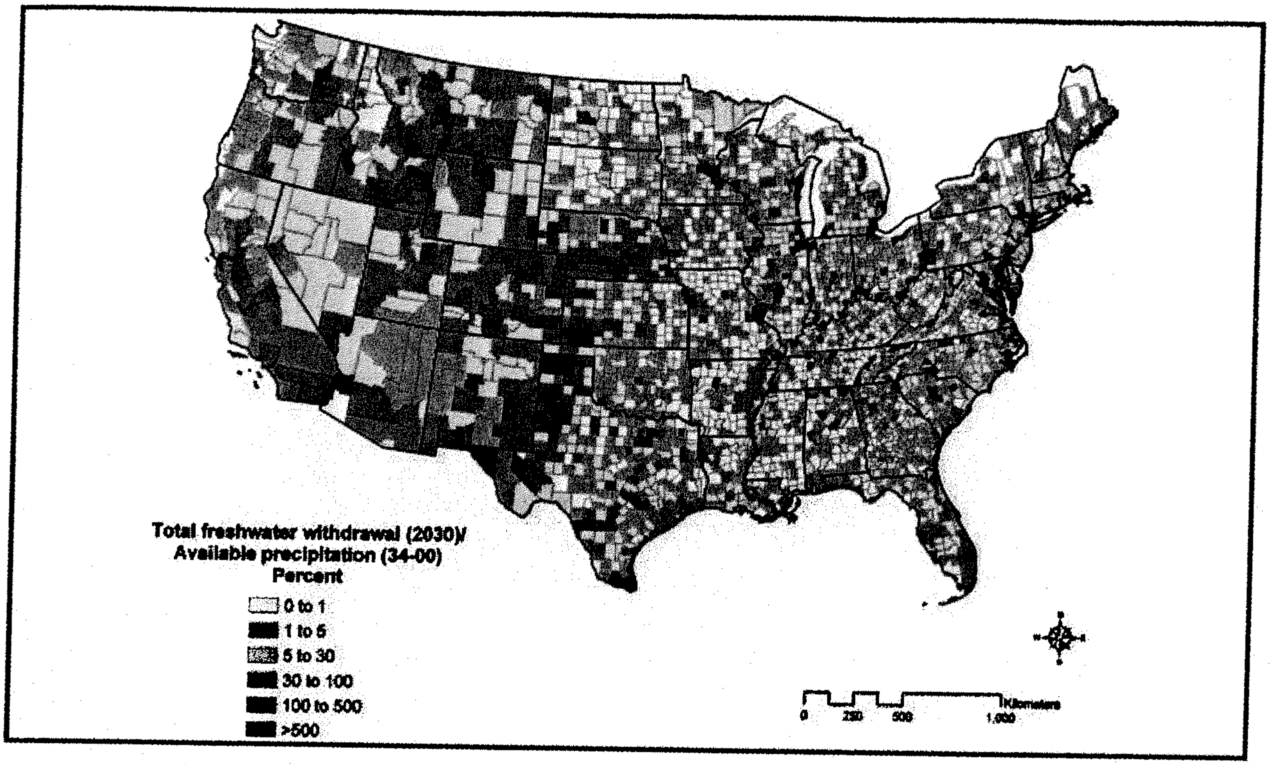


Figure A-6. Total freshwater withdrawal in 2030 as percent of historical (1934-2000) total available precipitation.





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# FRACKING:

# THE NEW GLOBAL WATER CRISIS


food&water watch

COVER: BOTTOM CENTER IMAGE BY IVAN DEMITROV; BOTTOM RIGHT IMAGE BY LAURIE BARR / COURTESY OF COMMONS.WIKIMEDIA.ORG

## About Food & Water Watch

Food & Water Watch works to ensure the food, water and fish we consume is safe, accessible and sustainable. So we can all enjoy and trust in what we eat and drink, we help people take charge of where their food comes from, keep clean, affordable, public tap water flowing freely to our homes, protect the environmental quality of oceans, force government to do its job protecting citizens, and educate about the importance of keeping shared resources under public control.

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# FRACKING:
# THE NEW GLOBAL WATER CRISIS


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## Executive Summary

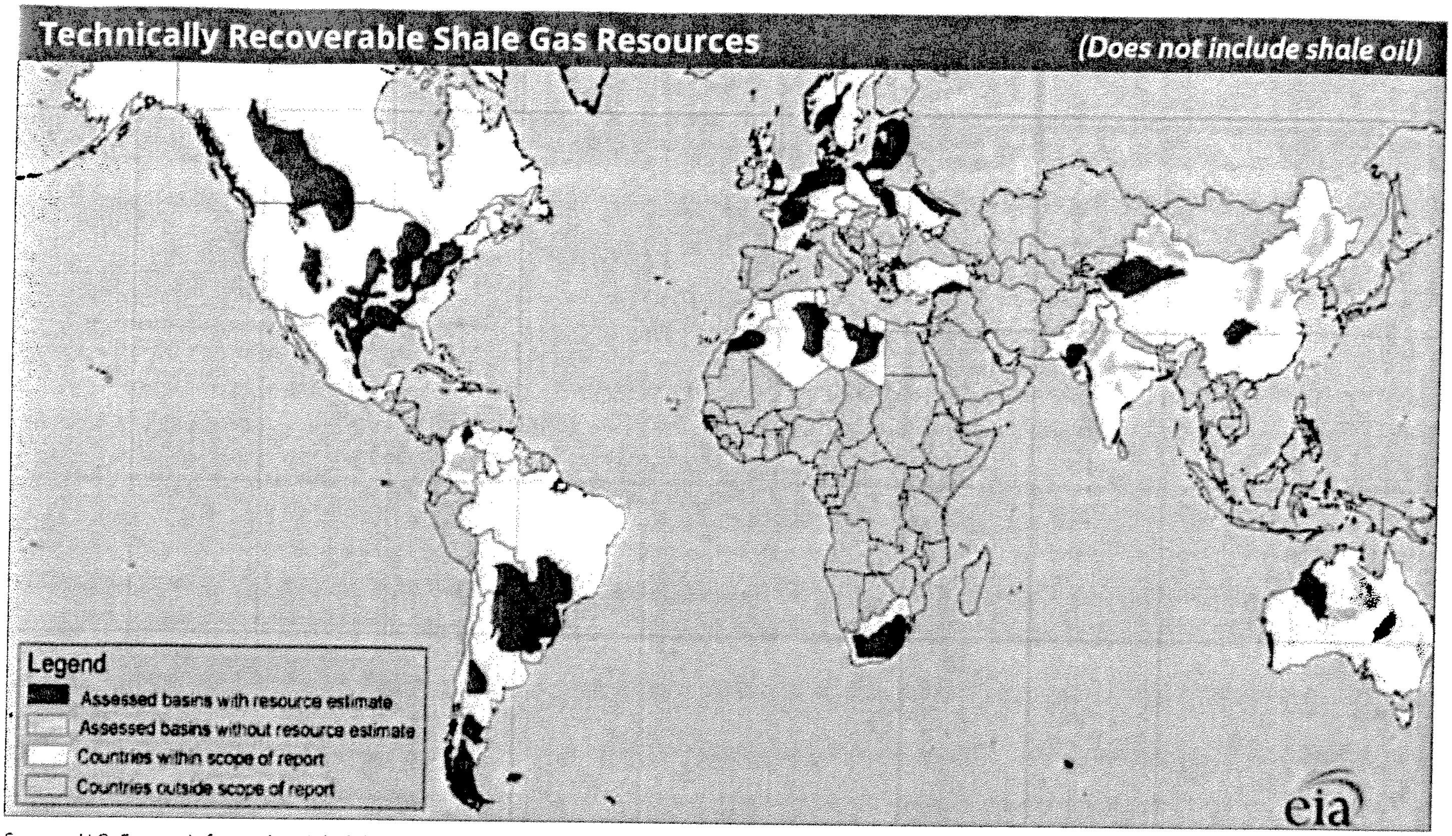
Within the past decade, technological advances in horizontal drilling and hydraulic fracturing, or "fracking," have enabled the oil and gas industry to extract large quantities of oil and natural gas from shale formations in the United States. However, the practice has proven controversial. Pollution from modern drilling and fracking has caused widespread environmental and public health problems and created serious, long-term risks to underground water resources.

In this report, Food & Water Watch reviews the risks and costs of shale development that have been demonstrated in the United States, including economic costs that run counter to industry-backed claims about the economic benefits of the practice.

Food & Water Watch then summarizes the state of shale development in six selected countries: France, Bulgaria, Poland, South Africa, China and Argentina. Briefly:

- Strong public opposition to fracking in France and Bulgaria has led to national bans on the practice.
- The government of Poland has welcomed oil and gas industry plans to develop shale resources in the country, but charges of bribery during the process of awarding leases have tainted these plans.
- Pending an environmental review by the South African government, Royal Dutch Shell may soon be granted permission to drill and frack in South Africa's Karoo Basin.
- The Chinese government is pushing an expansion of shale development, and numerous oil and gas companies are partnering with Chinese firms, both in the United States and in China.
- In Argentina, oil and gas companies have begun developing shale oil and shale gas resources in the Neuquén Basin, with the support of the Argentinean government.

Instead of exposing their citizens to the damages of modern drilling and fracking, countries around the world should enact national bans on the practice and invest aggressively in the deployment of energy efficiency and renewable energy technologies.




Source: U.S. Energy Information Administration, based on Advanced Resources International, Inc. data. Last updated April 5, 2011.

## Introduction

Advances in drilling technology and hydraulic fracturing, or "fracking," have now made it economically feasible to extract oil and natural gas from shale and other impermeable rock formations.[1] However, while such drilling and fracking has been a boon for the oil and gas industry in the United States, it has been a nightmare for Americans exposed to the pollution that accompanies shale development.[a]

The oil and gas industry is now poised to take this nightmare global. International private and state-owned oil and gas companies are partnering with U.S. companies, providing capital for U.S. shale development in exchange for the experience of learning drilling and fracking techniques pioneered in the United States.[2] Many of these companies are also working to secure rights to extract shale oil and shale gas resources worldwide, and in some countries exploratory drilling and fracking is already underway.[3]

a For simplicity, the term "shale development" is used in reference to the extraction of oil and natural gas from shale and other impermeable rock formations, including coalbeds, "tight" sandstones and siltstones. Shale development involves the modern combination of horizontal drilling and multi-stage, high-volume fracking.

Because natural gas is a relatively clean-burning fossil fuel, compared to oil and coal, natural gas has been touted as an energy source that could potentially serve as a bridge to a low-carbon future powered by clean and renewable energy resources.[4] However, looking beyond shale gas combustion to the full environmental impact of shale gas development reveals that shale gas is not the environmentally friendly natural gas that had been envisioned as a bridge. Not only does shale gas development lead to dangerous air and water pollution, but some scientific studies of greenhouse gas emissions from shale gas development suggest that using shale gas instead of coal to generate electricity may actually accelerate climate change in coming decades.[5]

Of course, in contrast to the case of shale gas, there is no pretense that shale oil will offer environmental benefits.

This report reviews the risks and costs of shale development, as demonstrated in the United States, and calls on countries to ban the dangerous practice. To illustrate the global reach of the threat that modern fracking now poses to public health and the environment, the status of shale development in six selected



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countries – France, Bulgaria, Poland, South Africa, China and Argentina – is briefly summarized.

## History and the Next Wave of Fracking

Fracking is the process of injecting fluid – typically a mixture of water, sand and chemicals – into wells at high pressure to crack rock formations, allowing oil and/or gas contained in these formations to flow more easily into a well.[6]

Fracking is not a new technique. Oil and gas companies have used fracking since the 1860s to stimulate oil-well production.[7] Halliburton is credited with the first commercial application of fracking to produce natural gas,[8] and by 2000, fracking was used in 90 to 95 percent of all U.S. oil and gas wells.[9] However, the scale of modern fracking is a radical departure from that used in conventional oil and gas development.[10]

Conventional natural gas drilling targets limestone and other rock formations through which gas readily flows.[11] Once a pocket of gas is identified within these permeable formations, a vertical well is drilled down until the reservoir is reached and gas begins to flow into the well.[12] After the flow rate of gas significantly declines, these conventional wells may be fracked to temporarily improve production from the aging well.

In contrast, unconventional natural gas development targets natural gas held in shale, tight sandstone and coalbed formations, which restrict the flow of natural gas unless they are fracked.[13] Similarly, fracking is essential to free "tight oil" from otherwise impermeable rock formations so it can flow into a well.[14][b]

The combination of advanced fracking and horizontal drilling technologies has made it economically feasible to extract large quantities of shale oil and shale gas.[15] While fracking allows the oil and gas to flow into a well to begin with, horizontal drilling through a relatively thin layer of shale, for example, gives each well more exposure to the oil and gas in the shale.[16]

Once vertical and horizontal drilling is finished, and well casings are cemented, developers inject millions of gallons of fracking fluid to crack apart the rock and prop it open so that the gas can be released.[17] Depending on geology, between 25 and 75 percent of the millions of gallons of fracking fluid used for each well returns to the surface as wastewater.[18] A large volume of salty water containing naturally occurring contaminants is also typically produced at each well as wastewater.[19] Combined, these wastewaters contain the toxic chemicals added to fracking fluid, as well as any radioactive materials and other pollutants leached from deep underground.[20]

Not content with its technological advances, the oil and gas industry is developing the capacity to increase the amount of fracking fluid and pressure being used in order to generate larger fractures and ultimately extract more oil and gas per well.[21]

### How Fracking Impacts the Human Right to Water

**Water use**

Fracking a single shale well requires millions of gallons of water. Widespread shale development would thus compete with essential water needs in regions prone to water shortages.

**Water pollution**

Shale development presents inherent short-term and long-terms risks to water quality.

**Climate change**

Shale development is likely to accelerate global climate change in the coming decades, contributing to increased variability in seasonal and annual rainfall patterns. Such variability, in the form of either flooding or prolonged droughts, will stress water utility systems.

## The U.S. Experience: Adding Up the Risks and Costs

The increasing scale of drilling and fracking operations needed for shale development has increased the risks and costs of the practice. Modern fracking requires millions of gallons of water for each well, and thus widespread shale development can compete with essential water needs in regions prone to water shortage.[22] Public water resources can also be polluted at different stages of shale development or long after the development has occurred, resulting in significant public health costs. Additional public health costs are due to air pollution from modern shale development,

b Shale oil, which requires fracking to extract, is usually referred to as "tight oil" so as to avoid confusion with oil shale.

and rural economies suffer from the negative impacts that widespread drilling and fracking have on agriculture and tourism.

## *Fracking's impact on public water resources*

### Examples of water pollution in the United States from shale development

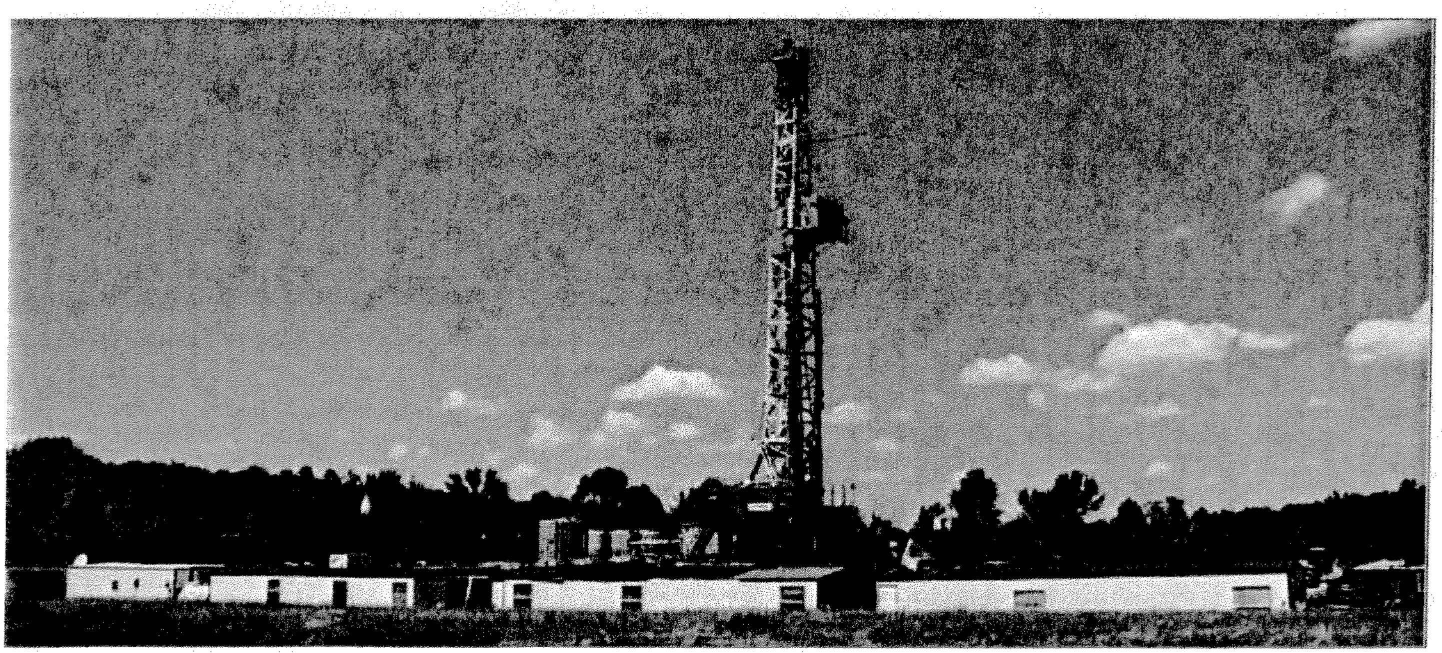
Fracking has been implicated in the contamination of water supplies across the United States. ProPublica identified more than 1,000 cases of water contamination near drilling sites documented by courts, states and local governments around the country prior to 2009.[23] Pennsylvania cited 451 Marcellus Shale gas wells for 1,544 violations in 2010 alone. Notable affected communities include:[24]

**Pavillion, Wyoming:** In 2010, the U.S. Environmental Protection Agency released a preliminary study that found possible drinking water contamination near fracking wells and recommended that residents avoid drinking their tap water.[25] The U.S. EPA investigated 39 rural water wells and found benzene and methane in wells and groundwater.[26] The wells were also contaminated with the fracking fluid additive 2-butoexythanol phosphate, which has harmful health effects.[27] In December 2011, the U.S. EPA released a draft report concluding that fracking likely led to methane contamination of deep groundwater near Pavillion, and that shallow groundwater contamination was likely due to surface spills of fracking wastewater.[28]

**Dimock, Pennsylvania:** In 2009, Pennsylvania regulators ordered the Cabot Oil and Gas Corporation to cease all fracking in Susquehanna County after three spills at one well within a week polluted a wetland and caused a fishkill in a local creek.[29] The spills leaked 8,420 gallons of fracking fluid containing a Halliburton-manufactured lubricant that is a potential carcinogen.[30] Fracking had so polluted water wells that some families could no longer drink from their taps.[31] Pennsylvania fined Cabot more than $240,000, but it cost more than $10 million to transport safe water to the affected homeowners.[32] In December 2010, Cabot paid $4.1 million to 19 families that contended that Cabot's fracking had contaminated their groundwater with methane.[33] In 2012, the U.S. EPA began providing clean drinking water to these families after Cabot had been released of its obligation to do so by the state of Pennsylvania.[34]

**Garfield County, Colorado:** Garfield County's 8,000 natural gas wells have inched closer to residential areas.[35] A hydrological study found that as the number of gas wells in the heavily fracked county increased, methane levels in water wells also rose.[36] State regulators fined EnCana Oil and Gas for faulty well casings that allowed methane to migrate into water supplies through natural faults.[37] In 2008, a wastewater pit in Colorado leaked 1.6 million gallons of fluid, which migrated into the Colorado River.[38]

**Parker County, Texas:** In 2010, the U.S. EPA determined that fracked gas wells had contaminated a drinking





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water aquifer with methane, benzene and other natural gas chemicals that were chemically fingerprinted to the gas well.[39]

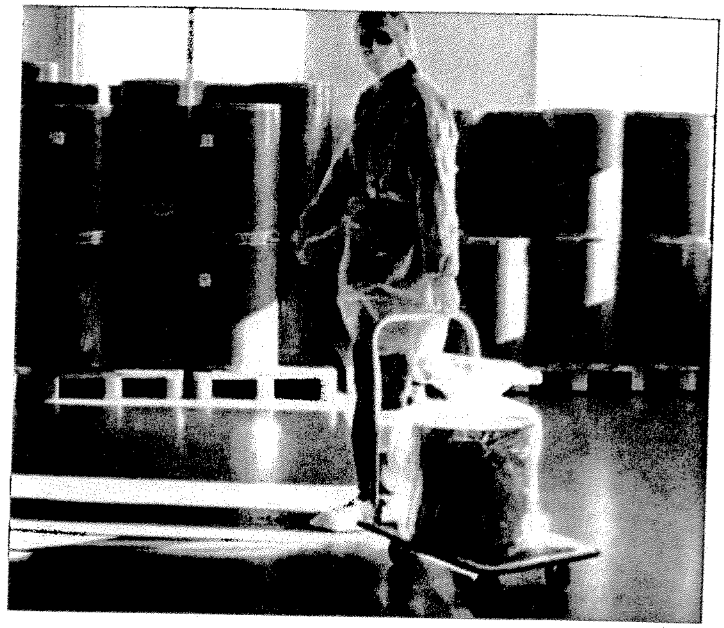
### How shale development pollutes freshwater resources

There are many ways that drilling and fracking contaminate public freshwater resources. First, even before fracking fluid chemicals are injected underground, they can be spilled at the sites of wells[40] or in traffic accidents,[41] resulting in local contamination.

The chemicals used to make fracking fluids are far from safe. Scientists have found that 25 percent of fracking chemicals could cause cancer; 37 percent could disrupt the endocrine system; 40 to 50 percent could affect the nervous, immune and cardiovascular systems; and more than 75 percent could impair sensory organs and the respiratory system.[42]

A second major pathway of contamination stems from the need to dispose of the several million gallons of fracking wastewater that flows to the surface after each well is fracked. This wastewater contains not only the potentially toxic chemicals used in fracking fluid, but also natural contaminants from deep underground, including total dissolved solids (e.g., salts, barium, strontium), organic pollutants (e.g., benzene, toluene) and normally occurring radioactive material (NORM) such as Radium 226.[43] A 2011 *New York Times* investigative report found that nearly three-quarters of the more than 240 Pennsylvania and West Virginia gas wells studied produced wastewater with high levels of radiation, including at least 116 wells with levels that were hundreds of times the U.S. EPA's drinking water standard, and at least 15 wells with levels thousands of times the standard.[44]

Surface water pollution from drilling and fracking occurs with leaks, blowouts and other accidents at the sites of a shale well[45]; spills from traffic accidents while fracking wastewater is being trucked to disposal sites[46]; or spills from the intentional and illegal dumping of fracking wastewater.[47] In 2010, a shale gas well blowout led to a 75-foot tall geyser of gas and drilling fluid that spilled 35,000 gallons on the ground before it was contained.[48] In January 2011, approximately 21,000 gallons of fracking wastewater spewed from a Tioga County, Pennsylvania, well when a valve was erroneously left open, releasing



hazardous chloride, sodium, barium and strontium, as well as hydrochloric acid used in the fracking fluid.[49] Two months after a fire in the company's fracking liquid storage tanks injured three people, a Chesapeake Energy well spurted thousands of gallons of fracking fluid in Bradford County, Pennsylvania, due to an equipment failure.[50] Pennsylvania had cited Chesapeake Energy 284 times for violations and taken 58 enforcement actions since the beginning of 2008.[51]

Also, surface water can be polluted by discharges from treatment facilities that receive fracking wastewater but that are not equipped to treat many of the contaminants this wastewater contains.[52] For example, between 2008 and 2009 in Pennsylvania, at least half of fracking wastewater went to public sewage plants that were not equipped to treat NORM.[53] Pennsylvania's rivers have also had rising levels of bromides, a trend of particular concern because bromides can react with disinfectants during water treatment to form brominated trihalomethanes (THM).[54] Once formed, THM are difficult and costly to remove from the water supply, and exposure to THM is implicated in cancer and birth defects.[55] Yet, according to ProPublica, no Pennsylvania wastewater treatment plant was expected to be able to remove total dissolved solids, including bromides and chlorides, from the water until 2013.[56]

In December 2010, the Center for Healthy Environments and Communities (CHEC) at the University of



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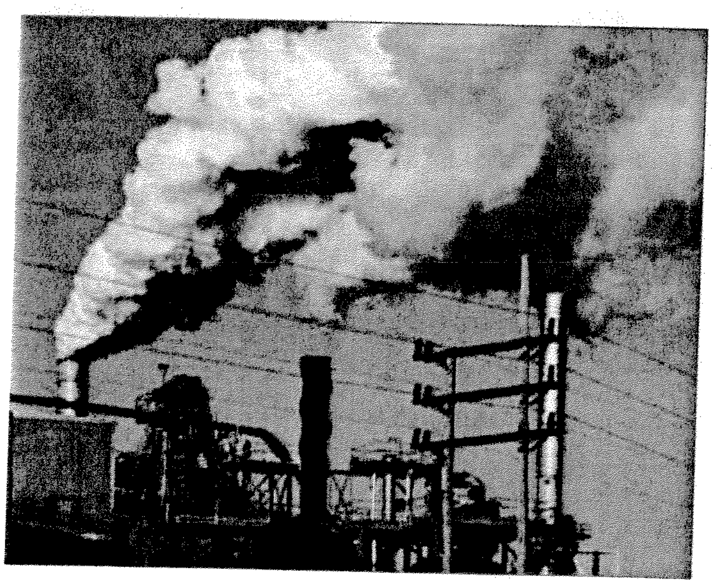
Pittsburgh tested treated water being discharged into a creek from a treatment facility in Indiana County, Pennsylvania, that had received fracking wastewater. The CHEC analysis found that the average concentration of barium was about 14 times the U.S. EPA drinking water standard, strontium was present at an average concentration of about 746 times the standard, benzene was present at twice the standard and total dissolved solids were present at 373 times the standard.[57]

Drilling and fracking have also caused methane and contaminants in fracking wastewater to seep into underground drinking water supplies directly, without ever reaching the surface.[58]

A National Academy of Sciences study found that average methane concentrations in shallow drinking water wells in active gas areas were 17 times higher than those in non-active areas, possibly due to leaky gas-well casings.[59] In 2008, a house in Ohio exploded after methane infiltrated its water source, largely because of fracking.[60] In 2010, after the U.S. EPA instructed Wyoming residents not to drink their water because of contamination from a common fracking fluid, some residents also used fans while bathing to reduce the likelihood of explosions.[61] In 2010, the U.S. EPA determined that two homes in Texas were at risk of explosion because of high levels of natural gas found in their water from nearby fracking operations.[62]

The U.S. EPA has reported that toxic fracking fluid has contaminated at least one water well in West Virginia and likely others.[63] In 2004, in Colorado, a faulty natural gas well casing led to contamination of water 4,000 feet away from the well site.[64] In November 2011, the U.S. EPA released a draft report on contaminated groundwater near drilling and fracking operations in Pavillion, Wyoming, concluding that "the data indicate likely impact to ground water that can be explained by hydraulic fracturing."[65]



Many of the cases of direct groundwater contamination, either by methane or fracking wastewater, are likely due to faulty casing of the well where the well passes through an aquifer. Multiple, concentric casings are being used to try to reduce the risk of such direct contamination, but human errors will always occur regardless of the robustness of the well casing designs. Yet this is not the only risk to underground resources.

The fact that, depending on geology, 25 to 75 percent of fracking fluid returns to the surface means that millions of gallons of fracking fluid stays underground indefinitely after it is injected into a well.[66] Once underground, fracking fluid mixes with the naturally occurring brines and is subject to geological forces and chemical processes over the long term, from years to decades. How far and how fast this blend can travel, and how it might change chemically, is impossible to know and control. Potential pathways for contaminants to flow into aquifers include the well into which fracking fluid is injected, nearby abandoned wells,[67] induced fractures in the shale from fracking, and existing natural fractures in the bedrock.[68]

Modern shale development thus risks irreversible damage to vital underground drinking water resources over the long term. While this possibility may be remote, it is too serious of a risk to accept.

### *Air pollution from fracking*

Shale development results in more emissions of greenhouse gases, smog-inducing compounds and other hazardous air pollutants than conventional oil and gas development. This air pollution comes from the exhaust of generators and compressors at shale well sites, from heavy-duty truck traffic and from the venting of wastewater storage tanks, and it can seriously degrade air quality. This means there are significant health and environmental impacts when examining the full life-cycle of shale gas, and these significant impacts negate some of the benefits that stem from shale gas being a clean-burning fossil fuel.

As for shale oil, there are no air-quality or climate benefits claimed.

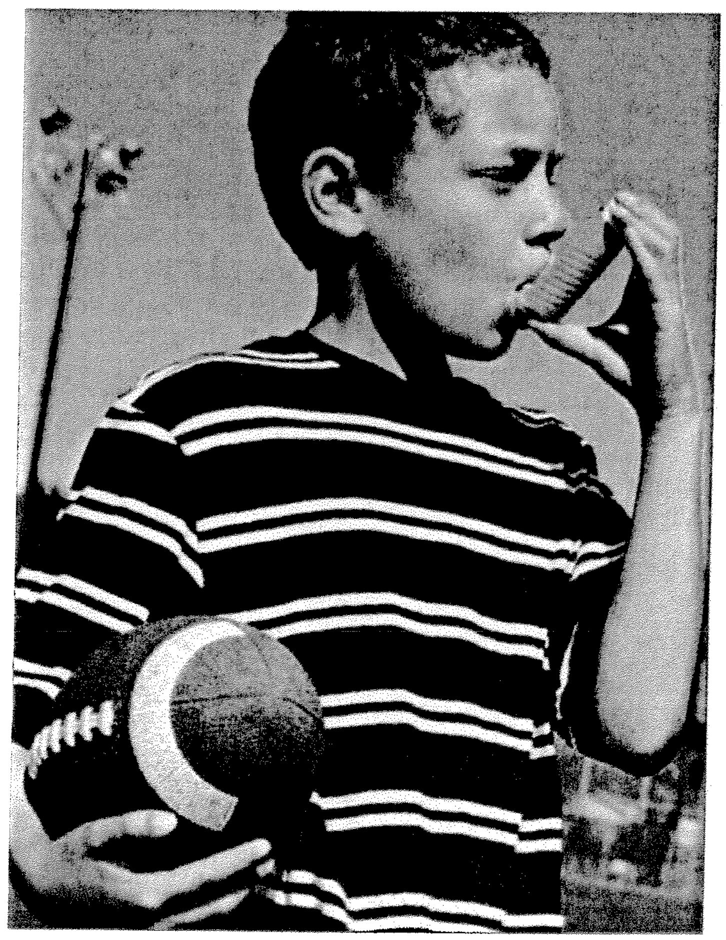
Shale gas is composed primarily of methane, which is a potent greenhouse gas.[69] Recent scientific studies have demonstrated that, due to the amount of fugitive methane released during modern shale gas development as compared to during conventional gas development, any increased use of shale gas instead of coal may actually accelerate climate change in the coming decades, not reduce climate change impacts.[70] This is despite the fact that shale gas emits significantly less carbon pollution when burned.[71] Crucially, this also assumes that demand for shale gas would displace demand for coal, not supplement it; if such displacement does not happen, then the impact on climate would be far worse.[72] It is therefore misguided for governments around the world to open up their countries to shale development under the pretext of fighting global climate change.

Hazardous air pollutants found near fracking sites include methanol, formaldehyde and carbon disulfide.[73] Volatile organic compounds, including nitrogen oxides, benzene and toluene, are also discharged during fracking.[74] These compounds mix with emissions from heavy-duty truck traffic, large generators and compressors at well sites to form ground-level ozone that can, in turn, combine with particulate matter to form smog.[75] Long-lasting exposure to smog has been linked to various cancers, heart disease, diabetes and premature deaths in adults, and to asthma, premature birth and cognitive deficits in children.[76]

It is extremely difficult to make direct links between individual health outcomes and unknown exposure levels to air pollutants. However, there are numerous reports of public health problems that coincide with the onset of shale development and that are likely due to the resulting air pollution.

For instance, residents of DISH, Texas, who lived near 11 natural gas compression stations became concerned about the odor, noise and health problems they were experiencing, which included headaches and blackouts. They also observed neurological defects and blindness in their horses.[77] Their mayor fruitlessly reported these accounts to Texas regulators and eventually hired a private environmental consultant, who in 2009 found that air samples contained high levels of neurotoxins and carcinogens.[78] The Texas Commission on Environmental Quality found airborne benzene, which can cause immune disorders and cancer, near Barnett Shale wells at levels of 500 to 1,000 parts per billion – more than five times higher than allowable limits.[79]

In Wyoming, drilling and fracking have caused ground-level ozone pollution to exceed amounts recorded in Los Angeles, affecting the quality of life for Wyoming residents.[80] In Texas, a hospital system serving six counties with intensive shale gas development reported asthma rates three times higher than the state's average.[81] The natural gas and oil industry in the Barnett Shale area produced more smog-forming emissions during the summer of 2009 than were produced by all motor vehicles in the Dallas-Fort Worth metropolitan area.[82] Yet ground-level ozone pollution from shale gas development is not just a local problem; it can be transported hundreds of miles by prevailing winds before combining with particulate matter to form smog.[83]





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These accounts illustrate how the serious public health impacts of modern shale development,[84] and highlight the narrow thinking in assuming that a transition to shale gas will reduce air pollution simply because shale gas burns more cleanly than other fossil fuels.

## The U.S. Experience: Exaggerated Claims of Economic Benefits

The shale development rush has not only endangered public health in the United States through pollution of the air Americans breathe and the water Americans drink; it has also harmed local economies. While industry promotes job creation and local investment, proponents typically do not account for the long-term economic damage and the significant erosion of communities' quality of life that can outweigh any benefits.[85] Many of the purported economic benefits are just a mirage – energy companies based elsewhere typically do not buy drilling and fracking supplies from local businesses, and shale development jobs typically go to transient workers who move from shale play to shale play.[86]

New wells bring fleets of trucks that crowd and damage rural roads and carry potentially hazardous wastewater. New York estimated that, if the state allowed shale gas development, each well would require between 890 and 1,350 heavy-duty truckloads.[87] Noisy drilling rigs operate 24 hours a day, 7 days a week.[88] Scenic vistas are replaced with a landscape of gas wells, which lowers property values and harms tourism and recreation industries like hunting and fishing. In Wise County, Texas, properties with gas wells have lost 75 percent of their assessed value.[89] Natural gas rigs devalue not only the property where they are located, but also the value of neighboring properties.[90]

During construction and drilling, gas wells significantly increase heavy truck traffic, and locals bear the cost of repairing wear and tear on local roads. The Pennsylvania Department of Environmental Protection estimates that building and fracking a well requires 1,000 heavy-duty truck trips.[91] Increased truck traffic damages local infrastructure and can increase the risk of truck accidents on small, rural roads.[92] Fracking also requires pipelines to transport the gas, which can pose safety hazards from explosions.[93] In 2011, a pipeline explosion in Allentown, Pennsylvania, killed five workers; other explosions have occurred elsewhere in Pennsylvania and in Ohio, California, Michigan and Texas, some fatal.[94]

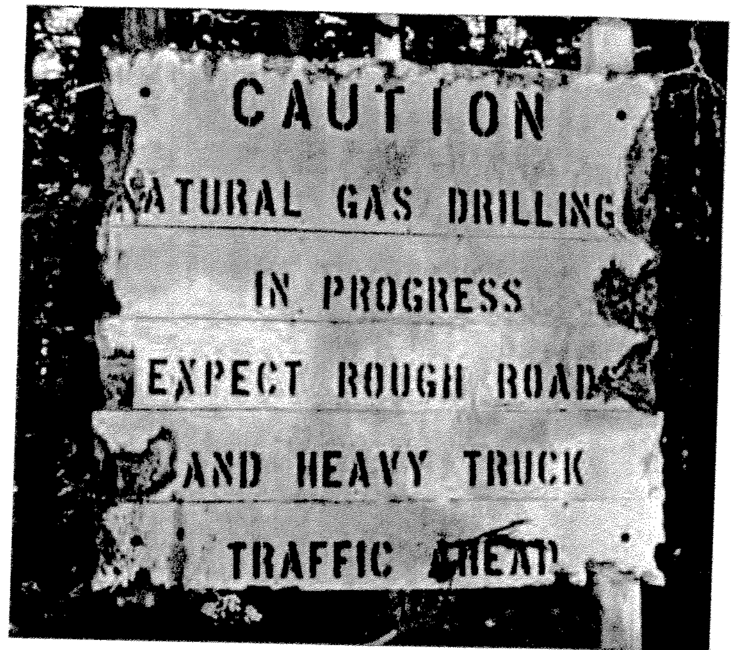

IMAGE BY NICHOLAS / COMMONS.WIKIMEDIA.ORG

Farmers, whose livelihoods depend on the health of the land, face especially stark choices. Persistently low milk prices have threatened dairy farms in Pennsylvania and New York, and the prospect of gas royalty payments is tempting. Farmers lease their land to gas companies with the promise of minimal impact.[95] However, livestock have died from drinking water tainted with spilled fracking fluids.[96] In 2009, 16 cattle died after apparently drinking fluid that escaped from a Louisiana fracking well.[97] In 2010, Pennsylvania quarantined 28 cows that may have consumed water tainted by a fracking spill that could contaminate their meat.[98] Organic farmers could lose their premium prices if industrial fracking fluid pollutes their crops or livestock.[99] Farm sales could be destroyed if pollution threatens livestock, crops or farmland.[100]

In contrast to the legacy of environmental pollution that shale development leaves behind, any economic gains from drilling and fracking are short-lived: employment, construction, housing demand and even royalty payments are significant at first, but diminish quickly as well productivity declines and drilling and fracking operations move elsewhere.[101] Almost all of the jobs associated with shale development come during the drilling and fracking stage, but it takes less than one year to prepare a well site and conduct the drilling and fracking.[102] This means that industry employees, most of whom are transient workers with shale development experience, just move from new well to new well as the number of drilled wells increases.[103] Also, there is considerable uncertainty over estimates of the amount of shale gas reserves that is technically recoverable using current technology, and over how long individual wells will actually be productive. If production falls more rapidly than expected, as some industry analysts anticipate,[104] then there would be smaller royalty checks and fewer production-phase jobs over the long term. In August 2011, it was reported that some shale gas producers received subpoenas from the U.S. Securities and Exchange Commission for documents on actual well production and reserve estimates, after the *New York Times* reported concerns expressed by some in the industry and government that the shale boom has been overstated.[105]

Finally, estimates of the amount of technically recoverable – not necessarily economically recoverable – shale resources in the United States have varied widely.[106] In January 2012, the U.S. Energy Information Administration cut its estimate of technically recoverable shale gas by about 42 percent from the estimate it used just one year earlier.[107] This raises serious questions about whether countries should stake their energy futures on shale resources, given that the U.S. EIA's estimates of international shale resources may be similarly flawed.[108] Indeed, initial exploratory drilling in Poland conducted by Exxon has not yielded commercially viable production levels.[109]

## Fracking Around the World

### *Mineral rights ownership*

In the United States, landowners typically own the right to develop oil and gas reserves beneath their own private land.[110] As a consequence, the oil and gas industry has had a natural alliance with landowners who seek individual financial gain from selling leases and receiving royalty payments.[111]

According to Ben van Beurden, head of Shell Chemical, "[shale gas development] works a whole lot better if the mineral rights to the gas actually belong to the land owners."[112] He continued, "[i]n places like north-

### Snapshot of Global Shale Gas Activity

**Africa:** Royal Dutch Shell has led the push to drill and frack for shale gas in South Africa's Karoo Basin.[115] The Sirt Basin, in Libya, and the Ghadames Basin, which underlies parts of Algeria, Tunisia and Libya, are also targeted for shale gas development.[116] In Tunisia, Cygam Energy has begun exploratory drilling and fracking, and Chinook Energy Inc. has leased 3 million acres of land.[117] In Morocco, the national oil and gas company has been studying its shale gas potential.[118]

**Oceania & Asia:** ExxonMobil, Royal Dutch Shell, Chevron, BP and ConocoPhillips are among the foreign companies investing in China's shale resources — be it shale oil or shale gas.[119] ConocoPhillips and New Standard Energy, an Australian company, are partnering to develop shale gas resources in western Australia's Canning Basin, although New South Wales, Australia's most populated province, has temporarily suspended shale development.[120] In New Zealand, the Taranaki Regional Council has granted permission for fracking of conventional natural gas wells to continue.[121]

**Latin America:** In Argentina, exploratory drilling has begun in the Neuquén Basin, led by Apache Corporation, Total and ExxonMobil.[122] In October 2009, Uruguay's government-owned petroleum company entered a contract with Texas-based Schuepbach Energy LLC to assess its shale gas potential.[123] While shale development is not actively underway in Mexico, Brazil, Chile, Paraguay and Bolivia, these countries are believed to each have significant shale resources.[124]

**Europe:** In June 2011, France became the first country to ratify a nationwide ban on fracking.[125] In January 2012, Bulgaria also enacted a nationwide ban on the practice.[126] Exploration in England, in Northern Ireland and in the German province of North Rhine-Westphalia has been suspended as of April 2011.[127] Chevron, ConocoPhillips and ExxonMobil have each leased over 1 million acres in Poland, and ExxonMobil has leased an additional 2 million acres combined in Germany and the Netherlands.[128] In November 2011, the Scottish government granted its first license to allow fracking,[129] and Ireland is expected to also grant exploratory shale drilling licenses, pending a government review of environmental impacts.[130]

western Europe, mineral rights are being held by the state so the only thing as a land owner you have is inconvenience."[113]

Indeed, in many countries, governments own and control subsurface mineral rights.[114] On one hand, this means that the oil and gas industry does not benefit in these countries from private landowners who apply public pressure on their governments to expand drilling and fracking in hopes of gaining financially. But, on the other hand, state control over mineral rights means that national governments around the world may view the potential revenues from selling access to the highest-bidding oil and gas companies as worth the public risks and costs of shale development.

### France

If French landowners receive both authorization and a concession from the French government, they do have the right to extract and dispose of minerals on their land.[131] However, the national government or a third party can also develop these same resources through the same permitting and concession process, after a public enquiry and bidding process.[132]

In 2010, numerous companies leased land in the Paris Basin, which is targeted as a resource of both shale gas and tight oil, and in the Southeast Basin, which is targeted for shale gas.[133] The French government issued exploration permits to many of these companies and their partners, including Vermillion Energy, Total SA, Torreador Resources in partnership with Hess, and Schuepbach Energy, an American company that was in partnership talks with the French energy company GDF Suez.[134] However, French citizens cried foul when they learned that the permits had been issued without public deliberation.[135]

Activists began circulating a petition in January 2011 that initially led to a moratorium on fracking in France, followed in June 2011 by a national ban on the practice.[136] France's Environment Minister, Nathalie Kosciusko-Morizet, stated "[w]e have seen the results in the U.S. There are risks for the water tables and these are risks we don't want to take."[137]

Total SA maintains that its permit to develop shale gas in the Southeast Basin should not have been revoked and has challenged France's ban on fracking.[138]

### Bulgaria

In Bulgaria, potential shale gas resources are owned by the state, not by landowners.[139] In June 2011, Chevron agreed with the Bulgarian government to pay €30 million for a five-year permit to conduct exploratory shale gas drilling on 4,400 square kilometers of land near the city of Novi Pazar.[140] The Bulgarian Prime Minister, Boyko Borisov, rejected charges by the leader of an opposition party that the agreement had been finalized.[141] The resulting confusion, combined with concerns about the environmental impacts of fracking, fueled demonstrations against the deal.[142] Months later, this grassroots political pressure culminated in the Bulgarian government revoking the agreement with Chevron and passing a national ban on fracking.[143]

### Poland

Poland has the highest estimated reserves of shale gas in Europe,[144] and the country's government has welcomed the industry with open arms.[145] ExxonMobil, Chevron, Total, Realm Energy and Talisman are among the oil and gas companies seeking to develop


SHALE GAS PROTEST IN BULGARIA. IMAGE BY ©ALEXHG1 / DREAMSTIME.COM



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shale gas reserves in Poland.[146] By 2012, over 100 licenses for shale gas exploration had been granted in the Baltic and Podlasie Basins by the national government of Poland,[147] which owns all gas deposits and transfers development rights through concessions.[148]

The Polish government has pushed for exploratory drilling to be intensified so that shale gas production can begin as soon as 2014.[149] However, the government's efforts to commercialize shale gas in Poland have been complicated by charges of corruption, in January 2012, involving government officials and the shale gas industry.[150] The government charged that bribes had been offered by the industry, and accepted by government officials, to secure shale gas leases.[151]

Rather than award these licenses through a competitive bidding process, the Polish government awarded them at low costs on a first-come, first-served basis, and some have argued this has made the process prone to corruption.[152]

### South Africa

Royal Dutch Shell has led the push for access to shale gas in South Africa,[153] where shale gas development rights are owned by the state, not by landowners.[154] In 2009, the Petroleum Agency South Africa granted permission to Shell to conduct an assessment of shale gas resources in the Karoo Basin.[155] However, farmers and environmentalists in the area expressed concerns about the risks and costs of drilling and fracking for shale gas.[156] In April 2011, South Africa's cabinet acknowledged these concerns and established a moratorium on shale gas exploration in the Karoo Basin to allow time for a government study of the impacts of fracking.[157] This moratorium was set to expire at the end of February 2012, pending recommendations in the government study.[158]

On November 11, 2011 the National Planning Commission, an advisory body to the South African government, released its National Development Plan (NDP).[159] In addressing energy, the NDP recommends enabling "exploratory drilling to identify economically recoverable coal seam and shale gas reserves, while environmental investigations will continue to ascertain whether sustainable exploitation of these resources is possible."[160] The NDP calls for shale gas development and investment in shale gas electricity generation to be "fast tracked," provided that "environmental concerns are alleviated"[161] and "provided the overall environmental costs and benefits outweigh the current costs and benefits associated with South Africa's dependence on coal, or with the alternative of nuclear power."[162]

However, widespread drilling and fracking in the Karoo could jeopardize the NDP's objectives to provide clean drinking water for all and reduce urban water demands by 2030,[163] and, with respect to climate change, scientific studies suggest that replacing one fossil fuel with another is likely misguided.[164]

### China

China's National Energy Administration has reportedly integrated shale gas into its national energy plan.[165] The chairman of Sinopec, China's second-largest oil company, believes that China could overtake the United States in shale gas.[166] In November 2009, the United States and China launched the U.S.-China Shale Gas Initiative[167] to facilitate Chinese efforts to gain technical expertise in shale gas development.[168]

Royal Dutch Shell, which has $4 billion in total energy investments in China, has teamed up with PetroChina.[169] Together, these companies drilled and fracked China's first exploratory horizontal shale gas well in March 2011 in the Sichuan Basin. Three months later, China's Ministry of Land Resources initiated bidding rounds for commercial shale gas development permits.[170] China, which maintains state ownership of oil and gas resources, has limited initial commercial development access to domestic companies.[171]

Fracking would risk the food and freshwater resources on which millions of Chinese depend. The Sichuan Basin lies beneath one of China's most populated and agriculturally important areas, Sichuan Province, which is home to almost 100 million people and has farmland that supplies a significant portion of China's staple foods.[172] Despite recent government efforts, environmental regulatory protections in China are lacking.[173]

### *Argentina*

In Argentina, either the national government or provincial governments own oil and gas rights.[174] According to the U.S. EIA, Argentina has the third highest amount of technically recoverable shale gas in the world, primarily in the Neuquén Basin, and shale gas exploration has commenced.[175] The Argentinian oil and gas company YPF is partnering with Apache Corporation, an American company that has about 1 million acres in shale leases in Argentina.[176] In December 2010, Apache Corporation conducted the first multistage fracking of a horizontal shale gas well in Latin America.[177]

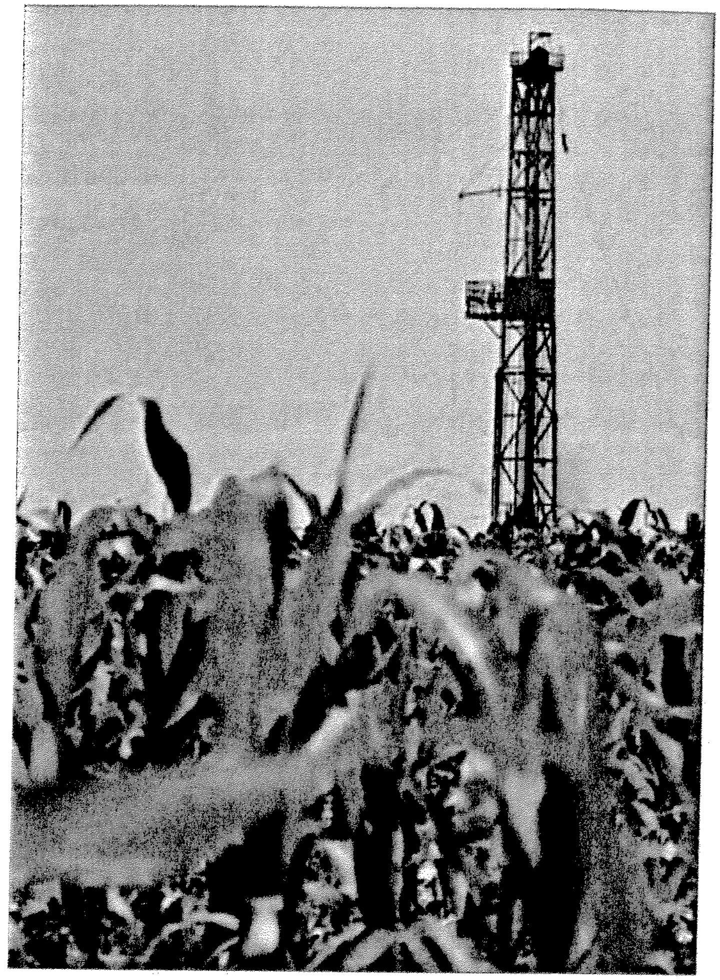
In addition to its gas resources, the Neuquén Basin is expected to hold significant quantities of tight oil.[178] Total, ExxonMobil and EOG Resources have each begun to invest in developing these resources.[179] However, widespread drilling and fracking for oil and gas in the Neuquén basin is likely to have negative impacts on tourism that is important to the economy of Neuquén Province.[180]

Shale development would also place large demands on water resources in the region[181] and, as such, can be expected to exacerbate environmental justice concerns about access to potable water in Neuquén Province.[182]

## Conclusion

Natural gas has long been considered as an alternative fuel, both for transportation and for generating electricity, that can serve as a bridge to a future powered by clean, renewable energy resources.[183] However, shale gas is not the natural gas that had been envisioned.

The rapid expansion of shale gas development and fracking in the United States has resulted in significant environmental and public health problems, and become an ongoing public health and environmental experiment. Many of these problems are inherent to the practice and cannot be avoided through regulation.



Taken together, spills of toxic fracking fluid and fracking wastewater,[184] water well contamination from the underground migration of methane[185] and toxic fracking fluid,[186] local and regional air pollution problems from shale development,[187] explosions at the sites of shale wells,[188] and substantial emissions of the global warming pollutant methane during drilling and fracking[189] make the dangers of shale development clear.

Countries not yet exposed to the risks and costs of drilling and fracking have an opportunity to choose a different path, one that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[190] Enacting a national ban on fracking and investing in the deployment of energy efficiency and renewable energy technologies will set a sustainable course.

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# Geochemistry of Black Shale Deposits—A Summary Report[1]

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## Abstract

Various sedimentary provinces in the United States and Canada were examined for beds of metal-rich black shale similar to those described as ore deposits in other parts of the world. From the samples analyzed for minor elements, 20 sets of samples (comprising 779 individual samples) were selected as representative of a wide variety of geologic environments of black shale deposition. These samples include black shale and associated organic-rich rocks transitional with black shale. Statistical methods were used to determine the composition of the average black shale and the normal range in composition of black shale and to provide a definition of metal-rich black shale for any one of 21 minor elements. A black shale sample is defined as metal-rich if any minor element occurs in excess of the 90th percentile as determined from the sum of the percent frequency distribution of elements in the 20 sets of black shale samples. A black shale deposit is classified as enriched if the percent of samples that are metal-rich with respect to each of 21 minor elements exceeds an arbitrary minimum. Principal component analyses of correlation data were used to determine the association of minor elements with major rock constituents.

As interpreted from statistical analysis of chemical data, the detrital mineral fraction of most black shale deposits is characterized by the elements aluminum, titanium, gallium, zirconium, and scandium, and may also include any of the following elements: beryllium, boron, barium, sodium, potassium, magnesium, and iron. The carbonate fraction of black shale deposits commonly includes calcium plus magnesium, manganese, or strontium. These elements are readily available from solution and are regarded as mobile. The organic fractions of black shale deposits are locally enriched in other mobile elements including silver, molybdenum, zinc, nickel, copper, chromium, vanadium, and, less commonly, cobalt, lead, lanthanum, yttrium, selenium, uranium, and thallium. Anomalously high syngenetic concentrations of these elements with organic matter are best explained by higher than normal concentrations in sea water. The enrichment of minor elements with organic matter in black shales is commonly an accumulative process beginning with the living organism and continuing throughout the periods of decay, burial, and exposure to ground waters of various compositions throughout the history of the deposit. Thin black shale beds may provide a local sink for minor elements after burial, whereas thick units that include much organic matter but are exposed to hypersaline solutions may provide a source of mobile elements that are expelled and transported to adjacent more permeable rock bodies.

## Introduction

SOME beds of black shale are known to contain minor elements in concentrations more than a hundred times their average crustal abundance (Krauskopf, 1955). The possibility of widespread occurrence of metal-rich black shale in the United States was pointed out by Davidson and Lakin (1961, 1962) and led to the present investigation. The detailed study of minor element distribution in 20 black shale deposits is summarized here. Although no commercial deposits were discovered, the increase in understanding of the enrichment of minor elements in black shale may eventually lead to the discovery of economically valuable concentrations of minor elements.

The discovery of concentrations of minor elements in black shales closely parallels the development and refinement of the emission spectrographic method by V. M. Goldschmidt and his students at Göttingen, Germany, for the analysis of rock and mineral samples. (See, for example, Goldschmidt and Peters, 1931, 1932, 1933; Minami, 1935; see Tourtelot, 1970, for more references). Part of their work was on samples of the Swedish Alum shale of Cambrian age and the *Dictyonema* shales of Ordovician age from the Baltic region. Some of these black shales contain unusual concentrations of vanadium, uranium, and other minor elements, but they lack the appearance of hydrothermally altered and mineralized rocks. They also lack the conspicuous sulfide minerals of copper, lead, and zinc such as characterize the black copper shale of Mansfeld, Germany. Metal-rich

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Table 1. Summary descriptions of 20 sets (779 individual samples) of black shale and associated rock samples.

| Set No. and identification | Stratigraphic names of sampled strata (Stratigraphic order not implied) | Ages represented | State | No. of samples | Type of samples | Environment of deposition | Reference |
|---|---|---|---|---|---|---|---|
| 1. Kentucky core | Tradewater and Carbondale Formations | Pennsylvanian | Kentucky | 66 | Core | Transgressive brackish or marine shelf. | Vine (1966) |
| 2. Kentucky outcrop | Do. | Do. | Do. | 42 | Outcrop | Do. | Do. |
| 3. Mecca Quarry | Mecca Quarry Shale Member (of Zangerl and Richardson, 1963) of the Linton Formation. | Do. | Indiana | 37 | Do. | Do. | Do. |
| 4. Western facies | Vinini Formation, Eureka Quartzite, Valmy, Basco (Lovejoy, 1959), Fourmile Canyon, Copenhagen, and Gazelle Formations, Ledbetter Slate, Active, Phi Kappa, Palmetto, Trail Creek, Toquima, Petes Summit (Kay, 1962), Sams Spring (Kay, 1962), Masket (Kay, 1962), and Stoneberger (Kay, 1962) Formations. | Ordovician and Silurian. | California, Nevada, Idaho, Washington and British Columbia. | 75 | Do. | Eugeosynclinal (abyssal slope). | Do. |
| 5. Pennsylvanian shales of Kansas and Oklahoma. | Stanton and Iola Limestones, Tacket Formation of Jewett and others (1965), Pawnee and Fort Scott Limestones, Excello (Searight and others, 1953), Verdigris (Smith, 1928), Croweburg (Abernathy, 1937), Scammon (Abernathy, 1937), Tebo (McQueen, 1943), Bluejacket (Howe, 1956), and Warner (Howe, 1956) Formations. | Pennsylvanian | Kansas and Oklahoma. | 40 | Do. | Transgressive marine shelf. | Vine (1969) |
| 6. Phosphoria | Meade Peak Phosphatic Shale Member of the Phosphoria Formation. | Permian | Wyoming | 43 | Mine adit. | Miogeosynclinal margin. | Do. |
| 7. Chattanooga | Chattanooga Shale | Devonian and locally Mississippian. | Tennessee and Alabama. | 51 | Core | Epicontinental shelf. | Do. |
| 8. Paradox | Paradox Member of the Hermosa Formation. | Pennsylvanian | Utah | 25 | Do. | Hypersaline intracratonic basin. | Do. |
| 9. Belden | Belden Shale | Do. | Colorado | 43 | Outcrop | Zeugogeosynclinal ~~(restricted sea)~~. | Vine, Tourtelot, ~~and Keith~~ (1969). |
| 10. Houy | Houy Formation | Devonian and Mississippian. | Texas | 51 | Core | Epicontinental shelf | Do. |
| 11. Cherokee | Cherokee Group and equivalents | Pennsylvanian | Kansas and Oklahoma. | 47 | Do. | Transgressive marine shelf. | Do. |
| 12. Upper Paleozoic black shales. | Stanley Shale, Atoka Formation, Arkansas Novaculite, and Jackfork Sandstone. | Devonian, Mississippian, and Pennsylvanian. | Arkansas and Oklahoma. | 30 | Outcrop | Eugeosynclinal | Do. |
| 13. Lower Paleozoic shales. | Collier and Mazarn Shales, Blakely Sandstone, Womble Shale, Bigfork Chert, and Polk Creek Shale. | Cambrian and Ordovician. | Arkansas | 32 | Do. | Do. | Vine and Tourtelot (1969) |
| 14. Tacket | Tacket Formation of Jewett and others (1965). | Pennsylvanian | Kansas | 19 | Do. | Epicontinental shelf. | Do. |
| 15. Heath and Tyler | Heath and Tyler Formations and equivalents. | Mississippian and Pennsylvanian. | Montana and Idaho. | 28 | Do. | Intracratonic basin (restricted sea). | Do. |
| 16. Nonesuch | Nonesuch Shale | Precambrian | Michigan and Wisconsin. | 20 | Core | Near-shore shelf | Do. |
| 17. Green River oil shale. | Green River Formation | Eocene | Colorado | 29 | Quarry | Carbonate lake | Do. |
| 18. Upper Cretaceous shales of Kansas. | Niobrara Formation and Pierre Shale. | Cretaceous | Kansas | 59 | Cuttings | Epicontinental shelf | Do. |
| 19. Upper Cretaceous shales of Texas. | Eagle Ford Shale and Buda Limestone. | Cretaceous | Texas | 28 | Core | Do. | Do. |
| 20. Upper Mississippian shale. | Unnamed equivalent to Heath(?) Formation. | Mississippian | Wyoming | 14 | Outcrop | Intracratonic basin (restricted sea). | Do. |

If mobile elements are defined as those most commonly available from solution they would certainly include the elements calcium, magnesium, manganese, and strontium, one or more of which characterize the carbonate fraction of most black shale deposits. These elements are commonly precipitated directly from sea water. The elements most commonly associated with the organic fraction of black shale deposits include many that occur in very low concentration in sea water. These are silver, molybdenum, zinc, nickel, copper, chromium, vanadium and less commonly cobalt, lead, lanthanum, yttrium, selenium, uranium, and thallium. Enriched black shale deposits where the enrichment is associated chiefly with the nondetrital fraction of the rock commonly include one or more of these elements in association with organic matter. Because enrichment of the organic fraction in contact with normal sea water requires such high geochemical enrichment factors, a plausible syngenetic hypothesis requires some prior concentration of the metals in sea water. Copper and lead were not found to be as concentrated in black shales as was anticipated from such reports as that of Wedepohl (1964). Gold, which was also reported in association with organic sediments in Europe (Leutwein, 1951), was not found in the black shale deposits included in the present study. Gold was below the limits of detection by routine analytical methods and therefore is presumably not enriched in any of the samples studied. The special environment wherein gold can be mobilized is probably not generally associated with black shales.

No evidence was found to verify or refute the suggestion of Krauskopf (1955, p. 420–421) that different suites of minor elements may be associated with coaly matter as contrasted with bituminous organic matter. Similarly, no evidence was found to suggest that different suites of minor elements are associated with different environments of black shale deposition, lithologic facies, age of the deposit, or type of organisms living at the time of deposition, although these possibilities did not lend themselves to convenient testing, such as could be done if there were sample sets identical in every respect but the one to be tested.

The availability of metals in the solutions that have come into contact with organic matter throughout its history is probably the most significant factor in determining the suite of enriched metals present. The enrichment process may in some cases be an accumulative one in which the organic matter plays a never-ending role of sorption of metallic ions from solutions in contact with it during the life of the organism, during the period of decay and drifting to a final burial site, after burial and during the expulsion of interstitial pore fluids resulting from compaction, after compaction and prior to regional uplift, after uplift and prior to weathering. For many deposits the most significant period of enrichment may be during the circulation and expulsion of interstitial pore waters resulting from compaction. Convincing proof of the period of sorption is difficult to find.

Thin beds of black shale interstratified with other lithologies may provide a sink for mobile elements that are transported by pore waters expelled during sediment compaction. This may be especially true if some of the interstratified sedimentary rocks contain entrapped pore waters that are chemically reactive. Conversely, thick beds of black shale that are deposited in hypersaline basins may provide a source of mobile elements that are removed from the sediment during compaction and transported to some other lithologic facies where reaction and precipitation may occur. This may explain why such strata as the Paradox Member of the Hermosa Formation and the oil shale in the Green River Formation are reltively low in metal content and such units as the Mecca Quarry Shale Member of the Linton Formation are high. Neither situation seems applicable, however, to the relatively thick Meade Peak Phosphatic Shale Member of the Phosphoria Formation. The high minor element content of this unit would seem to require some unusual condition at the time of deposition, as has been suggested by McKelvey (1967), to account for the deposition of phosphate. Similar phosphate deposits in other parts of the world should be examined for a similar association with metal-rich black shale.

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James I. Reese assisted during the field seasons of 1962 and 1963 and John R. Keith assisted with field work and data compilation in 1966 and 1967. The junior author aided in the literature search, data compilation, and report preparation from 1966 through 1970. Semiquantitative spectrographic analyses were by J. C. Hamilton, A. L. Sutton, Jr., and Chris Heropoulos; quantitative spectrographic analyses by Sol Berman; carbon analyses by I. C. Frost and E. J. Fennelly, and the other chemical and radiometric analyses were by Joseph Budinsky, G. T. Burrow, E. J. Fennelly, W. D. Goss, J. H. Goode, Carmen Hoy, Claude Huffman, Lorraine Lee, H. H. Lipp, B. A. McCall, J. D. Mensik, Wayne Mountjoy, Harriet Neiman, D. L. Skinner, J. E. Smith, and J. J. Warr. M. S. Niles, P. A. Zimmerman, and Josephine Boerngen transcribed the analytical data to punch cards. Computer programming and assis-

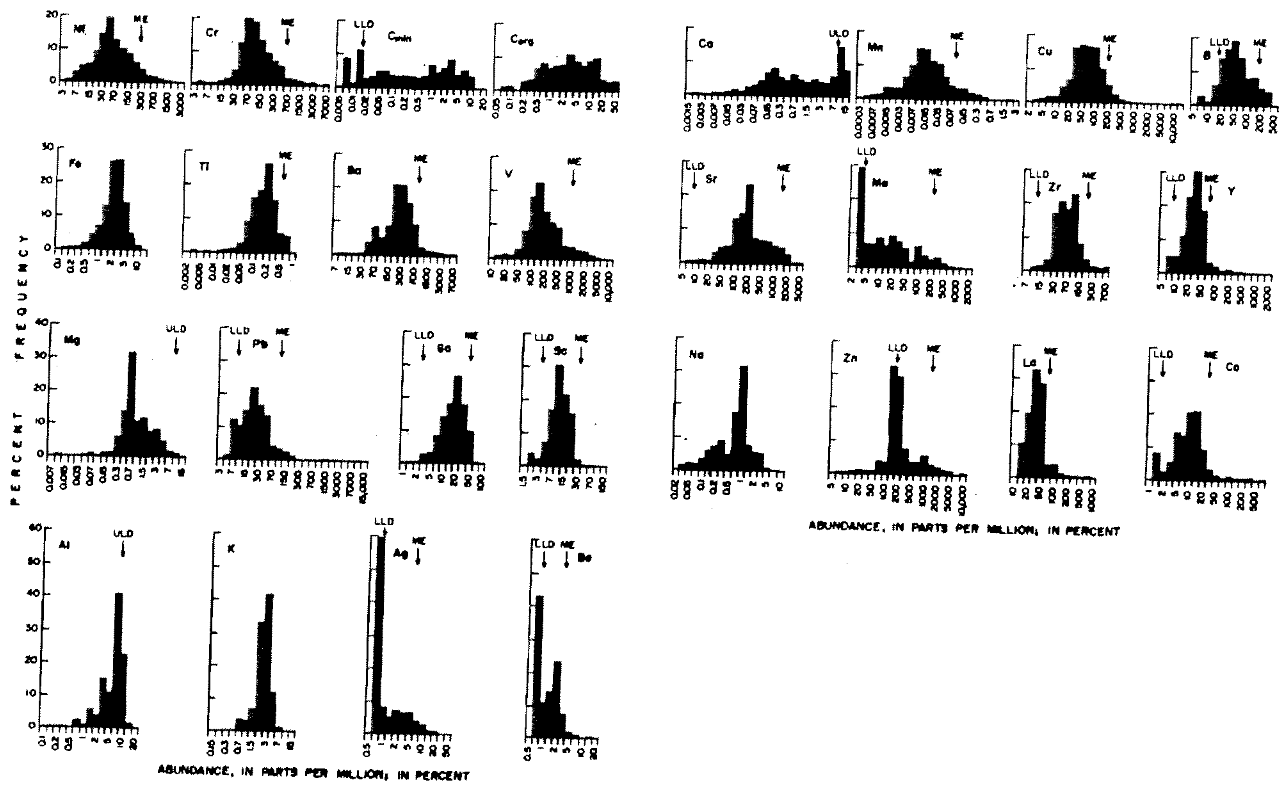


FIG. 2. Frequency distribution of elements in 20 sets of black-shale samples. *Explanation:* Histograms are drawn from the sum of the percent frequency distribution of individual sets giving equal weight to each set. Data used are mainly from six-step spectrographic analyses by the laboratories of the U. S. Geological Survey. The analyses are reported as geometric midpoints (1.0, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc.) of geometric brackets having boundaries 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc. The frequency distributions are computed using these brackets as class intervals. ULD—Upper limit of detection by spectrographic method; LLD—Lower limit of detection by spectrographic method; ME—Minimum enrichment value. The upper and lower limits of detection vary with lithology of the sample and analytical techniques. For some elements, for example zinc, chemical analyses are included that report values above or below the usual limits of detection.

The term "black shale" usually implies that the sediment was deposited in a marine or brackish-water environment in contrast to carbonaceous shale and coal which are usually deposited in a nonmarine environment. One set of oil shale samples from a carbonate-lake environment, however, is included in the group of 20 sets because they are similar to black shales of marine origin. Black shale can grade into common claystone, siltstone, limestone, coal, phosphate, and oil shale.

Before defining metal-rich black shale it was first necessary to know the ranges and average contents of minor elements in black shales. The published estimates of element abundance in shale (for instance, Green, 1959; Turekian and Wedepohl, 1961) are useful, but not definitive or specific for black shale. The estimates of Green (1959) and of Turekian and Wedepohl (1961) are both arithmetic mean values from analyses of many different types of shales, including marine and nonmarine, organic-rich and organic-poor. The arithmetic mean is very sensitive to a few high values and therefore a poor measure of central tendency for a skewed distribution. The median of the 20-set samples shown in Table 2 provides an average composition for black shales that is not unduly influenced by a few extreme values. In Table 3, the minor-element content of the average black shale (median of the medians of 20 sets of black shale) is compared with the previous estimates of average shale minor-element contents by Green (1959, Table 1) and Turekian and Wedepohl (1961, Table 2).

In general, the previous estimates for shale average are in close agreement with the present estimate of element abundance in average black shale. The major difference between the average black shale and the average shale is the content of organic carbon. The organic carbon content in the average black shale is about 3 percent, which is significantly higher than the 0.65 percent estimated by Green (1959) for average shale. The greater content of molybdenum and copper in the average black shale may reflect association of these elements with organic matter. The lower contents of manganese, beryllium, boron,

Table 7. Geochemical enrichment factors for elements in black shale compared with those in normal sea water.

| Element | Concentration in sea water (after Green, 1959) (in ppm) | Highest median of 20 sets of black shale samples (ppm) | Enrichment factor $\frac{col. 3}{col. 2}$ (rounded) | Highest 95th percentile of 20 sets of black shale samples (ppm) * | Enrichment factor $\frac{col. 5}{col. 2}$ (rounded) |
|---|---|---|---|---|---|
| Ag | 0.0003 | 10 | 33,000 | 20 | 67,000 |
| Cr | .00005 | 1,000 | 20,000,000 | 3,000 | 60,000,000 |
| Cu | .003 | 200 | 67,000 | 500 | 167,000 |
| Mo | .01 | 300 | 30,000 | 700 | 70,000 |
| Ni | .00005 | 500 | 10,000,000 | 1,000 | 20,000,000 |
| Pb | .003 | 50 | 16,700 | 100 | 33,000 |
| V | .001 | 1,000 | 1,000,000 | 2,000 | 2,000,000 |
| Zn | .01 | 1,500 | 150,000 | 7,000 | 700,000 |

* The highest 95th percentile does not include the values for epigenetic copper and silver in the Nonesuch Shale.

in ionic solution. No combination of metabolic processes is known, however, that can explain the large suite of elements including silver, chromium, copper, molybdenum, nickel, lead, vanadium, and zinc that are known to be enriched in association with organic matter in some black shales.

The adsorption of minor elements on decaying organic matter, as discussed by Swanson (1961), requires geochemical enrichment factors as much as tens of millions of times if the concentration of metals in normal sea water is compared with the concentration in metal-rich black shale. The geochemical enrichment factors (Table 7) were obtained by dividing the highest median and the highest 95th percentile of 20 sets of black shale samples by the metal concentration in sea water as estimated by Green (1959, Table 2). These enrichment factors are very large, especially when we consider that, unlike manganese nodules, black mud commonly accumulates in an environment of stagnant water and that a large proportion of the mud is inorganic matter not involved in the sorption process.

The large enrichment factors would be more plausible if one could assume that organic debris originated in aerated water and drifted for a long time thereby increasing its exposure to normal sea water before arriving at a final burial site or that a great abundance of organic matter was produced in a constantly replenished supply of nutrient-rich water. To explain an increase in metal content of sea water at depth Brongersma-Sanders (1968) suggested that trace metals are concentrated by living plankton in aerated surface waters and the dead bodies are carried by subsurface counter-currents to accumulate in great masses. Their decay causes high oxygen consumption, production of hydrogen sulfide, and precipitation of the enriched trace elements in bituminous sediments. She further suggested that the trade winds provide the constant wind direction necessary to produce the counter currents and upwelling adjacent to land and that these ideal conditions may precede an increase in salinity in the subtropics so that metal-rich bituminous shales occur below an evaporite sequence.

The decay of organic matter provides a source of sulfur and a reducing environment in which sulfides can be precipitated biochemically, as described by Temple (1964). However, he recognized the problem of introducing sufficient heavy metals into the stagnant environment to form an ore deposit. The counter-current hypothesis may be a partial answer, but there may be other as yet undescribed sources for heavy-metal concentrations in sea water.

A complete explanation of the source and cause of abnormally high concentrations of metals in sea water could minimize the problem of high geochemical enrichment factors needed for a syngenetic hypothesis of the enrichment of minor elements with organic matter. Local sources of metal-rich solutions can account for local concentrations of metals in sea water. For example, hot, metal-rich brine was reported in a deep trough of the Red Sea (Miller and others, 1966) and from a thermal well in the Imperial Valley of California (White, Anderson, and Grubbs, 1963). A metal-rich sediment is also associated with the East Pacific Rise (Bostrom and Peterson, 1966). The location of these occurrences along oceanic fracture zones and rift valleys suggests the possibility that such a local source of metals may have general application to troughs and eugeosynclinal depressions of tectonic origin. Although the concept of such a local source of metals is very appealing, it cannot adequately explain the source of metals in the shelf type of metal-rich black shale.

A hypersaline environment can also cause an abnormally high concentration of minor elements, and has been suggested by Davidson (1964, p. 249) as a source of the metal-rich black shale in the Kupferschiefer-Marl Slate deposits of northern Europe because they underlie the Zechstein salt deposits. In the United States, however, Zangerl and Richardson (1963, p. 221–222) suggested that the metal-rich black shale associated with coal beds in Indiana were deposited in brackish water. Black shale beds associated with hypersaline deposits, such as the Paradox Member in Utah, are among the least metal-rich deposits studied.

Clearly, not all types of metal-rich black shale deposits can be explained by a simple syngenetic hypothesis of sorption or precipitation from normal sea water. A more concentrated source of the elements, or a more effective mechanism for the removal of minor elements from sea water needs to be sought.

### *Diagenetic Enrichment*

Unconsolidated modern sediments contain much pore water. Compaction resulting from the weight

Table 2.--(continued)

| Set number 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Percentile Lowest | Median | Highest |
|---|---|---|---|---|---|---|---|---|---|---|---|
| >10 | >10 | 7 | 7 | 7 | 5 | 7 | 7 | 7 | 1.5 | 7 | >10 |
| >10 | >10 | 7 | >10 | 7 | 7 | >10 | >10 | 7 | 3 | >10 | >10 |
| 5 | 2 | 2 | 2 | *3.3 | 2 | 3 | 2 | 2 | .7 | 2 | 6.7 |
| 5 | 5 | 5 | 5 | *6.0 | 3 | 5 | 5 | 7 | 2 | 5 | 14 |
| .7 | 1.5 | .5 | .7 | *1.9 | 3 | 1.5 | .5 | .7 | .5 | .7 | 4.2 |
| 1.5 | >10 | 1.5 | 1.5 | *2.5 | 7 | 2 | .7 | .7 | .7 | 1.5 | >10 |
| .07 | .07 | 1 | 2 | >10 | >10 | 2 | >10 | .15 | .07 | 1.5 | 12 |
| 1 | 7 | 7 | >10 | >10 | >10 | >10 | >10 | .3 | .3 | >10 | 21.6 |
| 1 | .2 | 1 | .2 | 2 | 3 | 1 | .7 | .15 | .15 | .7 | 3 |
| 2 | 1.5 | 1 | 1 | 3 | 5 | 1 | 1.5 | .2 | .2 | 1 | 5 |
| 3 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 5 | 1.3 | 2 | 5 |
| 5 | 5 | 3 | 5 | 3 | 5 | 3 | 3 | 5 | 2.6 | 3 | 7 |
| .3 | .2 | .15 | .15 | *.44 | .15 | .2 | .1 | .7 | .1 | .2 | .7 |
| .5 | .5 | .2 | .5 | *.7 | .2 | .3 | .2 | .7 | .1 | .2 | .7 |
| .03 | .007 | .01 | .01 | *.23 | .03 | .02 | .02 | .0015 | .0015 | .015 | .23 |
| .1 | .02 | .1 | .1 | *.52 | .05 | .07 | .05 | .03 | .015 | .05 | .52 |
| <.0001 | <.0001 | .0002 | <.0001 | *.0003 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | .001 |
| <.0001 | .00015 | .001 | .0005 | *.0024 | <.0001 | .00015 | <.0001 | <.0001 | <.0001 | .0002 | .0024 |
| .003 | .007 | .003 | .01 | *.005 | .005 | .015 | <.002 | .03 | <.002 | .005 | .03 |
| .007 | .015 | .005 | .02 | *.010 | .02 | .02 | .02 | .03 | .005 | .01 | .03 |
| .05 | .05 | .02 | .01 | *.057 | .07 | .03 | .007 | .007 | .007 | .03 | .1 |
| .3 | .1 | .03 | .02 | *.096 | .1 | .15 | .2 | .007 | .007 | .05 | .5 |
| .0002 | <.0001 | .0001 | <.00015 | <.0002 | <.0001 | <.0001 | <.0001 | <.00015 | <.0001 | .0001 | .0003 |
| .0003 | .0003 | .0015 | .00015 | .0002 | <.0001 | <.0001 | <.0001 | .00015 | <.0001 | .0002 | .0015 |
| .0015 | .0005 | .0007 | .0005 | *.0017 | .001 | .0015 | .0005 | .0007 | <.0007 | .001 | .01 |
| .003 | .005 | .0015 | .002 | *.0024 | .0015 | .002 | .001 | .002 | .0007 | .0015 | .03 |
| .01 | .007 | .05 | .015 | *.0052 | *.0026 | .007 | .01 | .015 | .0026 | .01 | .1 |
| .02 | .01 | .1 | .05 | *.008 | *.0035 | .01 | .03 | .02 | .0035 | .02 | .3 |
| .005 | .005 | .01 | .003 | *.012 | .007 | .007 | .003 | .003 | .002 | .007 | .02 |
| .01 | .01 | .015 | .015 | >*1 | .01 | .02 | .007 | .015 | .005 | .015 | >1 |
| .005 | .002 | .0015 | .002 | *.001 | .0015 | .003 | .001 | .003 | .0007 | .002 | .005 |
| .005 | .005 | .002 | .005 | *.0013 | .003 | .005 | .005 | .003 | .0013 | .003 | .005 |
| .003 | <.003 | .003 | .003 | .003 | <.003 | <.003 | <.003 | .005 | <.003 | .003 | .01 |
| .005 | .005 | .005 | .005 | .005 | <.003 | .003 | .005 | .005 | <.003 | .005 | .05 |
| <.0005 | <.0005 | .0015 | .0005 | *.0012 | .0015 | .002 | .0005 | .002 | <.0005 | .001 | .03 |
| .0005 | .002 | .02 | .02 | *.0025 | .003 | .005 | .003 | .01 | .0005 | .005 | .07 |
| .005 | .003 | .015 | .007 | *.0027 | *.0038 | .007 | .005 | .0015 | .001 | .005 | .05 |
| .007 | .007 | .03 | .03 | *.0048 | *.0059 | .007 | .01 | .007 | .0048 | .01 | .1 |
| .002 | .0015 | .003 | .002 | *.011 | .003 | .003 | <.001 | .003 | <.001 | .002 | .011 |
| .005 | .002 | .005 | .005 | *.026 | .005 | .005 | .002 | .01 | .002 | .005 | .026 |
| .0015 | .0007 | .001 | .0015 | *.002 | .0007 | .001 | .0007 | .002 | <.0003 | .001 | .002 |
| .0015 | .001 | .001 | .002 | *.0021 | .001 | .0015 | .0015 | .002 | .001 | .0015 | .003 |
| .01 | .003 | .02 | .02 | *.02 | .1 | .03 | .07 | .007 | .003 | .02 | .1 |
| .03 | .07 | .07 | .15 | *.029 | .2 | .2 | .15 | .015 | .015 | .05 | .2 |
| .02 | .02 | .05 | .015 | *.012 | .015 | .03 | .03 | .015 | .005 | .015 | .1 |
| .03 | .05 | .2 | .1 | *.024 | .015 | .05 | .07 | .02 | .01 | .05 | .2 |
| .002 | .0015 | .0015 | .003 | *.004 | <.002 | .002 | .0015 | .005 | <.002 | .003 | .015 |
| .005 | .003 | .007 | .005 | *.007 | .003 | .003 | .003 | .005 | .003 | .005 | .05 |
| <.02 | <.02 | .02 | <.03 | *.0079 | <.02 | <.03 | <.02 | <.02 | .0034 | <.03 | .15 |
| <.02 | <.02 | .1 | .2 | *.015 | <.02 | .05 | <.02 | <.02 | <.02 | .05 | .7 |
| .01 | .01 | .003 | .005 | *.013 | .003 | .01 | .005 | .03 | .003 | .007 | .03 |
| .015 | .02 | .007 | .015 | *.017 | .007 | .01 | .01 | .07 | .007 | .015 | .07 |
| .6 | .8 | 8.9 | 2.2 | .4 | --- | 4.0 | 2.8 | .8 | .4 | 3.2 | 35 |
| 3.7 | 4.1 | 22.4 | 15.6 | .9 | --- | 5.1 | 4.5 | 2.1 | .9 | 5.1 | 51 |
| .05 | .05 | .19 | .33 | 2.66 | --- | .97 | 7.91 | <.01 | <.01 | .33 | 7.91 |
| .86 | 2.28 | 2.89 | 5.0 | 5.71 | --- | 7.93 | 11.1 | .01 | .01 | 2.28 | 11.1 |

matter. Beryllium is enriched in association with the detrital fraction. Some epigenetic enrichment or redistribution of minor elements may be indicated by their poor correlation with major rock constituents.

*Chattanooga Shale.*—The Chattanooga Shale of the southeastern United States has been regarded as a classic example of a syngenetic metal-rich black shale (Swanson, 1961, p. 76–77). Set 7 is comprised of core samples of the Chattanooga Shale in Tennessee and Alabama. These samples are characterized by the enrichment of uranium and cobalt in association with the organic fraction and beryllium in association with the detrital fraction. Molybdenum, nickel, and iron are also associated with the organic fraction of the rock but do not occur in concentrations sufficient to be classed as enriched. Four major fractions were identified from the correlation matrix of the sample analyses—a normal detrital fraction, a heavy-mineral detrital fraction, a carbonate fraction, and an organic-matter fraction. The normal detrital and organic fractions are inversely related to each other, and the heavy-mineral detrital (titanium, zirconium, and yttrium) and carbonate fractions are also inversely related to each other.

*Houy Formation.*—Core samples of the Houy Formation south of the Llano uplift in central Texas comprise set 10. The stratigraphic position of these samples is approximately equivalent to that of the samples from the Chattanooga Shale (set 7). However, the Houy Formation samples are much more metal-rich and have the second highest minor-element enrichment index of the 20 sets. In set 10, silver, cobalt, nickel, zinc, and thallium are enriched in association with both sulfur and organic carbon; copper and lead are enriched in association with sulfur; and lanthanum, yttrium, and zirconium are enriched in association with the detrital fraction. Molybdenum is the one minor element that shows close association only with organic carbon but it is not sufficiently abundant to be classed as enriched. The sulfur and iron in this set occur primarily as pyrite, and the copper, lead, and zinc also probably occur mostly as sulfides, as suggested by their close association with sulfur. Silver, cobalt, nickel, and thallium may occur both as sulfides and in the organic matter.

*Phosporia Formation.*—Samples of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation (set 6), representative of the entire member were collected from a mine adit in western Wyoming. This sample set has the highest minor-element enrichment index (570) of all the sets in this study. Most of the enriched minor elements are associated with organic matter or phosphate, or with both of these major constituents of the Meade Peak. The enriched elements chromium, copper, molybdenum, nickel, and selenium are associated primarily with organic matter, whereas strontium, yttrium, and equivalent uranium are associated primarily with phosphate. Lanthanum, vanadium, and zinc are enriched and associated with both phosphate and organic matter. Silver is enriched in association with both the detrital and organic fractions, which are closely related to each other. Only zirconium is enriched in association with the detrital fraction alone. The remarkable concentration of minor elements in this set of samples is emphasized by the fact that the minor-element enrichment index is so much greater than for any of the other sets. Moreover, the samples in this set represent nearly 100 feet of strata, compared to about 15 feet for the Houy Formation, which has the next highest enrichment index, and about 1 foot for the Mecca Quarry Shale Member, which has the third highest index. Thus, if the enrichment index were weighted by the thickness of the strata sampled, the Meade Peak Phosphatic Shale Member of the Phosphoria Formation would rank even farther above any of the other sample sets included.

*Nonesuch Shale.*—Core samples from the Nonesuch Shale of Michigan and Wisconsin (set 16) are unique in that two of the enriched elements, silver and copper, form a separate minor element group unrelated to the major rock constituents (the detrital fraction and the carbonate fraction) and are inversely related to a group of minor elements that includes nickel, zinc, selenium, yttrium, and total sulfur. Other enriched elements in these rocks include titanium in the detrital fraction, manganese in the carbonate fraction, and barium, lead, and yttrium in minor-element groups. These samples have the least organic carbon of any of the 20 sets and no minor elements are enriched in association with the organic fraction. These samples were collected from a bed that is outside the zone of copper mineralization in the White Pine copper district, and the occurrence of copper and silver as enriched elements unrelated to any major rock constituent was not anticipated. The enrichment of these two elements may be related to the epigenetic mineralization of rocks in this district as described by White and Wright (1966), although some of the samples were collected many miles from the principal area of mineralization.

### *Enrichment Associated with Both Detrital and Non-detrital Fractions*

*Cherokee Group and Equivalents.*—Core samples of Cherokee Group and equivalents from southeastern Kansas and northeastern Oklahoma (set 11) are from a geologic setting similar to that of sets per-study are grouped data based on the class intervals that are used in reporting six-step spectrographic analyses given earlier. With this kind of data the 95th percentile might fall in a class interval that includes much more than 5 percent of the samples. Moreover, it was decided that equal weight should be given to each set of samples, as the number of samples varies in each set. Therefore, the class interval that includes the 90th percentile was computed for each minor element from the sum of the percent frequency distribution in the 20 sets. Black shale is then defined as metal-rich if any minor element occurs in *excess* of the class interval that includes the 90th percentile. The midpoint of the next class interval above the 90th percentile of the 20 sets is arbitrarily defined as the minimum enrichment value for use in defining metal-rich black shale samples. Table 4 lists both the midpoint of the class interval that includes the 90th percentile and the minimum enrichment value.

### *Minor-element Enrichment Index*

The minor-element enrichment index is a scale of enrichment values for comparing black shale deposits having different degrees of minor element enrichment. If the percent of samples that are metal-rich with respect to each of 21 minor elements is totaled for each set, as shown on Table 4, the result is an index number that reflects the degree of enrichment in minor elements for each set. This total is called the minor-element enrichment index. The index ranges from a low of 16 for the Paradox Member of the Hermosa Formation (set 8) to a high of 570 for the Meade Peak Phosphatic Shale Member of the Phosphoria Formation (set 6).

### *Classification of Black Shale Deposits*

Variables that could be used in the classification of different types of black shale and that may have affected the amount and distribution of the contained minor elements include the following: composition of sea water, composition of terrestrial rocks that supply detritus to the oceans, lithologic facies and environment of deposition, type of indigenous organisms, and paleotectonic setting. Most of these variables cannot be precisely measured, however, and any classification based on them would tend to be equally imprecise. An empirical classification based (1) on the association of the enriched minor elements with major rock constituents, and (2) on the minor-element enrichment index as determined from the statistical analysis of the chemical data is used in this study in order to provide natural groupings that may be useful in understanding the geochemistry of the deposits.

Table 3. Estimates of element abundance (in percent) in average shale and average black shale.

| Element | Average black shale (median of the medians of 20 sets of black shale) | Shale average | |
|---|---|---|---|
| | | Green (1959) | Turekian and Wedepohl (1961) |
| Al | 7.0 | 7.8 | 8.0 |
| Fe | 2. | 4.3 | 4.72 |
| Mg | .7 | 1.9 | 1.5 |
| Ca | 1.5 | 5.2 | 2.21 |
| Na | .7 | .65 | .96 |
| K | 2. | 2.8 | 2.66 |
| $C_{org}$ | 3.2 | .65 | --- |
| $C_{min}$ | .33 | 1.62 | --- |
| Ti | .2 | .44 | .46 |
| Mn | .015 | .67 | .085 |
| Ag | <.0001 | .00009 | .000007 |
| B | .005 | .012 | .01 |
| Ba | .03 | .08 | .058 |
| Be | .0001 | .0007 | .0003 |
| Co | .001 | .0012 | .0019 |
| Cr | .01 | .016 | .009 |
| Cu | .007 | .0038 | .0045 |
| Ga | .002 | .004 | .0019 |
| La | .003 | .004 | .0092 |
| Mo | .001 | .000074 | .00026 |
| Ni | .005 | .0021 | .0068 |
| Pb | .002 | .002 | .002 |
| Sc | .001 | .001 | .0013 |
| Sr | .02 | .0299 | .03 |
| V | .015 | .013 | .013 |
| Y | .003 | .0033 | .0026 |
| Zn | <.03 | .008 | .0095 |
| Zr | .007 | .02 | .016 |

The 20 sets of blacks shale samples are divisible into three groups: (1) those in which the principal enrichment of minor elements occurs in association with the detrital fraction of the rock, (2) those in which the principal enrichment of minor elements occurs in association with the nondetrital fraction of the rock, and (3) those black shale deposits in which the enrichment of minor elements is about equally associated with the detrital and nondetrital fractions of the rock. Further subdivision of the black shale deposits is based on the minor-element enrichment index. This index is less than 200 for 14 sets and greater than 200 for 6 sets. The 14 sets having a minor-element enrichment index of less than 200 are defined as common black shale deposits and the 6 sets having a minor-element enrichment index of 200 or more are defined as enriched black shale deposits.

## Geochemical Association of Minor Elements in Black Shale Deposits

The following discussions are based on the data that are summarized in Tables 1–5 and Figures 1–3. Although element groupings were described in previous reports as cited in Table 1, individual elements may indicate an increase in the solubility of metals in saline waters, or a lack of chemically reactive organic matter.

*Paleozoic Shales of Arkansas and Oklahoma.*—Two sets of samples, the upper Paleozoic shales of Arkansas and Oklahoma (set 12) and the lower Paleozoic shales of Arkansas (set 13), are geochemically similar in many respects. Barium, beryllium, cobalt, gallium, and zirconium are all enriched in more than 5 percent of the samples of lower Paleozoic shales from Arkansas, and all are associated with the detrital fraction of the rock. Beryllium is queried on Table 5 because a number of samples were reported to contain less than the lower limit of detection, but the enrichment of beryllium and zirconium in some samples suggests that heavy minerals form a significant part of the detrital fraction. The upper Paleozoic shales of Arkansas and Oklahoma show enrichment of many of the same elements in the detrital fraction, including barium, beryllium, cobalt, and gallium. Manganese is also enriched in the detrital fraction of the upper Paleozoic shales, but zirconium is not. Gallium is enriched in half of the upper Paleozoic shales compared with only 6 percent of the lower Paleozoic shales. Few of the minor elements show significant association with organic carbon in either set.

*Western Assemblage.*—Siliceous black shale samples from the eugeosynclinal facies (western assemblage of Roberts and others, 1958) of the Cordilleran geosyncline comprise set 4. Organic carbon analyses were not obtained for the samples from this set so it was not possible to identify associations between the organic fraction and the minor elements in these samples. Two principal element groupings were recognized, however. One appears to represent the detrital fraction of the rock inasmuch as it contains several characteristic elements such as aluminum, potassium, and titanium, and also includes boron, barium, and lanthanum that are enriched in more than 5 percent of the samples. The other group is a minor-element group which could be divided into two subgroups, although the significance of the subdivision is not clear. In the minor-element group, copper, vanadium, and yttrium are enriched in more than 5 percent of the samples. These samples were collected from throughout central Nevada and parts of California, Idaho, Washington, and British Columbia and, although they represent rocks of similar facies, they are too varied to provide as good correlation data as some of the other sets.

*Belden Shale.*—Many samples of black shale and associated rocks from the Belden Shale of Colorado (set 9) are enriched in boron, beryllium, gallium, lanthanum, and scandium in association with the detrital fraction of the rock. In addition, manganese is enriched in many samples in association with the carbonate fraction and lead is enriched in many samples in association with the organic fraction. Lithium is probably also enriched in the detrital fraction, but the analytical data for lithium were not sufficiently quantitative to be of use in the statistical analysis. More than half of the samples are enriched in beryllium and lanthanum and more than 25 percent of the samples are enriched in manganese, boron, gallium, and scandium. The degree of enrichment in the detrital fraction is greater than for any other set except the Upper Mississippian samples from western Wyoming. It may therefore be significant that the Belden Shale is a first-cycle sediment deposited in a restricted basin that includes gypsum and halite. The enrichment of minor elements in the Belden Shale may reflect to some extent an unusual composition of the source rocks, including the Precambrian granites of central Colorado known to be high in beryllium and other minor elements (Hawley and others, 1966). Moreover, it should be noted that the association of many minor elements with the detrital fraction of the rock does not preclude the possibility that such elements as boron were deposited from solution.

*Upper Missisipian Shales of Western Wyoming.*—The Upper Mississippian shales of western Wyoming (set 20) are unique in that an unusually large proportion of samples show enrichment of some minor elements in association with the detrital fraction of the rock. Zirconium is enriched in all the samples, whereas titanium and boron are enriched in 79 and 93 percent of the samples respectively. Lead is also enriched in 14 percent of the samples, although it is not associated with any major rock fraction. Because titanium and zirconium, in particular, commonly occur in heavy detrital minerals, their enrichment probably indicates an unusual amount of winnowing, such as occurs on certain beaches to form black sands that are rich in heavy detrital minerals. Like the Belden Shale of Colorado, these Upper Mississippian shales were deposited in a restricted basin in western Wyoming, and are actually interbedded with gypsum. The source of the sediment is not known, however, and it seems unlikely that they are first-cycle sediments.

A comparison of the Belden Shale of Colorado and the Upper Mississippian shales of western Wyoming with the Paradox Member of Utah is of interest because all three were deposited in restricted basins. The Belden and Mississippian shales are enriched black shale deposits with minor-element enrichment indices of 254 and 286, respectively, whereas the Paradox samples, with a minor-element enrichment index of 16, are the least enriched on the 20 sets studied. In view of the fact that the minor-were not always identified as being associated with one of the major rock constituents. The element groupings can be identified on vector diagrams constructed from the principal component analysis of the correlation matrix of each set. By reference to characteristic elements it is generally possible to further identify each element group with one of the major rock constituents. For example, aluminum alone, or in combination with titanium and gallium, if they all show a strong intercorrelation, can be regarded as characteristic of a detrital mineral fraction. If authigenic aluminum silicates are present, these are not generally distinguishable from the detrital mineral fraction. Where analyses are available for mineral carbon and organic carbon, these are regarded as characteristic of the carbonate fraction and the organic matter fraction of the rocks respectively. Studies of thin sections and of X-ray diffraction analyses of numerous samples were used to supplement the correlation data and further identify major rock constituents in the various sample sets. In this way all sample sets were interpreted and the results tabulated in Table 5.

The major rock constituents in these sample sets are detrital minerals, carbonate minerals, and organic matter. In some sets, phosphate minerals, sulfide minerals, and nondetrital silica[3] were also identified as major rock constituents. Where some of the minor elements showed strong intercorrelations in a sample set but did not correlate with any of the identified major rock constituents, these minor elements were called, simply, a minor-element group. Some of the minor-element groups may result from postdepositional movement of the elements, and other minor-element groups may result from insufficient data so that associations were not recognized. Some of these groups might have correlated with sulfur, if sulfur analyses had been available for more of the sets.

The geochemical association of the enriched minor elements with the detrital and nondetrital fractions of the rock are listed in Table 6. This listing also indicates the sequence in which the various sample sets are described in the following paragraphs.

Table 6. Geochemical association of enriched minor elements in 20 sets of black shale and associated rock samples.

| Set number and identification | Minor-element enrichment index | | |
|---|---|---|---|
| | Enrichment of elements associated with detrital fraction | Enrichment of elements associated with nondetrital fraction | Total |
| **Enrichment associated chiefly with the detrital fraction** | | | |
| 8. Paradox | 16 | -- | 16 |
| 12. Upper Paleozoic black shales | 70 | 23 | 93 |
| 13. Lower Paleozoic shales | 48 | -- | 48 |
| 4. Western assemblage | 89 | 36 | 125 |
| 9. Belden | 219 | 35 | [1] 254 |
| 20. Upper Mississippian shale | 272 | 14 | [1] 286 |
| **Enrichment associated chiefly with the nondetrital fraction** | | | |
| 17. Green River oil shale | -- | 66 | 66 |
| 5. Pennsylvanian shales of Kansas and Oklahoma | -- | 18 | 18 |
| 14. Tacket | -- | [2] 136 | 136 |
| 1. Kentucky core | -- | 44 | 44 |
| 2. Kentucky outcrop | -- | 26 | 26 |
| 3. Mecca Quarry | 22 | 290 | [1] 312 |
| 7. Chattanooga | 35 | 109 | 144 |
| 10. Houy | 92 | 254 | [1] 346 |
| 6. Phosphoria | 5 | [3] 565 | [1] 570 |
| 16. Nonesuch | 10 | 245 | [1] 255 |
| **Enrichment associated with both detrital and nondetrital fractions** | | | |
| 11. Cherokee | 42 | 72 | 114 |
| 15. Heath and Tyler | 50 | 61 | 111 |
| 18. Upper Cretaceous shales of Kansas | 34 | 16 | 50 |
| 19. Upper Cretaceous shales of Texas | 29 | 21 | 50 |

[1] A total of 200 or more indicates an enriched black shale deposit.

[2] Includes a value of 5 for nickel, which is associated with both the detrital and nondetrital fractions of the rock.

[3] Includes a value of 74 for silver, which is associated with both the detrital and nondetrital fractions of the rock.

### *Enrichment Associated Chiefly with the Detrital Fraction*

*Paradox Member of Hermosa Formation.*—Black shale beds in the Paradox Member of the Hermosa Formation (set 8) were deposited in a hypersaline marine basin and are interbedded with beds of halite, anhydrite, and dolomite (Hite, 1960, 1961). Raup, Gude, Dwornik, Cuttitta, and Rose (1968) found rare-earth elements concentrated in the evaporite sequence and offer evidence that the adjacent highlands provided a source for these rare-earth elements. Initially it was thought that other minor elements also might be concentrated in the black shales. However, only boron was found to be enriched in more than 5 percent of the samples, although strontium content is somewhat higher than average. The abundance of boron and strontium most likely only reflects their concentration in the saline environment of deposition. Boron is not necessarily typical of elements associated with the detrital fraction of black shale. Moreover, the correlation of strontium with sodium and barium rather than mineral carbon suggests that it may occur as a sulfate. The correlation of organic carbon with copper, zinc, nickel, chromium, lithium, lanthanum, yttrium, and ytterbium suggests that elsewhere in the same environment these elements may be enriched in the black shale. The lack of enrichment of most minor elements in the samples examined

[3] Silica is inversely related in the siliceous shales of the Houy Formation, set 10, to elements that normally characterize the detrital fraction of black shales.

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Table 4. Minimum enrichment values and minor-element enrichment index (percent of samples in each set that are enriched in minor elements). [Minimum enrichment value is defined as the next class interval above the 90th percentile for the 20 sets of samples. All data in percent. Dashes indicate less than 5 percent of the samples are enriched.]

| Element | 90th percentile for 20 sets | Minimum enrichment value | Ratio of minimum concentration in metal-rich shale: median concentration in average shale | Percent of samples enriched in each set — Set numbers: 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ti | 0.5 | 0.7 | 3.5 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 10 | --- | --- | --- | 79 |
| Mn | .07 | .1 | 6.6 | 15 | --- | --- | --- | --- | --- | --- | --- | 28 | 10 | 6 | 13 | --- | 5 | 11 | 100 | --- | --- | --- | --- |
| Ag | .0005 | .0007 | >7 | --- | --- | 11 | --- | 5 | 74 | --- | --- | --- | --- | 6 | --- | --- | 37 | --- | 15 | --- | --- | --- | --- |
| B | .015 | .02 | 4 | --- | --- | --- | 12 | --- | --- | --- | 16 | 30 | --- | --- | --- | --- | --- | 11 | --- | 7 | 7 | 11 | 93 |
| Ba | .07 | .1 | 3.3 | --- | --- | --- | 59 | --- | --- | --- | --- | --- | --- | --- | 13 | 9 | --- | --- | 10 | 14 | 5 | 7 | --- |
| Be | .0002 | .0003 | 3 | 20 | --- | 22 | 5 | --- | --- | 35 | --- | 65 | --- | --- | 10 | 15 | 5 | --- | --- | --- | --- | --- | --- |
| Co | .002 | .003 | 3 | --- | --- | --- | --- | --- | --- | 29 | --- | --- | 82 | 15 | 7 | 6 | --- | --- | --- | --- | --- | --- | --- |
| Cr | .05 | .07 | 7 | --- | --- | --- | --- | --- | 77 | --- | --- | --- | --- | --- | --- | --- | 31 | --- | --- | --- | --- | --- | --- |
| Cu | .015 | .02 | 3 | --- | --- | 22 | 9 | --- | 14 | --- | --- | --- | 71 | 19 | --- | --- | --- | --- | 35 | --- | 5 | --- | --- |
| Ga | .003 | .005 | 2.5 | --- | --- | --- | --- | --- | --- | --- | --- | 28 | --- | 36 | 50 | 6 | --- | 39 | --- | --- | 17 | 11 | --- |
| La | .005 | .007 | 2.5 | --- | --- | --- | 11 | --- | 74 | --- | --- | 56 | 41 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Mo | .015 | .02 | 20 | 9 | 26 | 95 | --- | --- | 11 | --- | --- | --- | --- | --- | --- | --- | 5 | 7 | --- | --- | --- | --- | --- |
| Ni | .02 | .03 | 6 | --- | --- | 57 | --- | --- | 23 | --- | --- | --- | 69 | --- | --- | --- | 5 | 7 | --- | --- | --- | --- | --- |
| Pb | .007 | .01 | 5 | --- | --- | --- | --- | 13 | --- | --- | --- | 7 | 10 | 21 | --- | --- | --- | --- | 60 | --- | --- | --- | 14 |
| Sc | .002 | .003 | 3 | --- | --- | --- | --- | --- | --- | --- | --- | 40 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sr | .1 | .15 | 7.5 | --- | --- | --- | --- | --- | 49 | --- | --- | --- | --- | --- | --- | --- | --- | 11 | --- | 45 | 16 | 21 | --- |
| V | .07 | .1 | 6.6 | --- | --- | 73 | 17 | --- | 30 | --- | --- | --- | --- | --- | --- | --- | 37 | 7 | --- | --- | --- | --- | --- |
| Y | .005 | .007 | 2.5 | --- | --- | --- | 5 | --- | 77 | --- | --- | --- | 25 | --- | --- | --- | 11 | --- | 25 | --- | --- | --- | --- |
| Zn | .1 | .15 | >5 | --- | --- | 32 | --- | --- | 56 | --- | --- | --- | 22 | 11 | --- | --- | --- | 18 | --- | --- | --- | --- | --- |
| Zr | .015 | .02 | 3 | --- | --- | --- | 7 | --- | 5 | --- | --- | --- | 16 | --- | --- | 12 | --- | --- | --- | --- | --- | --- | 100 |
| U(eU) | .002(est) | .003 | ? | --- | --- | --- | --- | --- | 80 | 80 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Totals (enrichment index) | | | | 44 | 26 | 312 | 125 | 18 | 570 | 144 | 16 | 254 | 346 | 114 | 93 | 48 | 136 | 111 | 255 | 66 | 50 | 50 | 286 |

Table 5. Geochemical associations among the constituents in 20 sets of black shale and associated rock samples. [D, detrital group; O, organic matter group; C, carbonate group; M, minor element group; I, independent; P, phosphate group; S, sulfide group; N, nondetrital silica; H, hydrous; D/O, element occurs in both groups. Underlining indicates the element is enriched in 5 percent or more of the samples of the set. Query indicates element was not included in the correlation statistics.]

| Set no. and identification | Major elements: Si | Al | Fe | Mg | Ca | Na | K | Minor elements: Ti | Mn | Ag | B | Ba | Be | Co | Cr | Cu | Ga | La | Mo | Nb | Ni | Pb | Sc | Sr | U* | V | Y | Yb | Zn | Zr | Carbon: $C_{org}$ | $C_{min}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Kentucky core | -- | D | I | M | M | M | M/D | D | I | O | M | K | M | I | M | M | D | M | M | -- | M | I | D | M | -- | M | M | -- | O | I | O | -- |
| 2. Kentucky outcrop | -- | D | C | D | C | D | D | D | C | M | D/M | D | D | C | M | K | D | D | M | -- | M | D | D | D | -- | M | D | -- | I | D | O | -- |
| 3. Mecca Quarry | D | D | D | D | I | D | D | D | D | K | D | D | D | M | M | M | D | M | O/M | -- | M | M | M | D | -- | M | M | -- | M | M | O | -- |
| 4. Western assemblage | -- | D | M | M | M | D | D | D | M | M | D | D | M | M | M | M | D | D | M | D | M | M | D | M | -- | M | M | -- | M | D | -- | -- |
| 5. Pennsylvanian shales of Kansas and Oklahoma. | -- | -- | D | C | I/O | C | D | L | C | O? | D | D | D | C | O | O | D | D | O | -- | O | O | D | C | -- | O | I | -- | -- | D | O | -- |
| 6. Phosphoria | D | D | D | C | -- | I | I | D | C | D/O | D | D | -- | -- | O | O | D | O/P | O | -- | O | -- | O | P | P | O/P | P | -- | O/P | D | O | C |
| 7. Chattanooga | -- | D | O | D | C | C | I | D | C | -- | D | I | D | O | D | I | D | D | O | -- | O | I | D | D | O | I | D | -- | -- | D | O | -- |
| 8. Paradox | D | D | D | C | C | I/M | D | D | I | -- | D | D/M | -- | -- | O | O | D | O | -- | -- | O | I | -- | I/M | D | D | O | O | O | D | O | C |
| 9. Belden | -- | D | D | C | C | D | D | D | C | -- | D | D | D | D | D | O | D | D | -- | -- | D/I | O | D | O/C | -- | D | D/I | -- | -- | D | O | C |
| 10. Houy | N | D | S | S | D | D | D | D | D | S/O | I | D | -- | S/O | D | S | D | D | O | -- | S/O | S | D | D | -- | D | D | D | S/O | D | O | D |
| 11. Cherokee | -- | D | D | C | C | D | D | D | D | O | I | D | I | I | O | O | D | I | O | -- | O | C | D | C | -- | O | C | -- | O | D | O | C |
| 12. Upper Paleozoic black shales. | -- | -- | D | D | I | D | D | D | D | -- | I | I | M | D | D | I | D | M/D | -- | D | D | D | D | C | -- | I | M | D | -- | D | O | I |
| 13. Lower Paleozoic shales. | -- | -- | D | D | C | I/C | D | D/I | D/I | -- | D/I | D | D? | D | D | I | D | -- | -- | -- | I | D | D | C | -- | I/O | I/O | I/O | -- | D | O | C |
| 14. Tacket | -- | D | O/D | I | C | D | D | D | C | O | D | O | I | D | O | O | D | I | O | -- | D/O | I | D | C | -- | O | O | -- | O | D | O | C |
| 15. Heath and Tyler | -- | D | D | D | C | D | D | D | I/C | M/O | D | D | -- | D | N | M/O | D | D | M/O | D | M | I | D | C | -- | M/O | M | I | M/O | D | O | C |
| 16. Nonesuch | -- | D | D | D | C | D | D | D | C | M | D | M | -- | M | D | M | D | M | M/C | -- | M | M | D | C | -- | D | M | M | M | D | O | C |
| 17. Green River oil shale. | -- | D | M | M | -- | H | M | M | M | -- | M | M | -- | M | M | M | D | -- | O | -- | M | -- | M | M | -- | M | -- | -- | -- | D | -- | -- |
| 18. Upper Cretaceous shales of Kansas. | -- | D | D | D | C | D | D | D | D | -- | D | D | -- | O | D | D | D | D/I | O | D/I | O | D | D | C | D | I | D | D | D | D | O | C |
| 19. Upper Cretaceous shales of Texas. | D | D | D | D | C | D | D | D | I | -- | D | D | -- | D | D | D | D | D | D | -- | D | D | D | C | I | D | D | D | -- | D | D | C |
| 20. Upper Mississippian shale. | -- | -- | M | O | D | D | D | D | M | -- | D | M | -- | M | D | M | -- | M | M | D | M | M | -- | M | D | D | -- | -- | -- | D | O | -- |

* This column includes both uranium determined chemically and equivalent uranium determined radiometrically.

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element in all three sets is associated chiefly with the detrital fraction of the rocks it may be significant that the detrital fraction of the Paradox samples is diluted to a much greater extent than the other two sets by the addition of chemically precipitated mineral matter, chiefly carbonate minerals.

### *Enrichment Associated Chiefly with the Nondetrital Fraction*

*Green River Formation.*—Samples of oil shale from the Mahogany zone of the Green River Formation of Eocene age, near DeBeque, Colorado, comprise sample set 17. The elements boron, barium, and strontium are enriched in more than 5 percent of the samples from the set, but the degree of enrichment is not great, for the minor-element enrichment index is only 66. Most of the minor elements, including these three that are enriched in some of the samples, show little or no relation to the principal elements of the detrital fraction which is characterized by aluminum, gallium, and zirconium. The minor elements are probably related to the formation of authigenic minerals, which represent a significant fraction of the mineral matter in the Green River oil shale. The enrichment of boron, barium, and strontium in some of the oil shale samples is probably related to the abundance of these elements in the hypersaline waters from which these sediments were deposited. Among the sets of samples studied, the oil shale samples from the Green River Formation are unique in the large quantity and bituminous nature of the organic matter that has been preserved. However, only molybdenum shows any tendency to correlate with the organic matter.

*Pennsylvanian Black Shales from the Interior Coal Province.*—Many coal beds in the Interior coal province are interbedded with thin beds of black shale, commonly less than 3 feet thick. Typically, the black shale lies on top of the coal and represents a marine transgression over a coal swamp. Locally a few thicker beds of black shale also occur within the sequence of marine and nonmarine strata that characterizes the Pennsylvanian rocks of the midcontinent region, and these thicker units are not so closely associated with coal beds.

A group of outcropping Pennsylvanian black shales from southeastern Kansas and northeastern Oklahoma comprises set 5. More than 5 percent of these samples are enriched in lead in association with organic matter. Silver is also enriched in about 5 percent of the samples, but in many samples it was not detected and so could not be included in the correlation statistics. An association between silver and organic matter is inferred, however, from inspection of the reported values. Other elements associated with organic matter are chromium, copper, molybdenum, nickel, and vanadium. Locally these elements may be expected to reach the level of enrichment.

Samples of the Tacket Formation of Jewett, Emery, and Hatcher (1965) (set 14) were collected from southeastern Kansas. There the Tacket Formation consists chiefly of black shale with an average thickness of about 30 feet. Many of these samples are enriched in minor elements, including silver, chromium, molybdenum, vanadium, and yttrium in association with organic matter, nickel in association with both organic matter and the detrital fraction, and manganese in the carbonate fraction. Beryllium is enriched also, but appears to be independent of any major rock fraction. One sample in this set contains 15 times more beryllium than the average black shale, but this sample is not enriched in any other minor element.

Black shales associated with coal beds in western Kentucky comprise set 1 (core samples) and set 2 (outcrop samples). Both sets include elements that on Table 5 are assigned to "minor element groups" because they are not clearly associated with either the detrital, organic, or carbonate fractions of the rocks. More than 5 percent of the core samples are enriched in manganese, beryllium, and molybdenum, but the outcrop samples show enrichment only of molybdenum. The geochemical significance of the separate minor-element groups cannot be fully evaluated from the present data. The distribution of manganese in the core samples is independent of any other element. Beryllium, however, is associated with a group of minor elements, and molybdenum is less clearly associated with this same minor-element group. Although these distribution patterns may have some unknown environmental significance, it seems equally probable that they reflect epigenetic introduction or redistribution of the enriched elements.

The samples that comprise set 3, from the Mecca Quarry Shale Member (of Zangerl and Richardson, 1963) of the Linton Formation in Indiana, are from a geologic setting similar to that for sets 1 and 2 from western Kentucky. However, the Mecca Quarry Shale Member is a thin stratigraphic unit, and the samples represent 37 thin splits from a 1-foot-thick bed that was previously known to be metal-rich (Zangerl and Richardson, 1963, p. 99). The Mecca Quarry has the third highest minor element enrichment index of the 20 sets. Silver, copper, nickel, vanadium, and zinc are enriched in more than 5 percent of the samples, but are not clearly associated with any major rock constituent. Molybdenum is enriched with the aforementioned elements but it also shows a positive correlation with organic

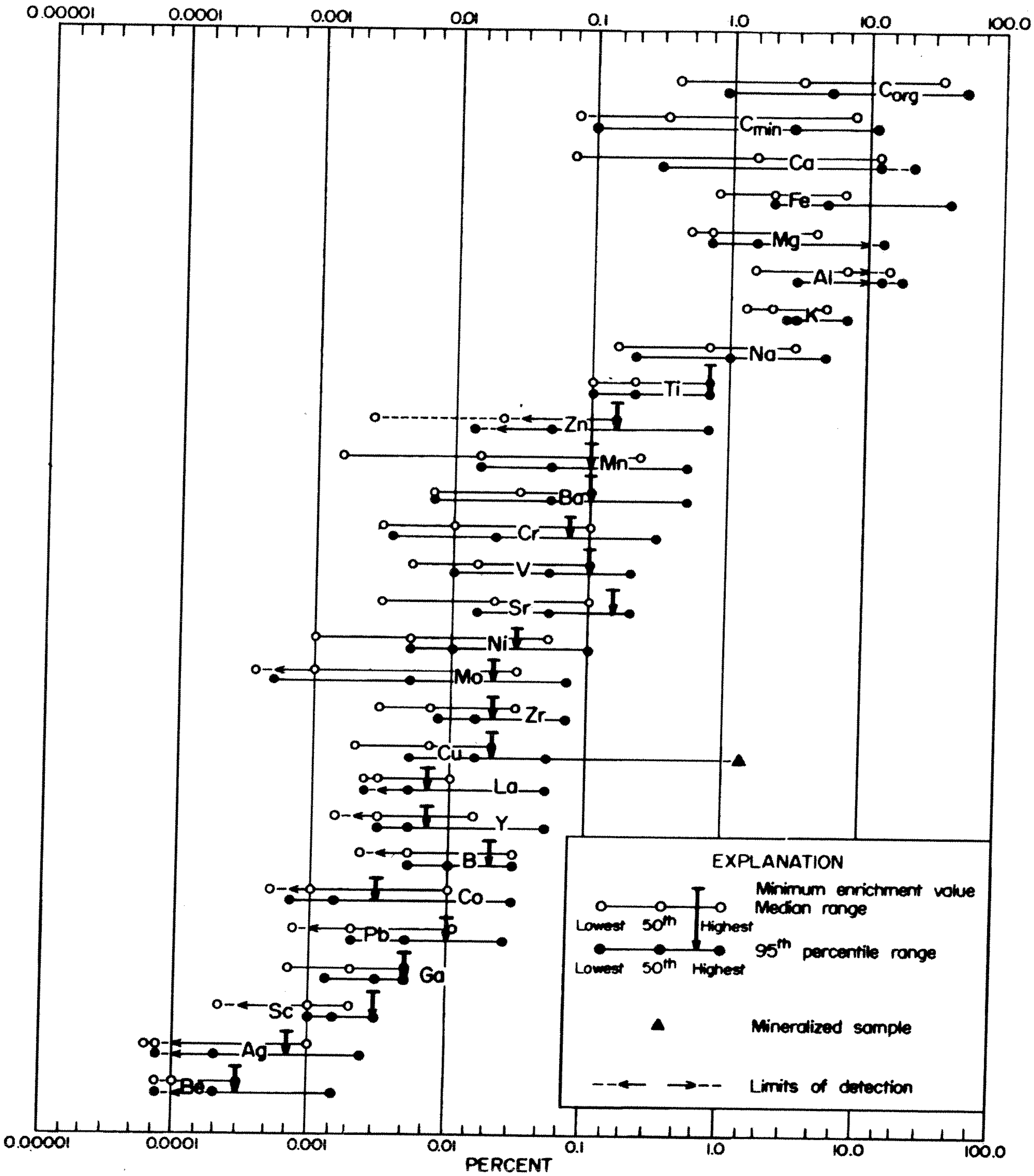


FIG. 3. Concentration range of the medians and 95th percentiles for sample sets 1 through 20.

and zirconium probably reflect the smaller proportion of detrital minerals in the average black shale compared to average shale.

A satisfactory definition for metal-rich black shale should take into account the fact that some minor elements have a much greater range in values than others. With ungrouped data this can most easily be done by arbitrarily selecting a value near the top of the range in values, for example the 95th percentile. However, most of the analyses used in this

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viously described under the heading "Pennsylvanian black shales from the Interior coal province." The Cherokee is approximately the subsurface equivalent of the outcropping samples in set 5, but it is somewhat older than samples in set 14 from the Tacket Formation. However, all three sets are composed of samples from the same geologic area. One difference that may have geochemical significance is that the samples of the Cherokee include some gray shales that are low in organic carbon content. Samples from the Cherokee are enriched in silver, copper, and zinc in association with organic matter; manganese and gallium in association with the detrital fraction; lead in association with the carbonate fraction; and cobalt, which is apparently independent of any major rock constituent. Vanadium, nickel, molybdenum, and chromium are also associated with the organic fraction but are not sufficiently abundant in any of the samples to be classed as enriched. Lead is enriched in both the outcropping rocks of set 5 and the subsurface rocks of set 11, but it is associated with the organic fraction of set 5 and with the carbonate fraction of set 11. This may indicate that lead is leached from the carbonate minerals during weathering and is transferred to the organic matter. Except for silver, most minor elements show less tendency to be enriched in the outcrop samples than in the subsurface samples.

*Heath and Tyler Formations and Equivalents.*—Set 15, which consists of 28 samples from the Heath and Tyler Formations of Montana and Idaho, contains several enriched elements that do not correlate with any major rock constituent. On table 5, molybdenum, nickel, vanadium, and zinc, all enriched, are assigned to minor-element groups whose significance is uncertain. Boron and gallium are enriched in association with the detrital fraction, strontium in association with the carbonate fraction, and manganese is enriched, but is independent of any major rock fraction. Because this set included samples from two closely related but different formations (Maughan and Roberts, 1967) and from two widely separated areas, one in central Montana and one in the mountains of western Montana and Idaho, the samples were divided into several subsets to see if the element associations might be different in some of the subsets than in the full set. The results, described in detail by Vine and Tourtelot (1969), show that in the subset of 10 samples from the Heath Formation of central Montana, silver, copper, chromium, molybdenum, nickel, vanadium, and zinc are all associated with the organic fraction. In 7 samples of the Tyler Formation from central Montana, copper shows an association with the organic fraction, whereas molybdenum and vanadium are associated with the organic fraction in the 10 samples from equivalent rocks in western Montana and Idaho. The fact that none of the organic associations are apparent in the full set of samples is probably due to the statistically mixed population of samples that form the full set.

*Upper Cretaceous Shales.*—The Upper Cretaceous shales of Kansas (set 18) and the Upper Cretaceous shales of Texas (set 19) are similar. Those from Kansas include samples of the Sharon Springs Member of the Pierre Shale and the upper transitional part of the underlying Niobrara Formation. More than 5 percent of these samples show enrichment of boron, barium, copper, and gallium in association with the detrital fraction and enrichment of strontium in association with the carbonate fraction. Molybdenum, cobalt, and nickel tend to correlate with organic matter but show no tendency to be enriched. Samples of the Upper Cretaceous shales of Texas, taken mostly from the Eagle Ford Shale, are also enriched in boron, barium, gallium, and strontium and show much the same association as the samples from Kansas. In the Texas shales none of the minor elements are associated with organic carbon, and the organic carbon itself is associated primarily with the detrital fraction of the rock.

## Mechanisms for Minor Element Enrichment with Organic Matter

The enrichment of minor elements in black shale may be considered, in relation to the time of emplacement, as syngenetic, diagenetic, or epigenetic. For the purpose of this discussion, syngenetic refers to the concentration of minor elements contemporaneous with the deposition of the enclosing sediment; diagenetic refers to concentration of minor elements after burial of the enclosing sediment but prior to flushing out of the original pore waters; epigenetic refers to concentration of minor elements from solutions not indigenous to the sediment. These three terms refer to a coninuous series of overlapping processes.

### *Syngenetic Enrichment*

The syngenetic enrichment of minor elements with organic matter in black shale requires either concentration from sea water by living organisms or concentration from sea water by decaying organic matter or indirectly by precipitation of sulfide in a reducing environment. The metabolic processes of some marine organisms are known to be effective in concentrating some elements from sea water (Vinogradov, 1953; Goldberg, 1957; Boyle and Lynch, 1968). For example, the tunicates are able to concentrate vanadium in direct proportion to the amount

(In percent)

| Element | Percentile | Set number 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al | median | >10 | 7 | 3 | 3 | 7 | 1.5 | 7 | 5 | >10 | 2 | 7 |
| | 95th | >10 | >10 | 7 | >10 | >10 | 3 | >10 | 7 | >10 | *4.4 | >10 |
| Fe | median | 5 | 2 | 2 | 1.5 | 1.5 | .7 | 3 | 1 | 3 | *6.7 | 3 |
| | 95th | 7 | 5 | 3 | 5 | 3 | 2 | 5 | 2 | 5 | *14 | 5 |
| Mg | median | .7 | .7 | .5 | .7 | .7 | 1.5 | .7 | *4.2 | 2 | *1.2 | .7 |
| | 95th | 1 | .7 | 1 | 5 | 1 | 7 | 1.5 | *10.3 | 5 | *3.5 | 1.5 |
| Ca | median | .3 | .1 | .3 | .3 | 1.5 | >10 | .3 | *12 | 1.5 | *3.6 | .3 |
| | 95th | 3 | 1 | 1 | >10 | >10 | >10 | 1 | *17.2 | >10 | *21.6 | 7 |
| Na | median | 1 | .7 | .3 | .2 | .7 | .7 | 1 | .5 | 1 | *.16 | 1.5 |
| | 95th | 1 | 1 | 1.5 | 1 | 1 | 1.5 | 1 | *4.4 | 2 | *.36 | 1.5 |
| K | median | 3 | 2 | 2 | 3 | 2 | 2 | 3 | *2.1 | 5 | *1.3 | 3 |
| | 95th | 5 | 3 | 5 | 5 | 3 | 3 | 3 | *4.2 | 7 | *2.6 | 3 |
| Ti | median | .2 | .15 | .1 | .2 | .1 | .1 | .2 | .1 | .2 | .1 | .2 |
| | 95th | .2 | .2 | .3 | .3 | .2 | .2 | .2 | .1 | .3 | .2 | .3 |
| Mn | median | .015 | .005 | .007 | .007 | .01 | .01 | .01 | .015 | .03 | .03 | .05 |
| | 95th | .15 | .03 | .015 | .05 | .05 | .02 | .03 | .02 | .15 | .1 | .1 |
| Ag | median | <.0001 | <.0001 | .0005 | <.0001 | .00015 | .001 | <.0001 | <.0001 | <.0001 | .0001 | *.0004 |
| | 95th | .0002 | .0002 | .0007 | .0005 | .0007 | .002 | .0001 | <.0001 | <.0001 | .0002 | *.0006 |
| B | median | .003 | .003 | .003 | .007 | .003 | <.003 | .007 | .01 | .015 | .001 | .005 |
| | 95th | .005 | .005 | .01 | .02 | .005 | .01 | .01 | .02 | .02 | .007 | .007 |
| Ba | median | .05 | .03 | .02 | .1 | .02 | .01 | .03 | .02 | .03 | .015 | .03 |
| | 95th | .07 | .07 | .03 | .5 | .05 | .02 | .05 | .05 | .05 | .03 | .05 |
| Be | median | .0002 | .0002 | .0002 | <.00015 | .00015 | <.00015 | .0002 | <.0001 | .0003 | <.0001 | .0002 |
| | 95th | .0003 | .0002 | .0003 | .0003 | .0002 | .00015 | .0003 | .00015 | .0007 | .0003 | .0002 |
| Co | median | .001 | .0003 | .001 | <.0007 | .0007 | <.0007 | .002 | .0005 | .001 | .01 | .0015 |
| | 95th | .0015 | .001 | .0015 | .0015 | .001 | .0007 | .005 | .0007 | .002 | .03 | .003 |
| Cr | median | .01 | .015 | .03 | .01 | .03 | .1 | .007 | .007 | .01 | .003 | .01 |
| | 95th | .015 | .03 | .05 | .03 | .05 | .3 | .01 | .03 | .015 | .015 | .07 |
| Cu | median | .005 | .007 | .015 | .005 | .007 | .007 | .01 | .002 | .003 | .02 | .01 |
| | 95th | .007 | .01 | .02 | .02 | .01 | .03 | .015 | .005 | .01 | .05 | .02 |
| Ga | median | .002 | .002 | .0015 | .0015 | .0015 | .0015 | .002 | .0015 | .003 | .0007 | .003 |
| | 95th | .003 | .002 | .003 | .003 | .002 | .003 | .002 | .002 | .005 | .0015 | .005 |
| La | median | .005 | .003 | .005 | .003 | .003 | .01 | .003 | .003 | .007 | .003 | .003 |
| | 95th | .005 | .005 | .005 | .007 | .005 | .05 | .005 | .005 | .01 | .01 | .005 |
| Mo | median | .001 | .005 | .03 | <.0005 | .001 | .005 | .007 | <.0005 | <.0005 | .007 | <.0005 |
| | 95th | .03 | .03 | .07 | .005 | .005 | .02 | .01 | .0007 | .002 | .015 | .003 |
| Ni | median | .007 | .007 | .03 | .001 | .01 | .015 | .01 | .003 | .003 | .05 | .005 |
| | 95th | .015 | .015 | .07 | .01 | .02 | .07 | .015 | .007 | .007 | .1 | .02 |
| Pb | median | .002 | .002 | .003 | .001 | .003 | .001 | .003 | .001 | .0015 | .005 | .002 |
| | 95th | .005 | .007 | .007 | .003 | .01 | .002 | .005 | .002 | .01 | .015 | .01 |
| Sc | median | .0015 | .0015 | .001 | .001 | .001 | .0007 | .0015 | .0007 | .002 | .0003 | .001 |
| | 95th | .002 | .0015 | .0015 | .002 | .002 | .002 | .002 | .0015 | .003 | .001 | .0015 |
| Sr | median | .02 | .015 | .01 | .01 | .02 | .1 | .01 | .05 | .015 | .02 | .03 |
| | 95th | .02 | .02 | .015 | .05 | .05 | .2 | .02 | .1 | .07 | .05 | .05 |
| V | median | .015 | .03 | .1 | .02 | .015 | .05 | .015 | .005 | .01 | .02 | .015 |
| | 95th | .05 | .05 | .2 | .2 | .07 | .15 | .05 | .01 | .015 | .05 | .05 |
| Y | median | .003 | .002 | .003 | .002 | .003 | .015 | .003 | .002 | .005 | .003 | .003 |
| | 95th | .005 | .003 | .005 | .007 | .005 | .05 | .005 | .003 | .005 | .01 | .005 |
| Zn | median | <.03 | <.05 | .07 | <.03 | <.03 | .15 | <.03 | *.0034 | <.02 | *.09 | *.014 |
| | 95th | .07 | .05 | .3 | .1 | .1 | .7 | .03 | *.011 | <.02 | *.24 | *.23 |
| Zr | median | .007 | .005 | .003 | .007 | .005 | .007 | .01 | .005 | .007 | .007 | .005 |
| | 95th | .01 | .01 | .007 | .02 | .01 | .015 | .015 | .01 | .015 | .02 | .015 |
| $C_{org}$ | median | 5.5 | 13 | 35 | --- | 14 | 5.2 | 10.4 | 2.1 | 1.3 | 5.0 | 3.2 |
| | 95th | 17 | 36 | 51 | --- | 24 | 14.5 | 14.5 | 3.4 | 2.7 | 12.5 | 14.1 |
| $C_{min}$ | median | .03 | <.02 | <.02 | --- | .03 | 2.70 | .07 | 3.97 | .72 | 1.63 | .55 |
| | 95th | 1.42 | 1.34 | .08 | --- | 2.73 | 7.61 | .53 | 9.10 | 5.58 | 6.99 | 1.15 |

* Value derived from chemical or quantitative spectrographic analysis having greater accuracy than the six-step spectrographic analyses, and is therefore reported with additional significant digits.

of overlying sediment produces a continual migration of pore water through the buried strata and a gradual upward loss of water. In a sequence of varied lithologies the water may come in contact with a variety of chemical environments. Pore waters that attain chemical equilibrium with one lithology may be highly reactive with minerals present in adjacent lithologies with the result that various anions and cations are dissolved and transported in solution. Included among these may be a number of ions of minor elements. Highly saline oil field brines containing as much as several hundred thousand parts per million of dissolved solids (White, Hem, and Waring, 1963, p. F30–F33) attest to the corrosive action of some ground waters. The chemical alteration of sediment by indigenous waters can be regarded as diagenetic alteration, but the minor-element enrichment of organic matter by such waters might be difficult to recognize. If new minerals were formed, the resulting deposit would appear to be epigenetic, but if minor elements were adsorbed on organic matter the deposit might be difficult to distinguish from a syngenetic deposit. Thus, if saline residual brines expelled during compaction and recrystallization of the authigenic minerals in the Green River Formation carried uranium ions into the adjacent, more permeable Wind River Formation and encountered a sandstone environment favorable for deposition of uranium, the resulting deposits would have all the characteristics of epigenetic deposits. If the solutions encountered a coal bed which adsorbed uranium on the organic matter the distinction between epigenetic and syngenetic might be more difficult to make.

Marine sediments are commonly buried under thousands of feet of overlying strata for tens or hundreds of millions of years during which time diagenetic alterations can proceed. Eventually, the basin of deposition is subjected to diastrophic or tectonic uplift which initiates a new hydrodynamic regime capable of destroying the indigenous chemical environment and superimposing a new chemical system by flushing the more permeable strata with meteoric or externally derived waters. Such flushing terminates the period of diagenetic alteration and marks the beginning of epigenetic alteration and enrichment.

### *Epigenetic Enrichment*

Many of the principal metallic ore deposits of the world were formed epigenetically by the introduction of metal-rich fluids into chemically reactive host rocks. Ore deposits are usually designated epigenetic if there is unequivocal evidence of hydrothermal alteration, structural control, two or more periods of mineral formation, or crosscutting relations between ore and host rock. Absence of these diagnostic criteria, however, is not sufficient reason to classify a deposit as syngenetic. Whereas black shales that are enriched in vanadium, chromium, uranium, or other metals in association with organic matter are commonly assumed to be syngenetic, sulfide-bearing stratiform deposits are subject to debate as to their origin. However, authigenic iron sulfide minerals are disseminated in nearly all carbonaceous rocks. Sulfide nodules, concretions, and replacements of plant parts are common in coal beds and probably represent diagenetic redistribution of sulfur, although similar features in black shale might be considered epigenetic by some geologists. Unequivocal crosscutting mineral zones such as those described by White and Wright (1966) in the Nonesuch Shale of Michigan provide the best evidence of an epigenetic origin. Such relationships cannot be established, however, without more detailed study of three-dimensional exposures than has been possible for most of the black shale deposits described here.

## Conclusions

Some elements are generally associated with the detrital fraction of black shales, others are commonly associated with the carbonate fraction, and several are repeatedly associated with the organic fraction. Only the more common elements associated with the detrital fraction are consistent in their geochemical association. Aluminum, titanium, gallium, zirconium, and scandium are characteristically associated with the detrital fraction, although scandium shows a strong association with organic matter in the Phosphoria Formation. The elements beryllium, boron, barium, sodium, potassium, magnesium, and iron are associated with the detrital fraction in about half or more of the sample sets but they are not as consistent as the first group. The pronounced enrichment of beryllium in the Belden Shale of Colorado and of titanium, boron, and zirconium in the Upper Mississippian black shale of western Wyoming is probably related to metal-rich granitic rocks in the source area of the Belden and to winnowing of heavy minerals in the Upper Mississippian of western Wyoming. Boron is readily available from the hypersaline waters from which these black shales were deposited, but the elements beryllium, titanium, and zirconium are generally associated with heavy minerals and not usually considered sufficiently mobile to be deposited from solution. However, Green (1959) reported the occurrence of all three elements in the ocean, and from the association with hypersaline deposits it might be useful to consider the possibility of deposition of all these elements from abnormally saline waters.

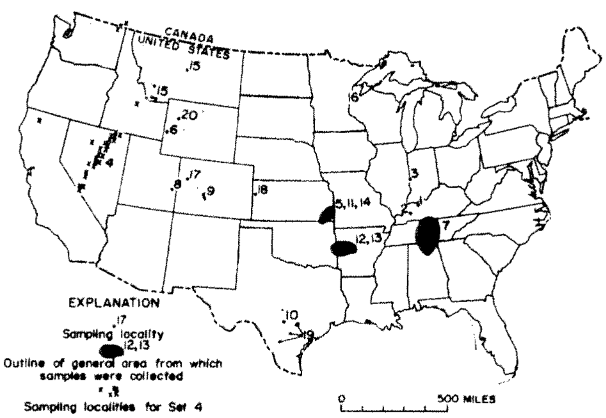


Fig. 1. Sampling localities for black shale sample sets 1 through 20.

formation and making appropriate substitutions for indeterminate values.[2] Principal component analysis of each correlation matrix was then used to identify groups of associated elements in each set. The groups of associated elements thus identified are used to interpret the element-mineral associations in each set.

The use of spectrographic analyses and correlation statistics to determine the distribution and association of minor elements has the advantage that the combination of spectrographic and statistical analyses is simple and inexpensive compared with physically separating the samples of black shale into their principal mineral and organic components. Conventional mineral separation techniques are unsatisfactory for separating organic-rich rocks into their major components because the adhesive quality of the organic matter cannot be destroyed without destroying chemical bonds as well. However, correlation statistics provide only an indirect means of identifying associations, and these may be subject to differences of interpretation.

The fact that the correlation data are part of a closed array (the sum of all constituents equals 100 percent) complicates the interpretations of the element groups. This problem, described by Chayes (1960), may be thought of as one of dilution. A set of samples including the major rock constituents: quartz, carbonate, and clay would include end members represented by siltstone, limestone, and shale, each of which may contain only one of the three constituents. A negative correlation exists between each major constituent and at least one of the other constituents. Also, a corresponding positive spurious correlation may be imposed on certain pairs of minor elements that vary with a major constituent even where there is little geochemical association of the minor element pair. The magnitudes of the correlations are, therefore, affected by dilution, and the problem is basically one of interpretation.

[2] For example, a value one step below the lowest reported value is generally substituted for a "not detected" value.

### Summary Description of Sets of Black Shale Samples

The 20 sets of black shale samples combined for this summary report have been individually described in previous reports, and they are only briefly described here for convenient comparison. Table 1 lists the stratigraphic units sampled, the age, location, number, and type of samples, the environment of deposition, and the reference to a more complete description for each of the 20 sample sets. Localities from which the samples were collected are shown on Figure 1. A summary of the analytical data for each element detected is shown in the form of histograms on Figure 2. Each histogram is drawn from the sum of the percent frequency distribution of individual sets in order to give equal weight to each set. For each element detected, the median and 95th percentile concentrations are listed for each of the 20 sets in Table 2. Some medians and 95th percentiles listed in Table 2 differ from those previously reported. Most of the discrepancies result from refinement in the techniques used on the grouped spectrographic data and generally involve one step up or down in the grouped data. Analyses previously reported as oxides have been converted to elemental form. The highest, median, and lowest of these values are plotted on a logarithmic scale on Figure 3 for visual comparison of the ranges of the medians and 95th percentiles.

### Definitions of Terms

#### *Average and Metal-rich Black Shale*

Sedimentary rocks are composed of detrital minerals, chemically or biologically precipitated minerals, and organic matter in varying proportions. Therefore, the names applied to specific sedimentary rocks are defined arbitrarily. In this report, the term "black shale" includes a wide range of dark-colored, fine-grained rocks. The term implies that the rock owes its dark color to the presence of organic matter which may be bituminous, humic, sapropelic, or graphitic. The mineral fraction of the rock consists of varying proportions of (1) detrital mineral grains such as quartz, feldspar, mica, and clays; (2) chemically and biologically precipitated minerals such as calcite, dolomite, biogenic silica, and apatite; and (3) authigenic or diagenetic minerals such as clay, feldspar, barite, and pyrite. If the rocks are even slightly weathered, joint surfaces and other openings are generaly coated with hydrous oxides of iron, sulfates, carbonates, and other secondary minerals.

tance were provided by R. N. Eicher, G. I. Selner, F. B. Sower, and George Van Trump, Jr.

U. S. Geological Survey,
Denver, Colorado,
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black shales like the Alum shale cannot be distinguished from barren black shale except by chemical analysis, and so it is generally assumed that the metals in the shales are syngenetic and that the post-depositional history of the shale did not affect the metal content significantly. If the deposits are syngenetic, a relationship should exist between metal content and the environment of deposition, the flora and fauna of the time, the paleotectonic setting, and the evolutionary stage of ocean development. If such relationships can be defined, they might be of use in formulating prospecting guides. If such relationships do not exist, then some modification of the syngenetic theory should be considered to account for the origin of enriched black shale deposits.

During the cycles of weathering and erosion of the earth's surface some minor elements tend to remain in resistant minerals and are transported in these minerals to new environments of sediment accumulation. Some elements, such as gold, may be released as native elements during weathering, and, because they are chemically inactive in many environments, their dispersal or accumulation in sediments is primarily a mechancial process. Less chemically stable minerals are destroyed during weathering and the elements released are transported as solutes or colloids, or their ions are adsorbed on other minerals and moved to new areas of deposition. Locally, the elements may be chemically concentrated by precipitation or by adsorption on clays or organic matter or by metal-organic complexing. The more mobile elements associated with the organic matter in fine-grained sedimentary rocks are of particular interest in this study because they may form extensive low-grade resources.

Many kinds of geologically unrelated outcrops of black shale and closely associated rocks that are rich in organic matter were examined and sampled in a reconnaissance fashion to determine what rock units might be of further interest. Some sample localities were suggested by extensive information compiled by the U. S. Geological Survey during the search for uranium in black shale. (Bibliography by Fix, 1958.) Where enough reconnaissance samples were collected from a single geologic environment to be analyzed statistically, they were grouped together in a sample set. Other sample sets are composed of selected samples from drill cores, quarries, mines, or drill cuttings. Twenty sample sets representing 779 samples were chosen for this summary report. Each sample set is intended to represent a specific geologic environment or group of related geologic environments. The 20 sets represent a wide range of geologic environments, geologic ages, and sampling techniques (core, outcrop, artificial exposures, and the like). All sample sets are composed chiefly of fine-grained sedimentary rocks that are characteristically dark gray to black or brown because of the contained organic matter, but they include a wide variety of lithologic types. Clay shale, siliceous shale, siltstone, calcareous or dolomitic shale, and phosphatic shale are all represented.

### Methods of chemical and Statistical Analysis

*Chemical and Spectrographic Methods.*—The samples discussed in this report were analyzed in the laboratories of the U. S. Geological Survey. Most of the data are from routine six-step emission spectrographic analyses. This method is similar to the three-step method previously described by Myers, Havens, and Dunton (1961). Results for the six-step method are identified with geometric intervals whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, 0.083, etc., and are reported as midpoints of these intervals, using the numbers 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, 0.07, etc. The precision of a reported value is approximately plus or minus one interval at 68 percent confidence, or two intervals at 95 percent confidence. Quantitative spectrographic methods were used to analyze for the minor elements in the samples of set 16. These results are reported to have an "overall accuracy of $\pm 15$ percent except near the limits of detection." Chemical methods were used to determine the following elements: sulfur in sets 10 and 16, selenium and arsenic in set 16, selenium in sets 6 and 20, uranium in set 7, phosphorus in set 7, and lithium in set 8. A beta-gamma scaler was used to determine equivalent uranium in sets 6, 8, 18, 19, and 20. In set 17, oil, gas, water, and ash contents were determined by the modified Fischer retort as described by Stanfield and Frost (1949). Separate analyses were made for total carbon and mineral carbon following the methods outlined by Tourtelot, Huffman, and Rader (1964, p. D74). Organic carbon was calculated by taking the difference between total and mineral carbon and rounding off the results to one less significant digit (generally the nearest tenth of a percent, or the nearest percent for large values). All samples were analyzed for gold by the atomic absorption method without finding any significant quantity greater than the limit of detection (0.02 to 0.2 parts per million).

*Statistical Methods.*—The statistical methods used in this summary are described in greater detail in the previously cited reports (Table 1). The frequency distribution was determined for each constituent in each set and those for various sets were mathematically combined into total frequency distribution representing all data sets. The coefficient of correlation was calculated for each pair of constituents detected in each set after first making a log trans-

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# BLACK SHALE—ITS DEPOSITION AND DIAGENESIS[1]

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**Abstract**—Black shale is a dark-colored mudrock containing organic matter that may have generated hydrocarbons in the subsurface or that may yield hydrocarbons by pyrolysis. Many black shale units are enriched in metals severalfold above expected amounts in ordinary shale. Some black shale units have served as host rocks for syngenetic metal deposits.

Black shales have formed throughout the Earth's history and in all parts of the world. This suggests that geologic processes and not geologic settings are the controlling factors in the accumulation of black shale. Geologic processes are those of deposition by which the raw materials of black shale are accumulated and those of diagenesis in response to increasing depth of burial.

Depositional processes involve a range of relationships among such factors as organic productivity, clastic sedimentation rate, and the intensity of oxidation by which organic matter is destroyed. If enough organic material is present to exhaust the oxygen in the environment, black shale results.

Diagenetic processes involve chemical reactions controlled by the nature of the components and by the pressure and temperature regimens that continuing burial imposes. For a thickness of a few meters beneath the surface, sulfate is reduced and sulfide minerals may be deposited. Fermentation reactions in the next several hundred meters result in biogenic methane, followed successively at greater depths by decarboxylation reactions and thermal maturation that form additional hydrocarbons. Suites of newly formed minerals are characteristic for each of the zones of diagenesis.

**Key Words**—Black shale, Deposition, Diagenesis, Organic matter, Syngenetic ores.

## INTRODUCTION

The study of black shales has been difficult until a relatively few years ago. Outcrop observations have yielded relatively few kinds of data for interpreting their origin and the factors governing their formation. Recently, however, a growing body of chemical data on the organic as well as the inorganic constituents of black shale has widened the scope of inferences that can be drawn on the genesis of such rocks. Current investigations of eastern black shale, particularly the Chattanooga Shale and its correlatives of Late Devonian and Mississippian ages, as a source of gas (Schott *et al.*, 1978) are producing a new generation of data; and the time is appropriate to review the processes involved in the accumulation of black shale. Recently, data from deep-sea drilling, such as the composition of pore fluids, and new methods applied to the studies of organic matter and the formation of oil and gas have clarified many aspects of the deposition and diagenesis of organic-rich sediments.

This paper summarizes the work of many specialists with emphasis on guides to the study and interpretation of black shale sequences.

## DEFINITION OF BLACK SHALE

Black shale is a dark-colored mudrock containing organic matter and silt- and clay-size mineral grains that accumulated together (Swanson, 1961, p. 69). Vine (1966, p. E1–E2) pointed out the compositional variations included in this definition and the ways that these variations can be used to study black shale.

Most shales that immediately meet this color criterion contain 1% or more organic carbon; 2–10% is a common range. A few shales contain more than 20% organic carbon. Pyrolysis yields variable amounts of liquid and gaseous hydrocarbons, the amount depending in part on the nature of the original organic material and in part on subsequent burial history. Minor amounts of authigenic carbonate minerals, either dispersed in cements or in concretions, are characteristic features of many black shale units. Most black shales are marine and may have areal extents of thousands of square kilometers.

Black shale units may have beds enriched in metals by factors greater than 50 for Ag, for example, and greater than 10 for Mo (Krauskopf, 1955, p. 417). Such increased concentrations of Ag, Mo, Zn, Ni, Cu, Cr, V, and less commonly Co, Se, and U are conspicuous features of only some black shales (Vine and Tourtelot, 1970, p. 270).

## IMPORTANCE OF BLACK SHALE

Black shales are important to the natural fuel-resource economy of the world because black shales, along with their nonmarine analogue, coal, constitute the most important accessible reservoir of organic compounds in the Earth's crust. The organic matter may have generated liquid and gaseous hydrocarbons found in reservoir rocks in the subsurface into which they

[1] Invited paper at 1978 Clay Minerals Conference, Bloomington, Indiana.

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# BLACK SHALE—ITS DEPOSITION AND DIAGENESIS[1]

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**Abstract**—Black shale is a dark-colored mudrock containing organic matter that may have generated hydrocarbons in the subsurface or that may yield hydrocarbons by pyrolysis. Many black shale units are enriched in metals severalfold above expected amounts in ordinary shale. Some black shale units have served as host rocks for syngenetic metal deposits.

Black shales have formed throughout the Earth's history and in all parts of the world. This suggests that geologic processes and not geologic settings are the controlling factors in the accumulation of black shale. Geologic processes are those of deposition by which the raw materials of black shale are accumulated and those of diagenesis in response to increasing depth of burial.

Depositional processes involve a range of relationships among such factors as organic productivity, clastic sedimentation rate, and the intensity of oxidation by which organic matter is destroyed. If enough organic material is present to exhaust the oxygen in the environment, black shale results.

Diagenetic processes involve chemical reactions controlled by the nature of the components and by the pressure and temperature regimens that continuing burial imposes. For a thickness of a few meters beneath the surface, sulfate is reduced and sulfide minerals may be deposited. Fermentation reactions in the next several hundred meters result in biogenic methane, followed successively at greater depths by decarboxylation reactions and thermal maturation that form additional hydrocarbons. Suites of newly formed minerals are characteristic for each of the zones of diagenesis.

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have migrated. Recently, however, the potential of black shale itself as a reservoir for gaseous hydrocarbons has been recognized, and this potential is being explored intensively. Estimates of the gas content of the Chattanooga Shale, for instance, range from tens to thousands of trillion cubic feet (U.S. Dept. of Energy, 1977, p. 99; Brown, 1976, p. 94).

Hydrocarbons also can be obtained by pyrolysis from thermally immature black shale. Increasing attention will be given to this possibility as demands increase and supplies from conventional sources dwindle.

Black shale units also are important as syngenetic hosts for metal deposits. The Kupferschiefer of Permian age in central Europe is a spectacular example of a metal-enriched black shale, containing a few percent Cu and Pb. Recent lead-isotope data clearly indicate that the metals in the Kupferschiefer were incorporated syngenetically in the shale (Wedepohl *et al.*, 1978). The lead-zinc deposits at Rammelsberg in West Germany are in organic-rich rocks of Devonian age and have a similar origin. The Nonesuch Shale of Proterozoic age has been mined for copper in Michigan (Ensign *et al.*, 1968, p. 464), and at least part of the copper is syngenetic. Oklo, the natural nuclear reactor and uranium deposit in Africa, may represent a maximum concentration of uranium in which the black shale involved may have played an important role in localizing the deposit and in retaining fission products (Brookins, 1976). In Sweden, alum shales of Cambrian age containing about 14% organic carbon have been used as a source of pyrolytic oil and uranium (Armands, 1972).

Only a few metal deposits have been found in black shale units in the United States, but others have not yet been sought systematically. The rich deposits of Rammelsberg occupy less than a square kilometer (Anger *et al.*, 1966). It is still possible that the rocks in a similar small area of the Chattanooga Shale, for instance, are rich enough in metals to constitute an ore deposit. Other metal-rich black shales may eventually serve as metal sources whenever normal sources are depleted (Davidson and Lakin, 1961, 1962; Vine and Tourtelot, 1970).

Metals concentrated syngenetically in a black shale unit either survive metamorphic processes to be retained in graphitic schists (Gammon, 1966; Peltola, 1968) or are released by metamorphic processes to be concentrated elsewhere (Boyle, 1968, p. 838). Conversely, black shale units might be receptor beds for metals released in hydrothermal or metamorphic systems. Exploration strategies in the search for metal deposits are beginning to be based on these concepts (Cox and Curtis, 1977; Gulson, 1977).

Lastly, black shale units seem to excite greatly the intellectual curiosity and imagination of the people investigating them. There is something fascinating about black shale: as Mark Twain said about science, "One gets such wholesale returns of conjecture out of such a trifling investment of fact" (Clemens, 1874, p. 136).

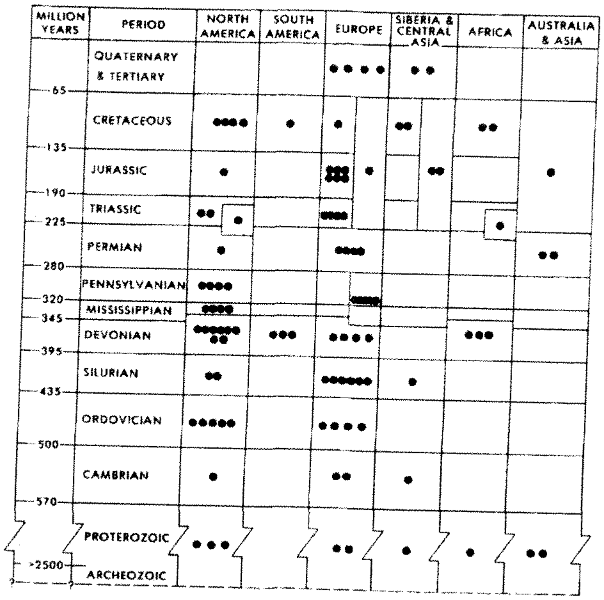


Figure 1. Distribution of black shale units in time and space. Filled circles indicate occurrences. Compiled from Tourtelot (1970) and Fulton (1977). Occurrences differ greatly in areal extent, thickness, and other characteristics.

## DISTRIBUTION OF BLACK SHALE IN TIME AND SPACE

Figure 1 was compiled chiefly from the bibliography on black shale prepared by Tourtelot (1970), but the record of some occurrences was taken from Fulton (1977). The symbols do not have equal significance: for instance, the Chattanooga Shale in the Appalachian region and the Houy Formation in Texas are each counted as a single occurrence among black shales of Late Devonian and Mississippian ages in North America despite the great disparity between their areal extent and thickness. The figure indicates that black shale units have formed commonly throughout most of the history of the Earth and in many places. Black shale units are being found also in the ocean basins now being explored by drilling (e.g., Gardner *et al.*, 1977; Dean *et al.*, 1977; Hallam, 1977; Kerr, 1978). This wide geographic distribution of black shale occurrences in itself suggests that a range of geologic settings must be suitable for the accumulation of black shale.

The organic material that gives black shale its distinctive characteristics is derived from living things. Since black shale has accumulated throughout the entire evolution of life on the Earth, the composition of the organic matter in a black shale should reflect evolutionary development of living things at the time the shale was deposited. The importance of biochemical studies of different stages of evolving life, particularly plant material as preserved in black shale, was pointed out by Woodring (1954), but systematic studies still have not been made, and the significance of the evolutionary stage of life available to provide organic material to a black shale has been largely overlooked. For example, land plants did not evolve until the Late Silurian (Arnold, 1969, p. 129). The organic matter in black shales older than that must therefore be derived from aquatic plants and simpler life forms. The parameters widely used to indicate the "marineness" or "nonmarineness" of depositional environments, such as the hydrogen content of kerogen (Breger and Brown, 1962) or carbon isotopic composition, may be misleading or invalid if the interpretation is based primarily on analogies with the present. The assumption that geochemical effects of metabolic processes have been the same from the beginning as they are now probably is not wholly correct.

## GEOLOGIC SETTINGS OF BLACK SHALE DEPOSITION

The geologic settings of typical black shales were classified by Vine and colleagues in very broad terms (Vine and Tourtelot, 1970) that can be further generalized into geosyncline, cratonic basin, and shelf, as shown in the following table (asterisks indicate metal-rich units):

| | | |
|---|---|---|
| Geosyncline | Permian | Western Rocky Mountains (Phosphoria Formation*) |
| | Upper Paleozoic | SW Midcontinent |
| | Lower Paleozoic | SW Midcontinent |
| Cratonic Basin | Pennsylvanian | Colorado |
| | | Utah (Paradox Formation evaporites) |
| | Pennsylvanian–Mississippian | Montana |
| | Upper Mississippian | Wyoming |
| Shelf (Alternating Marine and Nonmarine) | Pennsylvanian | Midcontinent (Mecca Quarry Shale Member* of Linton Formation) (Zangerl and Richardson, 1963) |
| | | Midcontinent (other similar shales) |
| | Proterozoic | Michigan (Nonesuch Shale*) |
| (Entirely Marine) | | |
| | Cretaceous | Western Interior |
| | | Texas |
| | Pennsylvanian | Kansas (Tacket Formation) (Jewett *et al.*, 1965) |
| | Devonian–Mississippian | Appalachian Region* |
| | | Midcontinent* |
| | | Texas* |
| | | Rocky Mountains* |

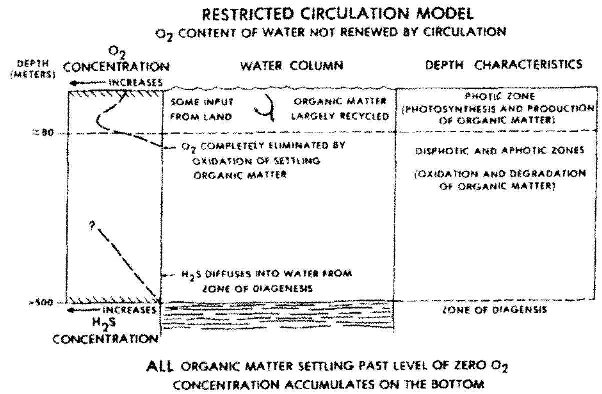


Figure 2. Restricted circulation model for accumulation of organic-rich sediments. Modified from Didyk *et al.* (1978).

In geosynclinal settings, the shales of Paleozoic age form thick deposits the paleogeography of which is not easy to reconstruct because of complex later tectonic history. Black shale in the Phosphoria Formation is the only one of the geosynclinal shales that is enriched in metals (Vine and Tourtelot, 1970). The Phosphoria Formation itself is unusual among sedimentary rocks because of its enrichment in P. The paleogeography of the cratonic basin shales also is difficult to reconstruct. None of those studied by Vine and Tourtelot (1970) are enriched in metals. The black, carbonate-rich shale in the Paradox Formation is unusual because of its association with evaporites.

Classification of a shale as having been deposited in a shelf setting probably would vary from one person to another. All the deposits included here, however, can be viewed broadly as being transgressive. One group includes those deposited in settings in which marine and nonmarine deposition alternated. The other group includes shales that seem to be entirely marine in their associations.

More examples of metal-enriched shales are found among those deposited in the shelf setting than in other settings, but there still is a puzzling variability between some of the shales in the shelf setting. For instance, the Pennsylvanian Mecca Quarry Shale Member (Zangerl and Richardson, 1963) of the Linton Formation is the only one in the Midcontinent region that is enriched in metals. Other marine shales of the same age and lithologic associations in the Midcontinent region are not enriched in metals. Other metal-enriched shelf shales are the Nonesuch Shale of Proterozoic age and shales of Devonian and Mississippian ages.

The interesting metal content of enriched shales is clearly related to the amount of organic matter in the shales. Trace metal adsorption, sulfate reduction, and sulfide precipitation are the chief processes involved (Swanson, 1961; Tourtelot, 1964; Vine and Tourtelot, 1970). A large content of organic matter does not necessarily identify a metal-rich shale. Other factors to be

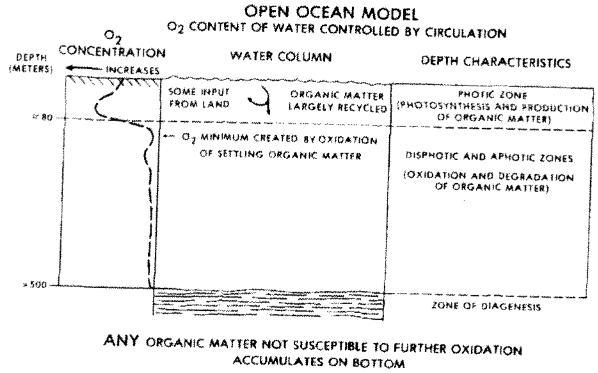


Figure 3. Open ocean model for accumulation of organic-rich sediments. Modified from Didyk *et al.* (1978).

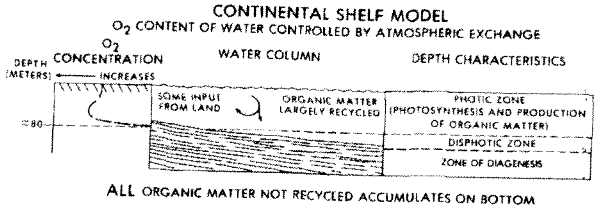


Figure 4. Continental shelf model for accumulation of organic-rich sediments. Modified from Didyk *et al.* (1978).

considered include the nature of the organic material and its metal content, the nature of sediments and water in the source areas, volcanic ash, and submarine volcanic exhalations.

The abundances of some elements are related to those of other constituents of black shales. The contents of Si and Al obviously are related to the abundance of detrital minerals, and the Sr content is related to the abundance of diagenetic carbonate minerals. Vine and Tourtelot (1970) discussed the complexities of these and other relations between elemental compositions and mineral or constituent abundance.

The fact that black shale has accumulated in a wide range of geologic settings implies that geologic setting such as geosyncline or shelf is not of prime importance in the formation of black shale deposits compared to what goes on in these settings. Features of depositional environments within geologic settings, such as organic productivity, sedimentation rates, and availability of oxygen, are the important factors in controlling the deposition of the sediments that form black shale.

## DEPOSITIONAL ENVIRONMENTS

The range of depositional environments in which black shale may accumulate can be described by three models shown in Figures 2, 3, and 4. The formulation of these models stems directly from similar appearing diagrams presented by Didyk *et al.* (1978). They placed great emphasis on the chemical characteristics of the environment *per se*, such as the distribution of oxygen and hydrogen sulfide in the water column and sediments. Here, however, the role of the amount of organic material in relation to oxygen supply is emphasized. An abundance of organic material depletes oxygen and creates the conditions under which organic-rich sediments can accumulate. Similarly, hydrogen sulfide is produced under the conditions caused by the accumulation of organic material, which favors the further accumulation of organic material. The accumulation of organic material is a cause of conditions, not an effect.

The restricted circulation model is discussed first because it represents the classic view, and unfortunately often the only view, of the accumulation of organic material in ancient rocks (Figure 2).

### *Restricted circulation model*

The significant feature of the restricted circulation model is that the oxygen content of the water column is not renewed by circulation so that organic-rich sediments can accumulate even if organic productivity is relatively small. Organic material is produced by photosynthesis in the photic zone, mixed with some organic material from land if terrestrial plant life exists, and is largely recycled in the photic zone by chemical and biological processes such as "bigger things eating littler things." The oxygen content of the water may increase towards the bottom of the photic zone because of photosynthesis, but at some point it is completely consumed by the oxidation of the settling organic material. The oxygen depletion did not exist *a priori*, but was caused by the large oxygen demand of the decomposing organic material itself. All the organic matter that settles below the level of zero oxygen content accumulates on the bottom where it can be removed only by anaerobic decomposition. Hydrogen sulfide generated in the bottom sediments may diffuse into the overlying water mass. Both the sedimentational environment and the sediments are anoxic.

This situation prevails because there is too little circulation in the water mass to supply oxygen at a rate fast enough to equal or exceed the oxygen demand of the available organic material. If enough organic material is produced in the photic zone, considerable amounts of oxygen could be supplied and organic matter still would accumulate in the bottom sediments.

The restricted circulation model is represented in part by the Black Sea (the type euxinic setting: see Goldhaber, 1978) or Norwegian and other fjords, which provide good modern examples of the chemical and sedimentational processes outlined above. Organic-rich deposits will accumulate in such restricted basins, including basins formed tectonically such as the Carioco trench or those off the California coast, unless the rate of organic productivity in the photic zone above them is low. However, concepts of fjords and tectonic basins cannot be applied to the origin of widespread black shale units because of the contrast in area and the definite morphologic characteristics of such basins.

*Open ocean model*

In the open ocean (Figure 3), the oxygen content of the water may be controlled primarily by circulation, but it is also strongly influenced by the amount of organic material that escapes from the photic zone and settles through the water column. The oxygen minimum, just below the photic zone, is created by the oxidation of organic material. Some of the more resistant organic material settling past the oxygen minimum may undergo no further degradation en route to its accumulation on the bottom. Settling rates too rapid for oxidation of organic particles to be complete can be caused by incorporation of organic material in fecal pellets or by aggregation with mineral particles, even if the organic compounds are susceptible to oxidation. Organic-rich sediments thus can accumulate even though the sedimentational environment is completely oxic. In any event, the sediments themselves will become anoxic a few millimeters below the sediment surface because of bacterial processes and the slow replenishment of dissolved oxygen by diffusion below any zone of burrowing that is present.

The balance between organic productivity and available oxygen can shift because of changes in patterns of surface currents in response to tectonic events distant from the depositional site. Or, the depositional site might be carried by seafloor spreading (in the case of younger rocks) from an area of low organic productivity to one of high productivity and then to an area of low productivity again (e.g., White, 1979). The sediments deposited beneath the area of high productivity could be rich in organic matter and form black shales without there necessarily being an anoxic event in the sense of the formation of a barred basin or the cessation of circulation.

*Continental shelf model*

The continental shelf model (Figure 4) contains the same input factors as the other models, but there is little or no water between the photic zone and the bottom. Organic material is recycled in the photic zone to a lesser extent because of more rapid settling to the bottom. The concentration of oxygen in the water may remain large down to the top of the accumulating sediment because of circulation and the production of oxygen in the photic zone. In this setting also, the sediments become anoxic a very short distance beneath the surface because of bacterial processes.

This kind of sedimentational environment has been deduced for several transgressive black shales in North America, such as those in cyclothems of Pennsylvanian age (Zangerl and Richardson, 1963) and the black shales of Devonian and Mississippian ages (Conant and Swanson, 1961). This model, like the open ocean model, does not require any *a priori* conditions such as a restricted basin, density stratification, hydrogen sulfide in the water, or other characteristics based on analogies with the Black Sea.

## RELATIVITY OF FACTORS IN DEPOSITION

Different relations between rates of clastic sedimentation, organic productivity, and the intensity of oxidation result in similar kinds and, perhaps, similar amounts of black shale being deposited. Organic productivity is controlled chiefly by the availability of nutrients, although other factors such as temperature, salinity, and water clarity also are involved. In trying to understand the reasons for the distribution of black shales in time and space, the fundamental concept to be kept in mind is that organic-rich rocks result when and where organic material accumulates because it is produced faster than it can be destroyed.

## ZONES OF DIAGENESIS

The characteristics of the environment in which black shales were deposited are more or less imaginary in the sense that the characteristics have to be deduced from very few data of uncertain significance. In contrast, the zones of diagenesis can be fairly well defined on the basis of data on pore fluids and sediments from deep-sea drilling, laboratory experiment, and theoretical considerations. In addition, most of the products of diagenetic processes remain in the rocks and provide a record that can be deciphered. It is important to recognize the products of diagenesis so that data on them are not used misleadingly in the interpretation of conditions of deposition.

Krumbein and Garrels (1952) made clear the role of pH and oxidation-reduction potentials in influencing rock compositions during diagenesis. Postdepositional (diagenetic) changes during the accumulation of sedimentary rocks had, of course, been recognized earlier (Krumbein, 1942). Later, Berner (1964) explored iron and sulfur reactions in early diagenesis. Since then, diagenetic processes have been widely studied. The following discussion is based on four principal papers (Claypool and Kaplan, 1974; Curtis, 1977; Goldhaber and Kaplan, 1974; and Irwin *et al.*, 1977) that review, with some differences in emphasis, the processes of diagenesis of sedimentary rocks containing organic matter.

Figure 5 represents a sequence of diagenetic zones with depth at a particular point in time. The rocks in the zone of hydrocarbon formation already have passed through all of the overlying zones. If sedimentation continues, the sediments in the present zone of sulfate reduction can be expected to pass sequentially in order through the underlying zones. The ultimate nature of the rocks will depend chiefly on the maximum pressure and temperature that they reach during their burial history.

The diagram is only a model, and the boundaries between the zones are not sharply defined. The depths, temperature, and porosity may not be generally agreed to. The numbers in themselves are not important compared to the sequence of zones downwards. In an organic-rich sediment, a zone of oxidation at the top of the sediment column may be absent, thin, or, if present, the accumulating organic material may pass through it so rapidly as to be little affected. A zone of oxidation is not shown on Figure 5, but its presence can be important because in it any remaining free oxygen in the pore water is eliminated, a necessary condition before anaerobic sulfate-reducing bacteria can live. In addition, aerobic bacterial oxidation of part of the organic material may increase the abundance of compounds that serve as a utilizable substrate for the sulfate-reducing bacteria. The thickness of both the zones of oxidation and sulfate reduction depends on the extent of diffusion of oxygen and sulfate into the sediments from the overlying waters. The reduction of sulfate results in the formation of pyrite.

In both the zones of oxidation and sulfate reduction, the carbon dioxide formed is very light in carbon-isotope composition. Carbonate minerals in cements or concretions formed from such carbon dioxide would also be very light.

In the zone of fermentation, methane is produced by the bacterial reduction of carbon dioxide. This process begins when all available sulfate has been reduced. The bacterial population must be a mixed one containing not only methane-producing bacteria but also other bacteria capable of producing carbon dioxide. The fermentive production of biogenic methane causes a large fractionation of the carbon isotopes although the nature of the fractionation process is not well understood. Biogenic methane having the expected very light carbon-isotope composition is being produced commercially from rocks of Cretaceous age in eastern Montana where the fermentation zone represents the zone of greatest diagenesis yet reached by the rocks (Rice, 1975).

Ferroan dolomite, ankerite, and siderite are the carbonate minerals likely to be deposited in concretions and cements because of the depletion of sulfate and complete reaction of sulfide. Iron carbonate does not form in the presence of dissolved sulfide except under unusual circumstances.

With increasing temperature and depth of burial as sedimentation goes on, the rocks reach the zone of decarboxylation where the organic matter begins to decompose by chemical instead of biologic processes. The carbonate mineral deposited is likely to be siderite, perhaps with a mixed composition, because the higher temperatures promote the reduction of iron compounds

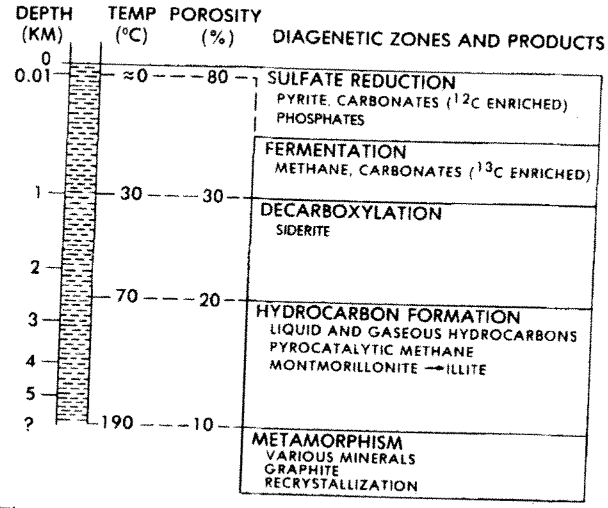


Figure 5. Zones of diagenesis. Modified from Curtis (1977). A zone of oxidation may or may not be present at top of sediment column: see text.

that could not be reduced under the milder conditions of the overlying zones.

The remaining organic matter presumably is different in composition than it was when the containing rocks entered the zone of decarboxylation. Such differences have not been detected, perhaps because rocks that have entered the zone of decarboxylation but gone no further have not been recognized.

The gradation from the lower zone of decarboxylation into the upper part of the zone of hydrocarbon formation is particularly broad. Pyrocatalytic formation of methane, for example, can begin at about 50°C, but large amounts may not be produced until much higher temperatures are reached. The carbon in pyrocatalytic methane has a $\delta C^{13}$ more positive than that in biogenic methane. Organic composition, vitrinite reflectance, and the color alteration index of conodonts are all promising tools for defining the characteristics of this hydrocarbon zone that has such great economic importance. This is also the zone in which montmorillonite is converted into illite through several successive intergrades. The expelled water is a potential force for driving the migration of liquid hydrocarbons. Such expelled water may also carry metals that can be deposited in favorable sites within a black shale, e.g., Cu replacing Fe in pyrite (Tourtelot and Vine, 1976, p. C26).

## RELATIVITY OF FACTORS IN DIAGENESIS

Temperature, pressure, and time are the chief factors that control what goes on in each successively deeper zone of diagenesis. The relations between diagenetic factors can be viewed in the same way as the relations of depositional factors. Diagenetic factors may vary regionally within a black shale of great areal extent. The eastern extent of a black shale unit, as a general example, may reach a more advanced zone of diagenesis than the western extent because of greater burial from thicker overlying rocks, tectonism, or igneous intrusions. Variation of this kind is indicated by the distribution of conodont color alteration indices shown by Harris *et al.* (1978). The relations of diagenetic factors can vary between shales, also. A shale of Tertiary age at a depth of 3–5 km in a region of large thermal gradient may have had most of its original montmorillonite transformed to illite. Another shale of Cretaceous age in a region of small geothermal gradient may still retain its original montmorillonitic composition even though at some time during its history it has been buried to a depth of 10 km. Given equal burial depths and thermal gradients, mineral transformations may have gone further in a shale of Paleozoic age than in one of Mesozoic age, simply because of more time having passed. It thus seems likely that a moderate range of relations between pressure, temperature, and time can yield the characteristics of a given diagenetic zone. This relativity of parameters must be taken into account in interpreting data on the chemical and mineralogic composition of black shales.

## CONCLUSIONS

In any depositional setting, rates of clastic sedimentation and organic productivity and the intensity of oxidation are the primary controls for the accumulation of organic material.

In zones of progessive diagenesis, the mixture of organic matter and clastic sediment is operated on in rather predictable ways by biologic and chemical processes controlled chiefly by temperature, pressure, and time.

The separate products of the processes operating in the depositional environment and in the zones of diagenesis should be clearly distinguished to avoid misleading interpretations of either setting.

The factors influencing both the amount and composition of organic matter in a black shale can be expressed in an equation of the form sometimes derisively stated as "some of it plus the rest of it equals all of it," as follows:

BLACK SHALE — DEPOSITIONAL ENVIRONMENT — ZONE OF DIAGENESIS

$$\begin{matrix}\text{Organic}\\ \text{matter}\end{matrix} = \left\{\begin{matrix}\text{Organic}\\ \text{productivity}\end{matrix} - \text{Oxidation}\right\} - \left\{\begin{matrix}\text{Oxidation}\\ \text{Sulfate reduction}\\ \text{Fermentation}\\ \text{Decarboxylation}\\ \text{Pyrocatalytic reactions}\end{matrix}\right\} \pm \left\{\begin{matrix}\text{Migration}\\ \text{of}\\ \text{products}\end{matrix}\right\}$$

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**Резюме**—Чёрные сланец является темно окрашенной глинистой породой, содержащей органический материал, который мог явиться источником углеводородов в недрах или из которого можно получить углеводороды пиролизом. Во многих видах чёрного сланца содержание металлов в несколько раз превышает их содержание в обыкновенных сланцах. Некоторые виды чёрного сланца служат вмещающими породами для сингенетических отложений металлов.

Чёрные сланцы формировались в течение всей истории земли и во всех частях мира. Это указывает на то, что геологические процессы и не геологические условия являются определяющими факторами при формировании чёрных сланцев. Геологические процессы включают отложение, в результате которого накапливаются первичные осадки чёрного сланца, и диагенез, присходящий в результате увеличивающейся глубины захоронения осадков.

Процессы отложения включают целый диапазон отношений между такими факторами как органическая продуктивность, скорость седиментации, интенсивность окисления, разрушающего органическое вещество. Если присутствует достаточное количество органического вещества, чтобы истощить кислород в среде, образуется чёрный сланец.

Диагнетические процессы включают химические реакции, определяемые природой составных частей и режимами давлений и температур, вызванных продолжающимся захоронением. На глубине в несколько метров под поверхностю земли восстанавливается сульфат и могут отложиться сульфидные минералы. На глубине в несколько сотен метров в результате реакций брожения образуется биогенетический метан, а на больших глубинах в результате реакций декарбоксилирования и температурного метаморфизма образуются дополнительные углеводороды. Комплексы вновь образованных минералов характеризуют каждую зону диагенеза.

**Resümee**—Schwarzschiefer ist ein dunkler Schieferton, der organische Substanz enthält, die durch Überlagerung oder durch Pyrolyse Kohlenwasserstoffe bilden kann. Viele Schwarzschieferschichten zeigen eine Anreicherung an Metallen, sodaß ihre Metallgehalte um einiges höher liegen als die der üblichen Schiefer. Einige Schwarzschieferschichten dienten als Muttergestein für syngenetische Metallablagerungen.

Schwarzschiefer wurden während der ganzen Erdgeschichte und überall auf der Erde gebildet. Daraus folgt, daß geologische Prozesse, nicht geologische Gegebenheiten die ausschlaggebenden Faktoren für die Ablagerung von Schwarzschiefer sind. Diese geologischen Prozesse sind die Ablagerung, durch die das Ausgangsmaterial für den Schwarzschiefer sedimentiert wurde und die Diagenese infolge der zunehmenden Überlagerung.

Ablagerungsprozesse werden durch die Einwirkung mehrerer Faktoren beeinflußt, wie z.B. organische tätigkeit, Absatzgeschwindigkeit klastischer Sedimente, und Intensität der Oxidation, durch die organisches Material zerstört wird. Schwarzschiefer entsteht, wenn genügend organisches Material vorhanden ist, um den Sauerstoff der Umgebung zu verbrauchen.

Diagenetische Prozesse beinhalten chemische Reaktionen, die durch die Art der Komponenten sowie durch die herrschenden Druck- und Temperaturverhältnisse kontrolliert werden, die durch zunehmende Überlagerung entstehen. Denn unter einer Überlagerung von einigen Metern wird Sulfat reduziert, und Sulfidminerale können abgelagert werden. Fermentationsreaktionen in den nächsten hundert Metern führen zur Bildung von biogenem Methan. Ihnen folgen mit zunehmender Tiefe nach und nach Decarboxylierungsreaktionen und thermische Alterung, die weitere Kohlenwasserstoffe bilden. Abfolgen von neu gebildeten Mineralen sind charakteristisch für jede der Diagenesezonen.

**Résumé**—L'argile shisteuse noire est une roche argileuse foncée contenant de la matière organique qui peut avoir généré des hydrocarbones dans le sous-sol ou qui peut donner des hydrocarbones par pyrolyse. Beaucoup d'unités d'argile shisteuse noire sont enrichies de quantités de métaux plusieurs fois plus importantes que celles aux quelles on s'attendrait dans l'argile shisteuse ordinaire. Certaines unités d'argile shisteuse noire ont servi de roches hôtes pour des dépôts de métal syngénétique.

Les argiles shisteuses noires ont été formées tout au long de l'histoire terrestre et dans toutes les parties du monde. Ceci suggère que ce sont des procédes géologiques et non des lieux géologiques qui sont les facteurs controllants dans l'accumulation de l'argile shisteuse noire. Les procédés géologiques sont: la déposition par laquelle les matières premières d'argile shisteuse sont accumulées et la diagénèse rèpondant à une profondeur d'enterrement croissante.

Les procédés de déposition comprennent une étendue de relations entre des facteurs tels la productivité organique, la vitesse de sédimentation clastique et l'intensité d'oxidation par laquelle la matière organique est détruite. S'il ya assez de matière organique pour épuiser l'oxygène de l'environnement, il en résulte une argile shisteuse noire.

Les procédés diagénétiques comprennent des réactions chimiques contrôlés par la nature des composants et par les régimes de pression et de température imposés par l'enterrement continuel. A une èpaisseur de quelques mètres sous la surface, la sulphate est réduite et des minéraux sulphides peuvent être déposés. Les réactions de fermentation dans les prochaines centaines de mètres résultent en de la mèthane biogènique, suivie successivement à de plus grandes profondeurs de réactions de décarboxylation et de maturation thermale qui forment d'avantage d'hydrocarbones. Des suites de minèraux nouvellement formés sont caractèristiques de chacune des zones de diagénèse.

## Consideration of Radiation in Hazardous Waste Produced from Horizontal Hydrofracking

*Report of E. Ivan White*
*Staff Scientist for the*
*National Council on Radiation Protection*

Radioactivity in the environment, especially the presence of the known carcinogen radium, poses a potentially significant threat to human health. Therefore, any activity that has the potential to increase that exposure must be carefully analyzed prior to its commencement so that the risks can be fully understood. Horizontal hydrofracking for natural gas in the Marcellus Shale region of New York State has the potential to result in the production of large amounts of waste materials containing Radium-226 and Radium-228 in both solid and liquid mediums.

A complete and thorough analysis of the potential environmental pathways for exposure of people to these radioactive materials is a prerequisite to any regulatory approval of activities involving their extraction, handling, transportation and storage.

> The guiding principle for this work is that ***radioactivity should never be released into the environment in an uncontrolled manner*** because of the potential for exposure from the many potential pathways that exist.

Over the past fifty years, the Atomic Energy Commission (AEC) and the Nuclear Regulatory Commission (NRC) have spent millions of dollars on research that has resulted in computer models of the transport of radioactivity through the environment to humans. These environmental transport and human uptake models, known as "RESidual RADiation," or "RESRAD," are designed to be incorporated into governmental regulatory guidelines to ensure that people are not exposed to levels of radiation and radioactivity that would result in negative health impacts.

In April of 1999, the New York State Department of Environmental Conservation's Division of Solid and Hazardous Materials, assisted by representatives from sixteen oil and gas companies, conducted an internal investigation entitled *An Investigation of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Wells in New York State.* The report concluded that drill cuttings and wastewater from oil and gas drilling operations "do not constitute a health risk for the State's residents nor present a potential degradation of the State's environment."

A similarly cavalier attitude towards human exposure to radioactive material pervades the NYS DEC's 2011 Draft Revised Supplemental Generic Environmental Impact Statement (rSGEIS). The document's superficial characterization of radiation risks has prompted warnings from radiation experts, including those at the EPA whose public comments on the rSGEIS reflect deep concerns about the DEC's understanding and appreciation of the actual risks posed by radiation.

The National Council on Radiation Protection (NCRP) is a Congressionally-chartered agency charged with the authority and responsibilty to coordinate public information on radiation protection and radiation measurements. In its 2010 NCRP Report #169, *Design of Effective Radiological Effluent Monitoring and Environmental Surveillance Programs*, we describe the required radiation detection equipment and state-of-the-art modeling approaches for determining radionuclide transport pathways in the atmosphere, surface water, groundwater, and soil. Methods are presented for estimating potential radiation dose to the public and natural ecosystems resulting from releases of radionuclides into the environment.

Based on my experience in assessing potential transport pathways for radiation and a review of the DEC's internal report, I find two serious flaws that must be addressed and corrected prior to any final determination related to hydrofracking in New York State. The first is that the report examined a very different type of drilling than that which is being proposed. The second is that the authors used RESRAD in a limited way, resulting in faulty conclusions.

The 1999 DEC report examines vertically-drilled oil and gas wells in New York State that have been hydrofracked. This is very different from the ***horizontal*** hydrofracking currently being proposed for New York State. Vertical wells of the type measured by the NYSDEC are typically 1500-3000 feet deep with minimal penetration into the Marcellus shale formation. Horizontal slickwater hydrofracking wells, on the other hand, reach depths of 6,000 feet before turning horizontally for an additional mile or so. These deeper, longer wells have a much greater overall exposure to the Marcellus Shale formation and the radioactive materials contained within it, and thus an increased likelihood of bringing that radioactivity to the surface. (See Figure 1)

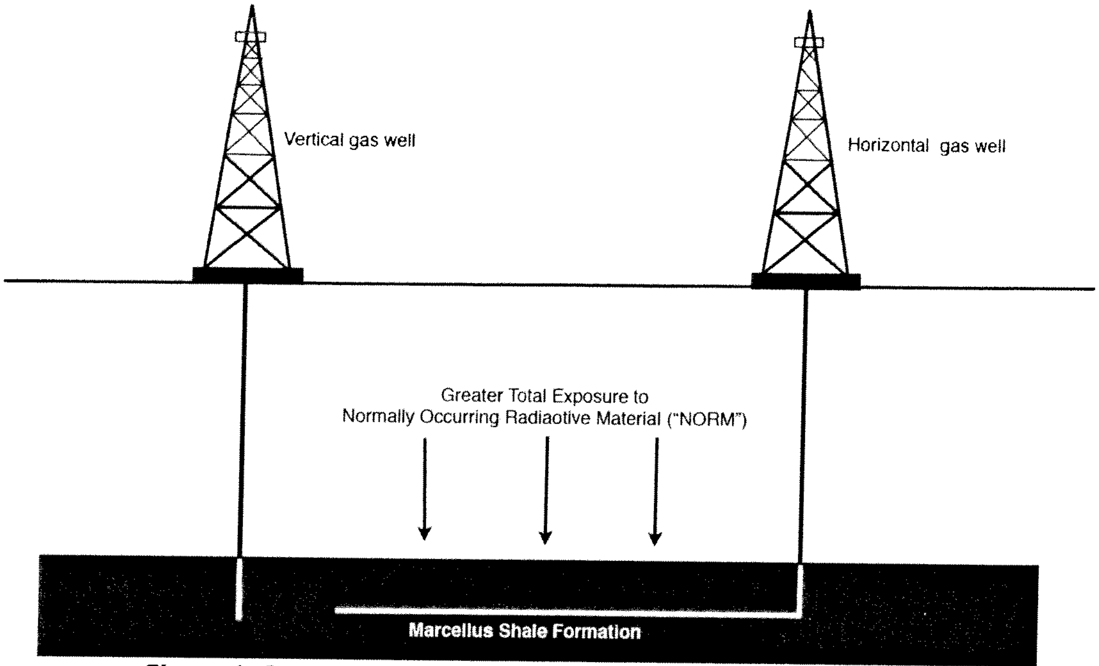



**Figure 1: Comparison of Exposure to NORM in Marcellus Shale for Vertical Wells and Horizontal Wells**

The second flaw is that RESRAD was not properly used to determine **all** of the potential pathways of the radiation. The following diagrams illustrate the potential pathways for radionuclides released into the environment in an uncontrolled manner, in air or in water.

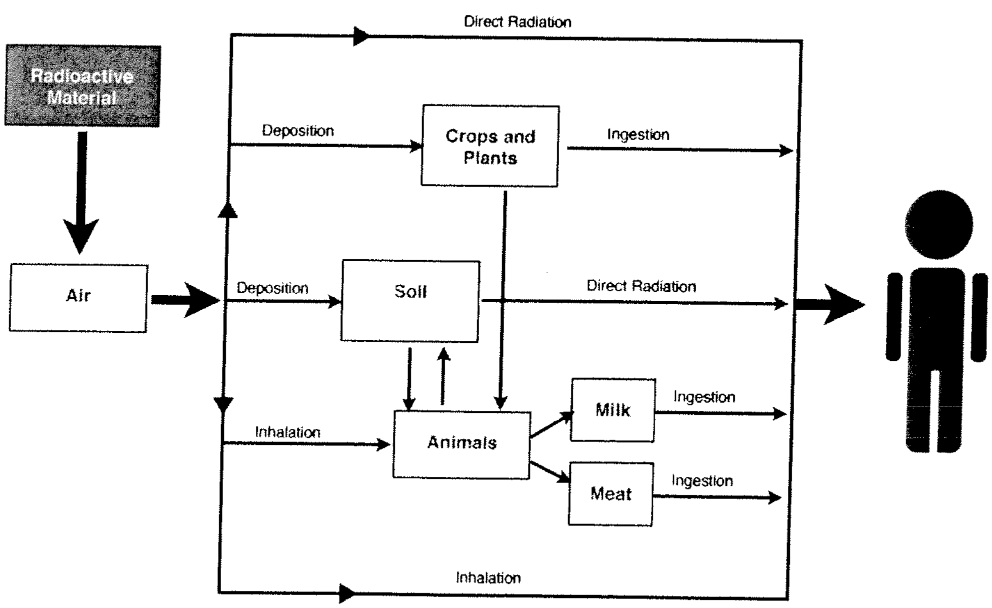



**Figure 2: Pathways for Radiation Migration Through Air**

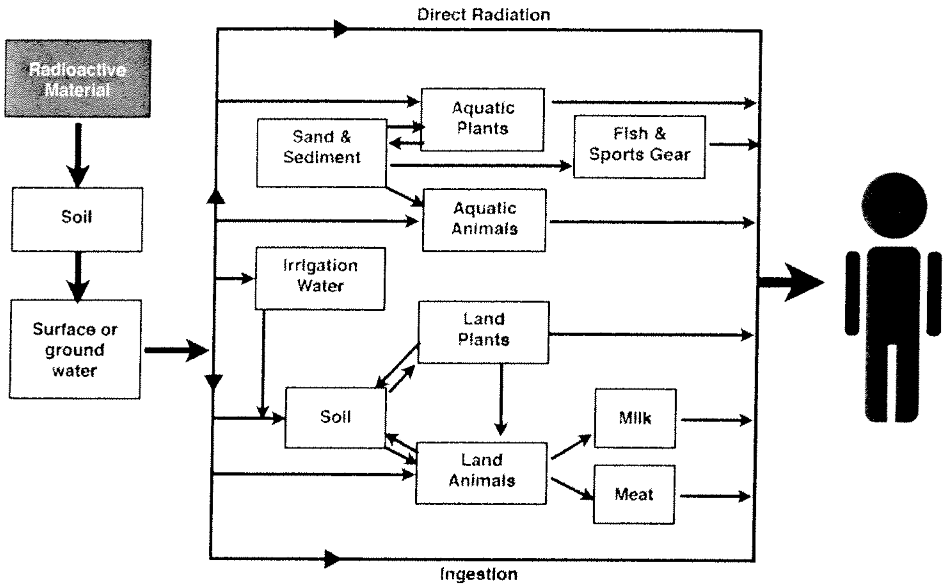



**Figure 3: Pathways for Radiation Migration Through Soil and Water**

For example, if radioactive wastewater from hydrofracking is spread on a road, there are two possible scenarios involving different pathways.

In one, the radioactive waste is spread on a paved road with a crown. Some of the waste will inevitably run off the road and find its way into a waterway or onto grazing fields or crops with the resulting pathways. The radioactivity in the waste remaining on the road will be resuspended by the traffic into the air with the resulting direct exposure to humans or biota.

In the second scenario, the waste spread on the dirt road is adsorbed by the dirt. When the dirt road dries out, the radioactive waste is resuspended in the dust from the road. The dust particle size and concentration is determined by the weight of a vehicle, the number of tires, and its speed. The dust is inhaled by humans and animals and deposited on the local vegetation, with the resulting pathways as illustrated above.

In both cases the cumulative impact of the radioactive waste will be determined by the amount of radiation contained in the waste, the number of vehicles and humans travelling on the road over years, proximity to residential or commercial areas, the amount of radiation migrating off road into streams or lakes or blowing onto agricultural land, and finally, the total potential dose to affected humans over time.

The radiation dose from a single truck travelling 40 miles per hour on a dirt road in rural New York State may appear to be insignificant, but the cumulative dose from 30 to 40 years of trucks could very easily be significant and needs to be rigorously calculated. Although there is considerable concern for the general population, exposed populations also include those most vulnerable; the old, the young and the ill.

**Importantly, the type of radioactive material found in the Marcellus Shale and brought to the surface by horizontal hydrofracking is the type that is particularly long-lived, and could easily bio-accumulate over time and deliver a dangerous radiation dose to potentially millions of people long after the drilling is over.**

Under the linear-no threshold hypothesis used in radiation protection, the goal is to limit the total radiation dose to large populations because of the increased probability of health effects. In the current case, the uncontrolled release of hazardous waste could result in the exposure of millions of people over decades.

Moreover, this scenario does not include any analysis of exposures to other hazardous chemicals used in the fracking process, which could have an unknown synergistic effect on the population.

SUMMARY CONCLUSIONS

**1. Radioactive materials and chemical wastes do not just go away when they are released into the environment.** They remain active and potentially lethal, and can show up years later in unexpected places. They bio-accumulate in the food chain, eventually reaching humans. Under the proposal for horizontal hydrofracking in New York State, there are insufficient precautions for monitoring potential pathways or to even know what is being released into the environment.

**2. The NYS DEC has not proposed sufficient regulations for tracking radioactive waste from horizontal hydrofracking.** By way of comparison, the nuclear industry has to rigorously account for all releases of radioactivity. No radioactive material leaves a nuclear facility without being carefully tracked to its safe final destination. Neither New York State nor the Nuclear Regulatory Commission would permit a nuclear power plant to handle radioactive material in this manner. (It is important to note that tracking of radioactive materials cannot be accomplished retrospectively; accurate accounting *must* be incorporated from the very beginning to ensure public safety.)

**3. RESRAD was made precisely for situations like this, but it must be used properly to produce valid conclusions.** Picking and choosing isolated scenarios and ignoring downstream exposures, as was done in the Report, is not a proper use of RESRAD and renders the conclusions invalid. All of the potential pathways over a span of decades as the hazardous material accumulates and the public's body burden build up must be considered to produce a valid RESRAD conclusion. This applies to both radioactive and chemical waste.

**4. While this statement deals only with the radioactivity of waste produced by horizontal hydrofracking, the same principles of exposure pathways must be taken into account for all of the toxic chemicals used in the process.** The EPA Pavillion Report demonstrates that there are hazardous chemicals in fracking fluid, and a recent review of the EPA report confirmed that it was valid.

E. Ivan White
October, 2012

*This report was edited for public release by Grassroots Environmental Education, a non-profit organization.*

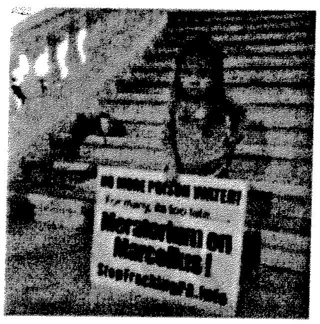
Local Voices

Liz Rosenbaum
KeepTapWaterSafe.org

# Frack Brine On Montgomery County Roads?

Posted on October 5, 2012 at 9:46 pm





***A Scary Thought***

Pennsylvania's municipal water treatment plants were designed to handle the bio solids of sewage, not the radioactive compounds contained in shale gas drilling waste. They can't handle the massive volumes of frack flowback produced in our state.

It takes 4.5 to 9 million gallons of fresh water to hydro-frack a single natural gas well. There are more than 30,000 permits awaiting approval in Pennsylvania over the next 10 years. In addition to the 8,982 frack wells currently operating in Pennsylvania, that equals 165 billion gallons of fresh water, largely from the Special Protection Waters of the Delaware River Watershed and the Susquehanna River Basin.

Once removed, this water is destined to become toxic, radioactive, frack "flowback." And, by the way, that's way more water than we actually have.

At first blush, recycling frack flowback – both onsite and at regional treatment plants – seems like the perfect solution. There's now a long list of companies who want to sell or lease their services to drillers, along with their glorified mobile distillation units. But this, too, poses new problems and raises even more questions about shale gas waste regulation and oversight. Ultimately, waste recyclers still have to deal with the disposal of the super salty waste bi-product known as brine.

So now, recycled frack brine is to be sold - at around $.05 a gallon - to PennDOT (Pennsylvania Department of Transportation) to spray on our roads for deicing in winter, and something called "dust suppression."

Seriously, dust suppression.

Untreated frack brine has been shown to include barium, radium, strontium and a range of radionuclides. Sometimes, there's even uranium. (Yes, there's uranium down there, too.) Flowback may also contain sodium and calcium salts, iron, oil, numerous heavy metals, diesel fuel and industrial soaps. And now this stuff might be on my running shoes, and the wheels of my kids' bikes. Heavy snows and spring rains will carry these compounds into our rivers and streams, lacing our waterways with toxins. Are you kidding me?

How is it, though they're using taxpayer dollars to buy this supposedly "clean" brine, that there was no public input?

Because DEP stamped a permit.

***Saline Solution***

According to Don Hopey in **PennFuture Accuses DEP of Permit Dishonesty** in *The Pittsburgh Post-Gazette*, October 5, 2012, **PennFuture** has filed a formal permit appeal with the PA Environmental Hearing Board, *"seeking to invalidate the permit and to protect the public's right to be heard **before** a permit of such public importance is issued."*

In the appeal, Hopey reports, *PennFuture* argues that *"The treatment byproducts -- crystallized sodium chloride and liquid calcium chloride -- could have 'potentially widespread impacts on public health and the environment... because the chemical salts are allowed by the permit to contain limited amounts of arsenic, lead, mercury, ammonia, volatile organic compounds and diesel hydrocarbons'."*

***DEP Pulled A "Switcheroo"***

In an email blast by *PennFuture*, *"DEP's public notice of the permit application, however, described it as seeking approval for a wastewater treatment process, not for spreading wastes generated by that process... Contrary to what DEP is saying, PennFuture is **not** attacking the practice of recycling wastewater. As our appeal makes crystal clear, we are challenging DEP's violation of its own public participation regulations."*

Obtaining public input before approving this permit would have been due course.

It appears, at the state level, Pennsylvania's Plan B is to use 165 billion gallons of Special Protection Waters to pump a frightful array of carcinogens, endocrine disruptors and other pollutants, plus loads of sand, deep down into the bedrock; and when it blasts back up at extremely high pressure, they're gonna capture it, store it, dispose of and process 100% of it with infallible machines from companies like *Seimans*, *Aquatech*, *AquaPure* and *Rolco*.

We'll simply spray whatever's left on the roads, potentially releasing toxins into our watershed.

Given a choice on the matter, I'd say, "No."

***The Ghosts of Frack Waste Past***

Frack flowback re-use accounts for about 20-30% of the total waste currently produced in the state. Out of 680 million gallons of frack waste produced in 2010, 320 million gallons were reportedly recycled, while 260 million gallons were sent to area water treatment plants, like the Eureka facility in Williamsport PA.

The rest, a highly toxic and radioactive sludge, was either transported by fleets of tanker trucks out of state, or injected back into the ground into Pennsylvania's handful of injection wells, which are underground toxic waste reservoirs. This is the practice which is reported to have caused recent earthquakes the UK, Texas and Ohio.

In 2010, at least 50 million additional gallons of frack flowback went unaccounted for in Pennsylvania, according to DEP records.

In 2009 and part of 2010, energy company Cabot Oil & Gas trucked more than 44,000 barrels of [gas] well wastewater to a treatment facility in Hatfield Township, a Philadelphia suburb. Those liquids were then discharged through the town sewage plant into the Neshaminy Creek in Chalfont, which winds through Bucks and Montgomery counties on its way to the Delaware River. [SOURCE: Associated Press, January 4, 2011]

Over a nine month period spanning 2009-2010, Cabot Oil & Gas was caught illegally discharging tens of thousands of gallons of waste into the Nockamixon Creek. Residents in Haddon Township, NJ were exposed to a massive illegal, partially treated frack water discharge in their drinking water system, and while authorities initially told residents that everything was fine, they were later informed that the release of frack brine was worse than officials had initially determined.

Indeed, these incidents precipitated the call for the gas industry to end their insane disposal habits and develop a Plan B. Nevertheless, Philadelphia Water Department Chairperson, Chris Crockett, took a passive syance, stating in ***Philadelphia Water Department Taking Measured Approach To Fracking*** by Andrew Maykuth in September, 2010, Philly.com, "*We want to take a constructive, scientific approach, not polarize people.*"

Environmental groups were outspoken in their criticism at the time.

" *'I find it sort of disappointing that the Water Department is not taking a more proactive first-do-no-harm approach,' said David Masur, executive director of PennEnvironment, the statewide advocacy group.* "

" *'I think the Philadelphia Water Department needs to be more assertive, like New York City," said Tracy Carluccio, deputy director of the Delaware Riverkeeper Network, an environmental advocacy group.* " [Source: **Philly.com**]

Two years later, much like PennFuture, these groups remain dissatisfied.

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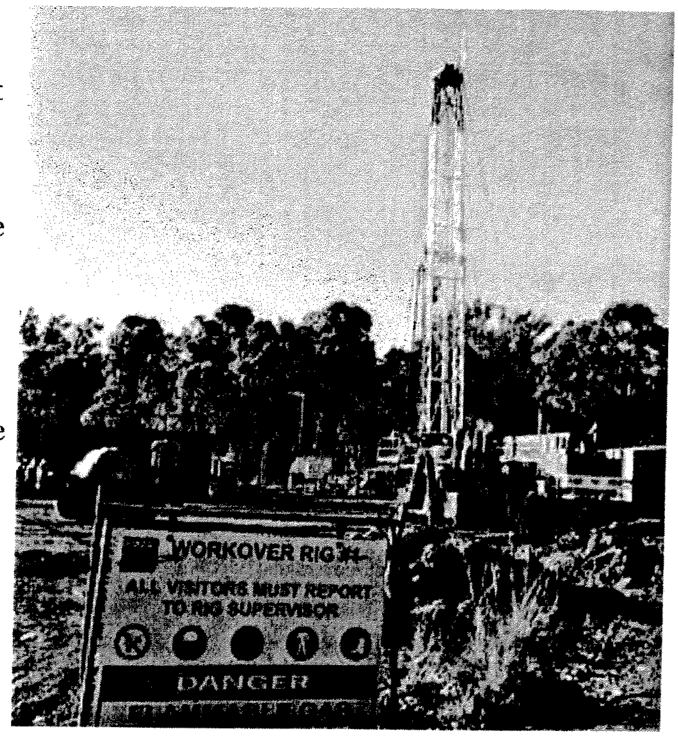
# Fracking Fatalities: Organized Labor Implores Federal Agencies to Stop the Killings

Wednesday, 06 June 2012 09:43

*By Mike Elk, In These Times | Report*

Washington - As hydraulic fracturing - also known as "fracking" - has become a more common way to extract natural gas from underneath the United States, employment in the natural gas industry has expanded dramatically. According to the Bureau of Labor Statistics, between 2003-2008 there was a 62-percent increase in the number of workers employed in the oil and natural gas industries in the United States. During this same period, the number of fatalities in the industries grew by 41 percent.



A gas drilling rig. (Photo: Jeremy Buckingham MLC)

Despite the increase in fracking sites, the number of inspections of areas being drilled has decreased. According to an analysis of more than 50,000 inspection reports by The New York Times, the number of drilling rigs rose by more than 22 percent in 2011 from the prior year, but the number of inspections at such worksites fell by 12 percent.

In a letter sent last week, the AFL-CIO, the United Steelworkers union and the United Mine Workers complain that the Occupational Health and Safety Administration (OSHA) and the Mine Safety and Health Administration (MSHA) are not doing enough to regulate the potential hazards that harm fracking workers.

"A strong effort by the federal safety and health agencies is needed to work with the industry and involve unions to ensure that these controls are properly implemented as employment in this industry sector rapidly grows," the unions and the labor federation wrote.

According to one study by the CDC National Institute for Occupational Safety and Health (NIOSH), workers in the oil and natural gas industries are seven times as likely to die on the job as workers in other industries. The three most common types of fatal accidents that those working for well-servicing companies fall victim to are motor vehicle accidents (29 percent), being struck by objects (20 percent), and explosions (8 percent).

Motor vehicle accidents are a leading cause of death among oil and gas industry workers in part because of an exemption from federal highway safety rules that allow truckers to work longer hours than drivers in most other industries. In March 2011, National Transportation Safety Board Chairwoman Deborah A.P. Hersman wrote a letter to the Department of Transportation asking the federal agency to end this exemption. Last December, the Federal Motor Carrier Safety Administration declined, saying the exemption had already "been in place for nearly 50 years."

Other oil and gas industry trucks crash due to poor maintenance. According to the Pennsylvania State Police, 40 percent of 2,200 oil and gas industry trucks inspected between 2009 and February 2012 had to be removed from the road because they were too unsafe to drive.

Those helping to pull oil and gas from the ground are also regularly exposed to cancer-causing silica dust. Fracking involves injecting large amounts of water, sand and chemicals into the ground to break up shales and bring natural gas to the surface. A large amount of the sand used in fracking often contains silica dust. A study by NIOSH found that 47 percent of all oil and natural gas workers breath air that exceeds the safe breathing limits for silica dust.

(Those mining silica sand are also affected by the dust, of course. Currently, an OSHA rule that would set safety standards on the amount of silica dust workers can be explosed to has been held up by the White House for more than a year; see my story "A Tale of Two Rules: Washington Bureaucracy and the Politics of Workplace Safety," for more on that.)

In order to reduce the number of oil and natural gas workers killed on the job, organized labor wants OSHA and NIOSH to issue a "joint hazard" alert identifying all the hazards and identify a way to deal with them. In addition, the unions want MSHA to identify increased hazards associated mining silica sand. Finally, they want the Obama administration to immediately implement the delayed rule limiting workers' exposure to silica dust.

"The development of new energy sources, and exploration of existing energy sources, must be done safely without putting workers in danger. Through extensive efforts, including effective regulation and oversight, tremendous progress has been made controlling hazards and reducing injuries, illnesses, and fatalities in coal mining and other energy related sectors," labor officials wrote in the joint letter. "We urge OSHA, NIOSH, and MSHA to apply the same kind of effort and attention to the hydraulic fracturing industry and related sectors to ensure that workers in these industries have the workplace safety and health protections that they need and deserve."

Originally published at InTheseTimes.com



## MIKE ELK

Mike Elk is a labor journalist and third-generation union organizer based in Washington, D.C. He writes frequently for In These Times, AlterNet, and the American Prospect. You can follow him on Twitter at @MikeElk.

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# Radioactivity in Marcellus Shale

Report prepared for

Residents for the Preservation of Lowman and Chemung
(RFPLC)

By Marvin Resnikoff, Ph.D.,
Ekaterina Alexandrova, Jackie Travers
Radioactive Waste Management Associates

May 19, 2010

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# 1.0 Qualifications

Marvin Resnikoff is Senior Associate at Radioactive Waste Management Associates and is an international consultant on radioactive waste management issues. He is Principal Manager at Associates and is Project Director for dose reconstruction and risk assessment studies of radioactive waste facilities and transportation of radioactive materials. Dr. Resnikoff has concentrated exclusively on radioactive waste issues since 1974. He has authored or co-authored four books on radioactive waste issues. In June 2000, he was appointed to a Blue Ribbon Panel on Alternatives to Incineration by DOE Secretary Bill Richardson.

He is a 1965 graduate of the University of Michigan with a Doctor of Philosophy in Theoretical Physics, specializing in group theory and particle physics. Dr. Resnikoff is a member of the Health Physics Society.

He has researched and written reports on radioactivity in oil and gas operations for the past 18 years. He has conducted dose reconstruction studies of oil pipe cleaners in Mississippi and Louisiana and is continuing to work on personal injury cases involving former workers and residents at the ITCO and other oil pipe cleaning yards in Louisiana and Texas. He is also presently working on several land contamination cases in Louisiana, Texas and New York involving radiological contaminants. He has conducted radioactive dose reconstruction studies of oil pipe cleaners in Mississippi and Louisiana, and of ranch hands in natural gas operations in Texas.

# 2.0 Process of Oil and Gas Drilling and Production

Since much of this discussion took place at the Issues Hearing, on April 14, 2010 in Elmira, New York, we will be brief.

## 2.1 Drilling

A vertical hole is first drilled down to the Marcellus shale formation using a rotary drill. As the drill digs deeper into the earth, additional drilling pipe is added to the wellbore. These pipes, known as a drill string when connected together, are each approximately 30 feet in length and add weight to the drill bit as it drills further through a rock formation. In order for the drill bit to drill deeper into the earth, rock cuttings generated during the drilling process must be moved out of the way and brought to the well surface. Thus, a drilling fluid is circulated through the drill string and used to bring the rock cuttings to the well surface. Drilling fluid can be a liquid or a gas or a combination of the two. Most often drilling fluid is a mud-like liquid consisting of water, clay, and chemical additives, such as scale inhibitors and biocides. Barium is also added for weight, and radium sulfate may form as well. The exact composition of drilling fluid varies from well to well and for different underground rock formations. In the case of vertical drilling to the Marcellus shale formation, pressurized air is used as the drilling fluid: the horizontal leg through Marcellus shale involves a liquid waste or slurry.

Once the vertical hole reaches the Marcellus shale formation, the direction of the drilling is transferred to horizontal drilling through the Marcellus formation. Often, one horizontal well will produce a better oil or gas reservoir than multiple vertical wells, and thus it is beneficial to drill horizontally. Most of the natural gas in the region is found within the Marcellus shale formation; thus, it is more economical and efficient for energy companies to use horizontal wells to tap directly into the stratum. It was stated at the Issues Conference that the spill waste disposed of in Elmira is coming from horizontal drilling at the Fortuna site in Bradford County.

As drilling fluid is circulated through the drill string and back up to the well surface, it mixes with rock cuttings and formation water from the underground formations. Formation water is water that occurs naturally within the pores and fractures of underground rock formations. Depending on the exact geology of a rock formation, formation water may have been present when the rock originally formed. Uranium, a radionuclide present in the Marcellus shale formation, is not soluble in water, but radium-226, a progeny of uranium, is soluble in water and can become mobilized when formation water is brought to the surface with drilling fluid and drill cuttings. Due to its prolonged existence in an underground formation, formation water can become highly concentrated in radium-226 and other radionuclides.

During horizontal drilling, a liquid drilling fluid is used to circulate drill cuttings to the well surface. Again, this drilling fluid mixes with formation water that may be highly concentrated in radium-226 and other water-soluble radionuclides. Once the gas or oil reservoir is reached and drilling is completed, casing is inserted into the newly-drilled hole and cement is forced into the void space between the walls of the casing and the rock formation. Production tubing, through which oil or gas will flow, is then inserted into the casing.

### 2.1.1 Drilling Waste Management

There is a variety of drilling waste management methods employed at the drill site that separate liquid and solid wastes before their respective disposal. Two of the most common methods in Pennsylvania involve the use of separation pits and shale shakers.

***Separation Pits*** – Drill cuttings are placed in a plastic-lined, unleveled containment pit where liquid (drilling fluid and formation water) separates from the drill cuttings and falls into one end of the pit. These fluids are pumped into a storage tank and later reused in the well hole or transported to a wastewater treatment plant. The drill cuttings are disposed of at a landfill.

***Shale Shakers*** – Drill cuttings are also dewatered via shale shakers, large sieves used to separate solid drill cuttings from liquid wastes (Figure 1). Drilling fluid and its contained wastes are passed through a vibrating screen on the shale shaker. Liquid wastes pass through the screen and are collected in an underlying basin, whereas the solid drill cuttings are retained above the screen. The shale shaker removes approximately 80% of the total liquid, which is pumped to a storage tank and can be later reused in the well hole or transported to a wastewater treatment plant. The drill cuttings, coated with any remaining liquid waste, eventually fall off the vibrating screen and are collected and disposed of at a landfill. These drill cuttings can also be mixed with sawdust or oak bark chips, creating a woody fiber mass which is transferred to a landfill.

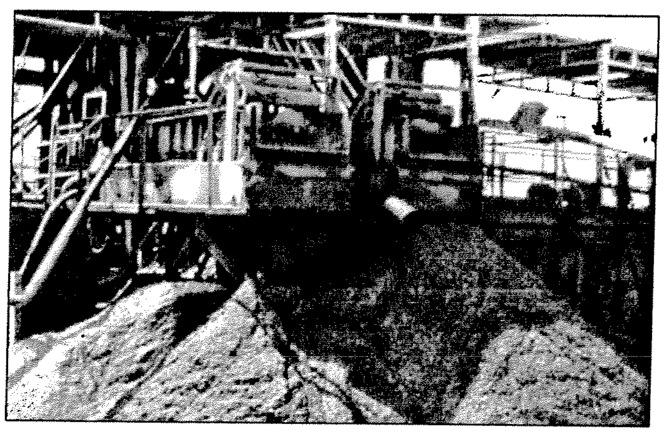

**Figure 1. Shale Shaker on an Oil Rig**

## 2.2 Production

Production is the process of extracting oil and gas from an underground hydrocarbon reservoir. Since the casing and the cement prevent access to the hydrocarbon producing zone, the casing and cement must be perforated before oil extraction begins. A special gun is used to set off shaped charges, similar to those used in armor-piercing shells, and puncture holes in the side of the casing and the cement so that the oil and gas can flow into the well (Figure 2).[1]

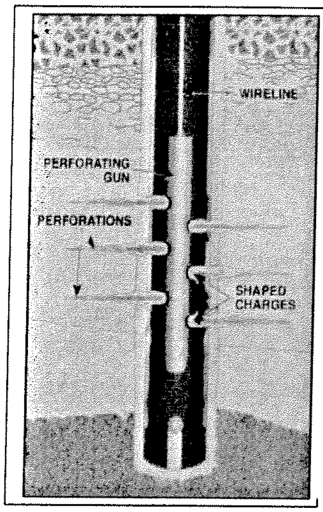


**Figure 2. Perforations Created by Charges in a Perforating Gun[2]**

As discussed above, formation water exists in the pores and fractures of underground formations, including hydrocarbon reservoirs found in such formations. Therefore, it is extracted from the formation with oil and gas as they are brought to the well surface. When produced water is brought to the surface, it carries with it dissolved solids and other compounds that may be present in the reservoir and rock formation, including Ra-226. Once the reservoir fluids are brought to the well surface, the oil, gas, and produced water are separated from each other. The oil and gas is then directed towards a pipe line, whereas the produced water is stored on site and later disposed of or injected into the underground formation.

# 3.0 Radionuclide Content of the Marcellus Shale

Radioactivity in the Marcellus shale results from the high content of naturally occurring radioactive uranium and thorium, their decay products including Radium-226, and radioactive potassium elements. The evidence of high radionuclide content is present in geochemical studies and in gamma-ray logs from wells drilled into the Marcellus formation.

In 1981 the United States Geological Survey performed a geochemical study of trace elements and uranium in the Devonian shale of the Appalachian Basin.[3] The Devonian layer refers to sediment formed 350 million years ago from mud in shallow seas. Its full profile consists of a number of strata as seen in Figure 3. Marcellus shale belongs to the Hamilton group of the Middle Devonian formation. Since the layers do not form in a line parallel to the ground surface, the depth at which Marcellus is found can vary from surface outcroppings to as deep as 7,000 feet or more below the ground surface along the Pennsylvania border in the Delaware River valley,[4] and as deep as 9000 feet in Pennsylvania.[5]

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[1] Baker, 2001
[2] Though Figure 2 shows perforation in a vertical leg, it is the horizontal leg in Marcellus shale that is punctured.
[3] Leventhal, 1981
[4] http://www.dec.ny.gov/energy/46288.html
[5] http://geology.com/articles/marcellus-shale.shtml

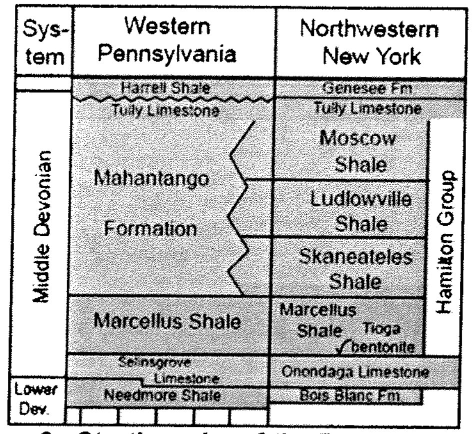


**Figure 3. Stratigraphy of the Devonian Shale**

The USGS study analyzed seventeen cores from wells in Pennsylvania, New York, Ohio, West Virginia, Kentucky, Tennessee, and Illinois. The researchers collected a variety of geochemical data to be used for resource assessment and identification of possible environmental problems. Rather than direct gamma spectroscopy employed by CoPhysics, uranium was measured in each core with a more appropriate and precise method, delayed-neutron analysis.

Although the cores varied in thickness and in depth, geologists identified the Marcellus stratum in several cores using data on the organic, sulfur, and uranium content of the samples. Table 1 summarizes the results from four cores that tapped into the radioactive Marcellus formation. The depths at which the layer was found as well as the uranium measurements are presented.

**Table 1. Uranium Content and Depth of Marcellus Shale in Four Cores**

| Location of the Core | Depth of Sample (feet) | Uranium Content (ppm) |
|---|---|---|
| Allegheny, NY | 7342 – 7465 | 8.9 – 67.7 |
| Tomkins County, NY | 1380 – 1420 | 25 – 53 |
| Livingston County, NY | 543 – 576 | 16.6 – 83.7 |
| Knox County, OH | 1027 – 1127 | 32.5 – 41.1 |

The four cores were taken from different geographical locations, but the characteristics of the identified Marcellus shale layer, specifically the layer thickness and high uranium content, are consistent. The thickness of the Marcellus shale formation varies between 0 and 250 feet, according to isopach maps. As seen in Figure 4, in Ohio and New York the Marcellus thickness is less than 100 feet, except in southeastern part of New York, where it is slightly greater.

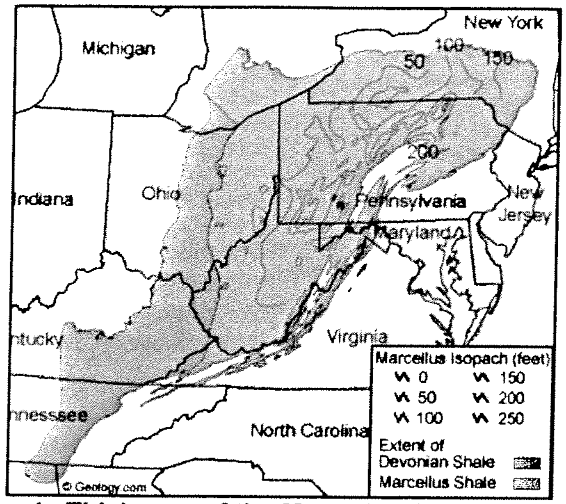


**Figure 4. Thickness of the Marcellus Shale Formation**

The thickness of the Marcellus layer in the four samples corresponds to the isopach map predictions and is approximately 123, 40, 33, and 100 feet (Table 1). Furthermore, the uranium content in the four samples is extremely high, as expected to be in Marcellus shale, and measures up to 83.7 parts per million (ppm), which is equivalent to 59.4 pCi/gram. Considering that the background uranium content in the four cores is approximately 4 ppm, or 2.8 pCi/gram, the radioactivity in the Marcellus is more than 20 times higher than background. Natural uranium radioactivity of 59.4 pCi/gram is attributed to uranium-234 and uranium-238, each of which contributes about 30 pCi/gram of radioactivity. Since Radium-226 is in secular equilibrium with U-238, it is also on the order of 30 pCi/g. These data show that the radioactivity of the Marcellus formation remains consistently high throughout.

In addition to geochemical studies, gamma ray drill logs also indicate high radioactivity in Marcellus shale. In fact, the Marcellus shale formation is *identified* using a gamma-ray detector that produces a chart of radioactivity (measured in GAPI units[6]) versus depth. Shale rock always displays a spike on such graphs, but compared to other shales the Marcellus shale formation spike is [7]substantially greater. The attached gamma-ray log (Attachment 1) shows a typical spike in radioactivity readings of >400 GAPI units, which is >24 pCi/gram and 25 times higher than background. This is consistent with DEC's findings for the radioactivity of Marcellus shale cuttings.

The gamma readings at the Marcellus shale horizon are uniform. The depth of the Marcellus shale varies, but the thickness of the formations and the uranium spike at all drill holes is remarkably consistent. We are confident that these are the radioactive levels measured in Marcellus shale.

# 4.0 Concentration of Radionuclides

As mentioned in Section 2 of this report, drilling fluid is used to remove the rock cuttings from horizontal wells in the Marcellus shale formations and to transport the drill cuttings to the well surface. The

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6 The GAPI unit is defined by a calibration facility at the University of Houston, Texas, where pits with different mixtures of thorium, uranium, and potassium are located. The unit is defined as $1/200^{th}$ of the deflection measured between the high and low activity zones in the pits. 16.5 GAPI units = 1 pCi/gram

7 NYSDEC reported in their 2009 Draft Supplemental Generic Environmental Impact Statement (DSGEIS) radioactivities for rock cuttings from two wells in Lebanon and in Bath, NY, where the total radioactivity levels were 25.4+/-4.6 and 29.2+/-4.3pCi/gram respectively, which is consistent with these findings. These radium concentrations are far higher than background concentrations in New York State (Myrik1983),which is 0.85pCi/g.

recovered solid rock cuttings, suspended in a mixture of drilling fluid and formation water with elevated radionuclide content, are placed on shale shakers and dewatered before disposal in the County landfill. However, not all of the liquid waste in which the drill cuttings are suspended will be removed.

There are several steps in the Marcellus shale drilling process that allow radionuclides, particularly Radium-226, to concentrate in liquid waste. First, drilling fluids that include various chemical additives are artificially introduced into the borehole by high pressure injection. Drilling fluids are used during the drilling process to cool and lubricate the drill bit, prevent the well hole from caving in, and circulate drill cuttings to the well surface. Formation water, or natural brine, contained within the pore spaces and fractures of the rock, through which the drill bit progresses, can mix with the drilling fluid and be circulated to the well surface. The formation water can be contained in the rock formations for centuries and can contain extremely high levels of water-soluble radionuclides that are present in the underground formations. In addition to mixing with brine, the drilling fluid may also become contaminated when it comes in contact with radioactive rock. Radium-226 is a highly water-soluble radionuclide and will preferentially dissolve in the drilling fluid under the pressure and temperature conditions below ground. Drilling fluid can be reused many times and radium will progressively concentrate in it after each reuse. Since no sources specify the radioactivity of produced water, we assume that it is the same as brine, which NYSDEC measures at 15,000 pCi/L.[8]

During the Issues Conference NEWNY proposed to exclude from disposal at the Chemung County Landfill wastes containing liquids in excess of 20%. This liquid waste is likely to contain Radium-226 and other water-soluble radionuclides.

### 4.1 NYSDEC Permit

According to the draft permit, at Condition 31(b), free liquids, sludges, slurries, chemical or industrial wastes that are at least 20% solids can be disposed of at the County landfill. This means that up to 80% of wastes disposed of at the landfill can contain free liquid, sludge, or slurry.

As mentioned in Section 2 of this report, there are currently four possible methods for managing drilling wastes at a Marcellus shale drilling site. The three disposal methods utilized in Pennsylvania, and therefore most likely to be utilized in New York, involve the use of a shale shaker, well pad, or plastic-lined pit to separate solid drill cuttings from drilling fluid, which is highly concentrated with radium-226 and other radionuclides. Since drill cuttings are suspended in liquid drilling fluid upon entering a shale shaker, well pad, or plastic-lined pit, it would be impossible to remove all of the liquid material from the surface area of the cuttings. Drill cuttings particles are roughly the same size as coarse sand and, therefore, provide substantial surface area within a small quantity of particles. As a result, a considerable amount of contaminated drilling fluid will be disposed in the Chemung County landfill with drill cuttings.

## 5.0 Impacts of Contaminated Waste Disposal

Rock cuttings enhanced in Ra-226 and deposited in the County landfill will pose several problems, which were not considered by NYSDEC.

### 5.1 Landfill Soil Contamination

Radium-226 has a half-life of 1600 years and, if deposited in the landfill, will remain there essentially forever. Landfill workers that come in contact with the contaminated materials may be exposed. Further, if the landfill is ever inhabited in the future, crops grown in the soil will concentrate radium and be ingested. Ra-226 is a carcinogen and, when ingested or inhaled, concentrates in the bone and can cause leukemia. As we noted in our April 7 memorandum, at page 4, exposures to landfill workers and

[8] NYSDEC, 2010, p. xxx

those who eat fruits or vegetables grown more than 1,000 years in the future over the closed landfill would exceed current health-based dose limits.

Our calculations show that the radiation dose from Marcellus shale drill cuttings, including the direct gamma dose, will exceed regulatory limits. Under the cleanup standards for land contaminated from inactive uranium processing sites, the EPA limits the concentration of radium within the top 6 inches of soil to 5 pCi/gram and to 15 pCi/gram at deeper depths.[9] Therefore, drill cuttings with concentrations of radium above 20 pCi/g (Table 1) would exceed these limits if deposited in a municipal solid waste landfill. Employing the standard Department of Energy software RESRAD, we find that radium concentrations of 20 pCi/g in soil lead to a direct gamma dose and ingestion of contaminated vegetation dose as high as 200 mrem/year. We assumed RESRAD default assumptions for a future resident farmer, including no earth cover in the landfill, a full-time resident, and a garden. Consumption of contaminated fruits and vegetables is the largest component of the dose.

### 5.2 Radioactive Leachate

Ra-226 is highly water-soluble and will dissolve in water under the temperature and pressure conditions present in the Marcellus shale formation and in water that is introduced into the well during the production process. The concentrations of radium in brine from the formation, or contaminated produced water, were measured by NYSDEC on the order of 15,000 pCi/L. Assuming that the Chemung County landfill accepts 2,000 tons of drill cuttings per week and that up to 20% of this waste is fluid, we estimate that up to 400 tons, or 40,000 liters, of contaminated water may be included in the waste. If we assume that this fluid contains up to 15,000 pCi/L of radium-226, then we calculate that 3.12E+11 picocuries of radium per year may be deposited into the landfill. Other assumptions may be reasonable, and the radium would not be released with leachate immediately, but we believe that NYSDEC has not adequately addressed the issue and has not completed a full analysis of the hazards presented by Chemung County landfill leachate when up to 2,000 tons per week of Marcellus shale cuttings waste is disposed in the landfill.

Several problems exist concerning contaminated liquid in the landfill. First, municipal waste landfills are lined with a layer of clay and plastic and are not designed to contain low level radioactive wastes. The leachate could mobilize radionuclides and distribute them in other locations throughout the landfill or potentially transport the radionuclides to groundwater sources outside the landfill in the event of a breach in the landfill lining. Second, the fluid will mix with leachate collected in the Chemung County landfill. This leachate with residues of radionuclides will be sent to the Elmira wastewater treatment plant, which, like the landfill itself, is also not designed to deal with radioactive waste. Radium-226 has a 1600-year half-life, so this is a long-term problem. Third, from the increasing inventory of radium-226, the landfill will generate progressively increasing volumes of radon gas over time, much of which can be expected to escape uncontrolled. As an inert gas, the landfill gas combustion device cannot control radon. Fourth, trucks transporting cuttings waste to the landfill will carry a substantial volume of liquid with the cuttings and therefore can be expected to leak on occasion. The leaking liquid is particularly radioactive and, over time, can be expected to contaminate local roadways and roadways inside the landfill site.

### 5.3 Radioactivity Detected by 375P-1000 Detector

Dump trucks transporting Marcellus shale drill cuttings from the drill sites to the Chemung County landfill will be monitored for radioactivity by a 375P-1000 radiation detector, manufactured by Ludlum Measurements Incorporated. These detectors will be placed approximately 6 feet from either side of the vehicles entering the landfill. According to Ludlum Measurements Incorporated, the 375P-1000 radiation detector will sound an alarm when it measures a radioactivity level that produces an exposure rate of 0.95 microCi per hour (μR/hr) above background radiation levels.

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9 40 CFR Part 192.12.

We used the program MicroShield version 8.02[10], developed by Grove Software, to determine the minimum radioactivity (in pCi/g) of Marcellus Shale drill cuttings that would result in an exposure rate of 0.95 µR/hr and therefore sound the alarm of the 375P-1000 detector. MicroShield is a program used to estimate dose rates due to a specific external radiation source. The program allows its user to choose from sixteen different source geometries (such as a cylinder, sphere, disk, or rectangle) and up to ten different radiation shield geometries. MicroShield users may also choose custom source and shield materials from the MicroShield database, or design their own source and shield materials with the option of over thirty different constituents. When designing a source or shield material, MicroShield calculates the attenuation and build-up factors of all constituents.

We assume that all Marcellus Shale drill cuttings transported from the drilling sites to the Chemung County landfill will be transported in 15-18 ton dump trucks. We assume that the dump body of each truck body is approximately 12 feet in length, 4 feet in height, and 7 feet in width[11,12]. In addition, we assume each dump body is constructed with two steel side walls with an inner steel wall approximately 0.188 inch thick and the outer wall approximately 0.135 inch thick (10 gauge steel)[13]. Many dump truck bodies are equipped with two side walls so that any dents, scratches, or additional damage caused by the payload to the inner wall of the dump truck body will not appear on the outer surface of the truck.

As inputs to the MicroShield program, we believe the dimensions of the dump body are best represented by a rectangular prism with the same dimensions as specified above. We accounted for the double steel walls of the dump body by incorporating two individual stainless steel shields with thicknesses of 0.188 and 0.135 inch, respectively. We assume the dump body is completely filled with Marcellus Shale drill cuttings. We placed the 375P-1000 radiation detector six feet from the side of the dump body, as this would be the detector's approximate location in reference to all dump trucks entering the Chemung County landfill. The MicroShield program allows its user to manipulate the geometric shape of the radioactive source material, but the radiation dose receptor is always represented as a single point. Since the 375P-1000 radiation detector is not a point but a cylindrical tube with a height of 183 cm and a diameter of 20 cm[14], we assume that the height of the center of the 375P-1000 detector would be located at the same height as the center of the dump truck body and calculate the radiation doses that would be detected at the top, center, and bottom of the detector.

Shale is not a custom source included in the MicroShield database and we therefore designed our own source material to best represent the Marcellus Shale drill cuttings. We assume that the shale is comprised of mostly quartz ($SiO_2$) calcite ($CaCO_3$) and has a density of 2.35 grams per cubic centimeter ($g/cm^3$)[15]. Although Marcellus Shale drill cuttings will contain radioactive uranium-238 (U-238) and all of its gamma-emitting progeny, we only calculate the exposure rate caused by radium-226 (Ra-226). Ra-226 is soluble in water and will concentrate in any residual water transported with the drill cuttings into the dump truck body.

The MicroShield program calculates exposure rates, in millirads per hour (mR/hr), which result from the radioactivity of any given source. In order to estimate the radioactivity of Marcellus Shale drill cuttings based on exposure rates, we calculated the radioactivity of Marcellus Shale needed to produce an

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10 Grove Software Incorporated, 2008
11 Valew Truck Bodies, 2009
12 John Deere, 2010
13 Valew Truck Bodies, 2009
14 Ludlum Measurements Inc., 2009
15 University of Melbourne, 2003

exposure rate of 0.95 µR/hr. The relationship between external gamma radiation and exposure rates is linear. Based on the exposure rates of Marcellus Shale drill cuttings with Ra-226 concentrations of 50, 150, 500, and 1,500 pCi/g, we calculated that the Ra-226 concentrations in Marcellus Shale that produced a reading of 0.95 µR/hr are 2,340 pCi/g measured at the top and bottom of the 375P-1000 detector and 2,043 measured at the center of the detector.

As previously discussed, the County landfill will accept 2,000 tons of Marcellus shale drill cuttings with up to 20% of contaminated water. Since the rock cuttings and contained fluid is far less than the estimated sensitivity of the detectors, the radioactive scale cuttings, with up to 20% contaminated water, may not be detected.

# 6.0 Issues in the CoPhysics Report

The CoPhysics report, commissioned by Fortuna, concludes that the rock cuttings are only 2 to 3 times above background radioactivity levels.[16] However, they make several major mistakes in their methodology.

First, they claim the use of EPA 701.1 measurement protocol in their analysis. The EPA 701.1 protocol is a method used for gamma detection in radioactive materials dissolved in water and is not to be used for measurement of a solid. To measure the radionuclide content in a solid, the material must be dissolved in acid. Ra-226 is then chemically separated detected by measuring emanating radon.

Second, the CoPhysics study does not measure radium directly and instead measures a surrogate. For the detection of thorium-232, CoPhysics measures actinium-228, a decay product with strong gamma emission, which is acceptable since the two radionuclides are in secular equilibrium and since processing does not alter this equilibrium. However, this is not the case for radium, which selectively dissolves in fluid during the drilling process. Thus, use of bismuth-214 as a surrogate for radium-226 in the report is not permissible.

Lastly, it is not clear where the measurements were taken and whether any processing took place before the gamma detector readings. The CoPhysics report does not state whether the rock cuttings were taken from a horizontal or from a vertical bore hole. Under the temperature and pressure conditions that exist in a deep hole, the introduction of liquids into a horizontal well, enhances Ra-226. Since it was stated at the Issues Hearing that the Fortuna site in Bradford County uses horizontal wells, the study should have also analyzed rock cuttings from horizontal wells.

# 7.0 Conclusions

1. The hazard associated with the disposal of incompletely dewatered Marcellus shale drill cuttings and drilling fluid in a municipal landfill has not been fully evaluated by NYSDEC. The Marcellus shale has elevated radioactive concentrations, approximately 25-30 times above background concentrations. The drilling and dewatering processes enhance the concentration of radium in the drilling fluid. Rock cuttings that hold up to 20% of this fluid are still considered solid waste and will be disposed of in the County landfill. The introduction of this radioactive material into the landfill will give rise to serious problems due to the generation of radon, radiologically contaminated leachate and to potential reuse of the site in the future. NYSDEC regulations regarding the radiation doses from a decommissioned site and the allowable concentrations of radium in soil will be exceeded. In our opinion, these radioactive rock cuttings and associated radioactive drilling fluids belong in a radioactive landfill, such as the Envirocare landfill in Clive,

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[16] CoPhysics Corporation, 2010

Utah. Radium-contaminated waste is similar to U mill tailings, which the Utah landfill is designed for.

2. Major uncertainties have not been resolved. The findings of the CoPhysics report conflict with borehole gamma readings and with the independent measurements of the USGS. The CoPhysics report does not explain where the cuttings were found and processed. The measurement methodology, EPA 701.1, and the use of a surrogate Bi-214 to measure Ra-226 are not appropriate for this case.

3. Worker exposure to radioactivity at the working face of a landfill that disposes such waste can be expected to exceed health-base dose limits set by EPA and NRC.

4. The waste at issue can be generated only by means of industrial processes in two gross phases: (a) fluids with chemical additives are forced into subterranean shale formations under high pressure, where they leach out NORM, making the fluids much more radioactive than they were before injection; solid waste is generated from the return waste water only by means of another set of industrial processes, including a shale shaker, centrifuge, and perhaps other mechanisms.

5. The drilling fluids that provide the source for the solid waste are chemically changed by pressurized contact with NORM, concentrating the NORM in the fluids. For example, barium is added to drilling mud pumped into a horizontal wellbore in order to extract radium sulfate from cuttings. This solid may be disposed of with the rock cuttings.

6. Based on RESRAD calculations, the radiation exposures received by a future resident farmer will exceed allowable regulatory limits. The radium concentrations in soil will exceed EPA regulatory limits. NYSDEC has not examined the environmental and health and safety implications of disposing of shale cuttings in a solid waste landfill. In our opinion, the radioactive scale cuttings and fluids are more appropriately deposited in a radioactive landfill designed for this disposal.

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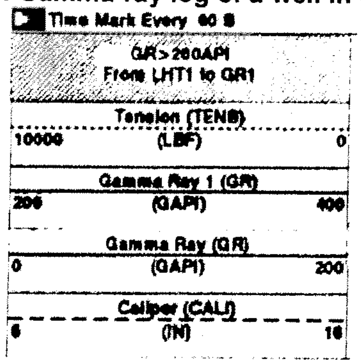
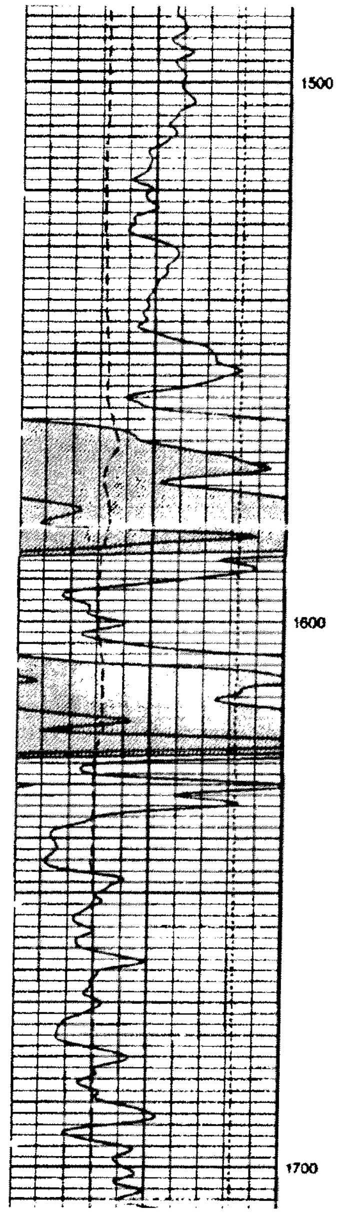
Attachment 1. Gamma-ray log of a well in Shiavone, NY

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SOUTHERN ILLINOIS UNIVERSITY

# THE CHALLENGES OF SHALE GAS PRODUCTION

Prepared for Geology 524, ADVANCED SEDIMENTARY GEOLOGY

[redacted]

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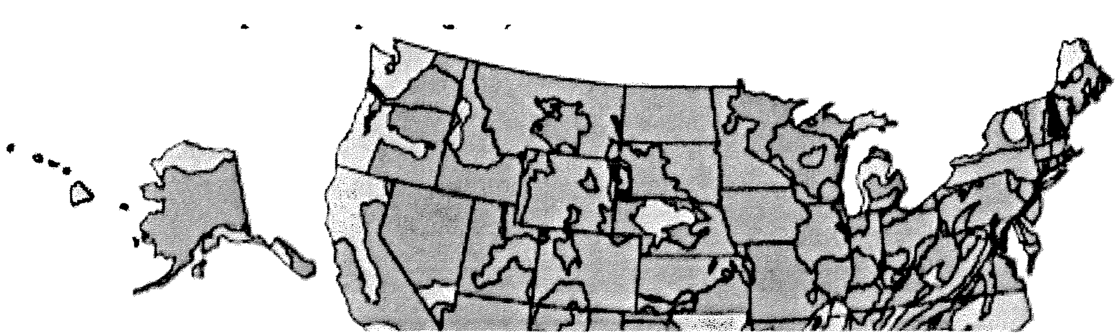
## 1. INTRODUCTION

The risks posed by the production of shale gas to human health and the environment have been recently receiving much attention from a concerned public and the media. Those risks include, but are not limited to, contamination of drinking water aquifers (either by hydraulic fracturing fluids, natural gas, or produced waters), improper disposal of high salinity wastewater and drill cuttings, induced seismicity, overuse of groundwater supplies, increased local air pollution, and exposure to elevated concentrations of radionuclides (Kargbo et al., 2010). This paper will address these risks, with special attention to the risks associated with naturally occurring radioactive material (NORM).

The health risks associated with NORM have been known about for many years. Radon, a Class A carcinogen formed from the decay of naturally occurring uranium, has been proven to cause lung cancer both within the mining industry, as well as in long term residential exposure, where it can seep into the interior of homes and concentrate (Lyle, 2007). Average concentrations of radon are shown in Figure 1. However, the health risks associated with the production of oil and gas from black shales, which are widely known to have elevated NORM concentrations (this fact is used to locate oil and gas source rocks using gamma ray logs), have not been as widely studied. Given the current prolific expansion of gas production in the United States, the risks associated with the disposal of shale cuttings, produced water, and technologically enhanced naturally occurring radioactive materials (TENORM) need further review.

## 2.NORM IN BLACK SHALES

The three main radioactive elements found in the earth's crust that contribute to natural background radioactivity include uranium, thorium, and potassium (and their decay products) (Rahon, 2010). The background range of these elements is 0.5 to 1 pCi/G each (Rahon, 2010). Natural radiopotassium (K-40) is ubiquitous in the environment, and is thus not usually regulated (Rahon, 2010). Naturally occurring uranium can be found in rocks, soil, and ground water (Felmelee and Cadigan, 1979). The average crustal abundance of uranium is 2.5 parts per



million, and it can be found within all rocks (Lyle, 2007). In an oxidizing environment, it is easily weathered into solution and can be transported long distances (Lyle, 2007). When it reaches a reducing environment, such as the environment in which black shales are deposited, it can become enriched in the sediment (Lyle, 2007). The depositional environment of black shales is also usually associated with high concentrations of phosphate, which can combine with uranium and concentrate it in the shale, sometimes as phosphate nodules or layers within the shale with high enough uranium concentrations that they can be economically mined (Plant et al., 1999). The clay minerals that are deposited in these types of environments can also form weak bonds with uranium, and may contain between 1 to 3 pCi/g (Lyle, 2007; Rahon, 2010).

# 3. HEALTH AND ENVIRONMENTAL RISKS ASSOCIATED WITH SHALE GAS PRODUCTION

### *3.1 NORM in Oil and Gas Production*

The natural gas recoverable from shale units in the United States is estimated to be over 1,744 trillion cubic feet (Kargbo et al., 2010). Some of the main shale units currently producing gas include the Barnett Shale, Haynesville/Bossier Shale, Antrim Shale, Fayetteville Shale, New Albany Shale, and Marcellus Shale (Kargbo et al., 2010). Due to the public concern over the impacts of hydraulic fracturing, some of these shale units have become household names over the past few years. The NORM constituents of concern from these units include uranium, thorium, and their products radium-226 and radium-228 (EPA, 2008). The initial concern had been the exposure of the general public to shale cores and cuttings. However, in 2009, the New York Department of Environmental Conservation (NYDEC) tested various sites and determined that cuttings and cores are of low exposure concern for either oil and gas workers or the general public. A similar study by Rahon (2010) found similar results for drill cuttings in Pennsylvania, and declared them safe for landfill disposal. The same study did, however, warn that gamma ray detection systems be installed so that only drill cuttings, and no pipe scale, filtrates, or sludges are "inadvertently" disposed. A more recent report by Walter et al. (2012) indicates that if these wastes are disposed of (along with sludge from treated drilling wastewater) in municipal solid waste landfills, biogas generation within the landfills could re-emit radon back into the atmosphere at levels exceeding those allowable for uranium mill tailings.

Brines brought to the surface during the production of oil and gas have also long been known to have elevated concentrations of NORM (Gundersen and Szabo, 1995; Lyle, 2007). A recent report from the NYDEC (2009), which has received a lot of media attention, indicated that thirteen samples of Marcellus shale wastewater contained 267 times the safe disposal limit of radium-226. TENORM is of special concern in regards to produced water because high concentrations of radionuclides can be precipitated as scale in pipes (see Fig. 2) and drilling equipment or in sludge in disposal pits (Kargbo et al., 2010). The U.S. Environmental Protection Agency (USEPA) has measured values of radioactivity ranging from 9,000 picocuries per liter (pCi/L) for produced water to over 100,000 pCi/g (picocuries per gram) for pipe and tank scale (NYDEC, 2009). Acceptable dose limits for radioactive exposure seem to vary between government agencies (Nuclear Regulatory Commission (NRC), U.S. Department of Energy (USDOE), and the U.S. Environmental Protection Agency (USEPA)), from tens to 5,000 mrem (NYDEC, 2009). A standard way to measure/calculate the dose limits from TENORM is needed.

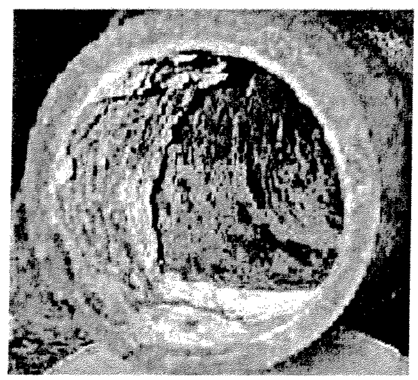


**Figure 2. An example of a TENORM scale deposit. From http://t3.gstatic.com/images?q=tbn:ANd9GcRfsbEUlLaQS5ex3-voKFmRdfuD2xUpwo0nu9WfS74-RbqC_Xc7Ug**

### *3.2 Contamination of Groundwater*

Some geologic risks associated with drilling for shale gas include gas blowouts (a problem whenever drilling for oil and gas), the disruption of aquifers, ground subsidence, and the triggering of small earthquakes, often referred to as induced seismicity (Kargbo et al., 2010). One of the main concerns expressed by the general public is the contamination of aquifers used for drinking water. Contaminants of concern include both the produced natural gas and the fluids used in hydraulic fracturing. A major criticism of the gas industry has been their secrecy about the constituents of "fracking" fluid, on which they perform a great deal of research (Kargbo et al., 2010). Since hydrofracture fluid formulas are not included in the Safe Drinking Water Act, they currently cannot be controlled by the U.S. Environmental Protection Agency (EPA) (Kargbo et al., 2010). These fluids generally include (in addition to water) proppants, gels, acids, biocides (to prevent microbial growth), scale inhibitors (prevent the precipitation of carbonates and sulfates), and surfactants (to increase fluid recovery) (Kargbo et al., 2010). Proppants are used to hold fractures open after pressure is released; common proppants include quartz sand or ceramic material (Kargbo et al., 2010). Kargbo et al. (2010) states that one of the most difficult challenges in hydraulic fracturing is to create fluids that are both environmentally friendly and can suspend proppants for a long period of time.

Some dangerous chemicals reported to be present in hydrofracture fluids include hydrochloric acid, muriatic acid, hydroxyethyl cellulose, glutaraldehyde, petroleum distillate, ammonium bisulfate, 2-hydroxy-1,2,3,-propanetricaboxylic acid, N,n-dimethyl formamide, ethylene glycol (2-butoxyethanol), methanol-based surfactants, fluorocarbons, naphthalene, butanol, and formaldehyde (Kargbo et al., 2010). Some of the chemicals listed are carcinogenic; others are toxic, with a variety of health effects including problems with the eyes, skin, lungs, intestines, liver, brain, and nervous system (Kargbo et al., 2010). In addition to the risk from hydraulic fracturing fluids, produced water from the formations can include toxic metals, high concentrations of salt, and radionuclides (Kargbo et al., 2010). Regulations regarding the disposal of formation water and hydrofracture wastewater are different between states, but common practices include open pits for evaporation and sending waste to wastewater treatment plants (Kargbo et al., 2010). Since the total dissolved solids in hydrofracking wastewater can exceed 200,000 mg/L, and wastewater treatment plants are not informed of the chemicals used in hydrofracking, the ability to sufficiently treat the water is reduced (Kargbo et al., 2010).

The most publicized incident of groundwater contamination occurred in Dimock, Pennsylvania, which was made famous following the release of the *Gasland* documentary (Kargbo et al., 2010). Following drilling by Cabot Oil and Gas, residents began reporting the presence of natural gas in their water (see Fig. 3) (Kargbo, et al., 2010). Improper cementation of Cabot's well casings was discovered during an investigation by the Pennsylvania Department of Environmental Protection (PADEP) (Kargbo et al., 2010). Therefore, this incident (and others, including small explosions within homes) was not attributed to hydraulic fracturing, but to the improper casing of the well.

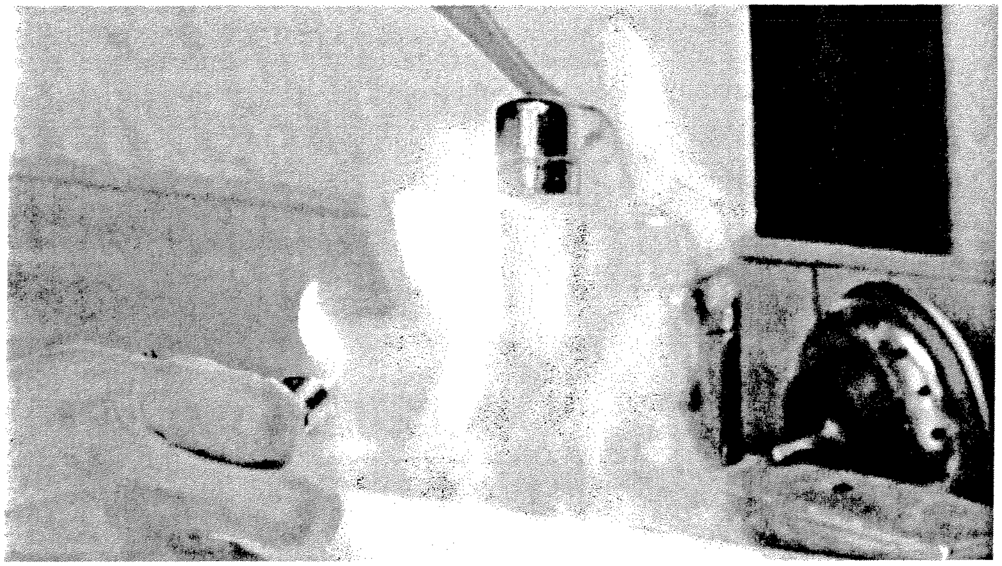


**Figure 3. Dimock, Pennsylvania resident igniting gas flowing from a kitchen faucet. From http://www.earthrights.org/ blog/fracking-really-freaks-me-out**

### *3.3 Overuse of Groundwater Supplies*

One of the growing concerns regarding hydraulic fracturing and shale gas drilling in general is the amount of water it takes to complete a well. It is generally too expensive for drillers to transport water to the well site, so they draw water from nearby streams or groundwater (Kargbo et al., 2010). Each well, depending on depth and permeability of the formation, can consume from 2 to 10 million gallons of water (Kargbo et al., 2010). In regions that are already water-stressed, this can have a significant impact on water supplies.

### *3.4 Increased local air pollution*

Another problem that may become a major challenge as gas production increases around the country is the release of volatile organic compounds (VOCs). The release of methane, carbon dioxide, and VOCs has already been blamed for reduction in air quality and the increase in ozone around gas producing areas of Texas, Wyoming, and Colorado (Kargbo et al., 2010). These pollutants are released from both gas processing plants and diesel trucks (Kargbo et al., 2010).

## 4.0 POSSIBLE SOLUTIONS

### *4.1 NORM in Oil and Gas Production*

It is clear that more research is needed on the safe disposal of cuttings, wastewater, and equipment that have elevated levels of radioactivity. The NYDEC has proposed that wastewater be measured for radioactivity before transportation away from the well site, which would require the workers to be licensed and tested for radioactive exposure (Kargbo et al., 2010). While the exposure of oil and gas workers to TENORM has been known about for decades, companies were hesitant to acknowledge that fact (Steinhausler, 2004). The situation has improved since the International Commission for Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) expressed concern over TENORM concentrations (Steinhausler, 2004). Smith et al. (1996)found that the injection of NORM wastes underground with downhole encapsulation is of little risk to the public, and that states should permit such injection wells more readily. The same report also called for more research on the safety of the common practice of "land-spreading" NORM wastes, such as spraying produced waters on roads to reduce ice buildup.

### *4.2 Contamination of Groundwater*

To reduce their environmental impacts, companies have been searching for either an alternative to hydraulic fracturing, or less toxic hydrofracture fluids. Some companies have been testing mineral or plant-based oils in place of diesel (Kargbo et al., 2010). However, more research is needed to find adequate replacements for the various chemicals needed for successful hydraulic fracturing (Kargbo et al., 2010). A couple of examples of new technologies that could reduce the impact of shale gas production include the use of liquefied petroleum gas (LPG) and the DryFrac technique. GASFRAC Energy Services is experimenting with LPG, which is essentially gel propane produced during the processing of natural gas that can fracture the shale and transport the proppants into the fractures (Lustgarten, 2009). Since the LPG is recollected when it is pumped out of the well, the process generates no fracture fluid wastewater (Kargbo et al., 2010). The success of the second example, DryFrac, has been demonstrated extensively in Canada and by several U.S. Department of Energy projects (Mazza, 1997; Smith, 2008). This technology also does not use water, relying on liquid carbon dioxide to act as the carrier fluid for a sand proppant (Kargbo et al., 2010). It has been tested by Universal Well Services in several wells in both eastern

Kentucky and western Pennsylvania (Kargbo et al., 2010). With DryFrac, gas production may be up to five times greater than conventional technologies (Kargbo et al., 2010). One problem with the DryFrac method is the formation of ice in the wells, which may be reduced by the addition of nitrogen gas, making the process even less expensive (Gupta and Bobler, 1998). As with enhanced oil recovery and carbon capture and storage, the lack of carbon dioxide pipeline infrastructure is the main challenge for this technology (Kargbo et al., 2010).

The disposal of wastewater is also being addressed. One option is to re-inject the wastewater deep underground, where the fluids are not at risk of contaminating aquifers (Kargbo et al., 2010). Other options include treating the water on-site, such as the sequential precipitation process currently being developed by ProChemTech (2008), the advanced GE Thermal Evaporation process from STW resources (Green Car Congress, 2007), or distillation-crystallization (Swistock, 2009). However, these technologies have not yet been tested on a large scale (Kargbo et al., 2010). As mentioned previously, treating wastewater with high concentrations of dissolved solids is still problematic and expensive, and more cost-effective technologies are required (Kargbo et al., 2010).

### *4.3 Overuse of Groundwater Supplies*

There are a few proposed solutions to increase water conservation during shale gas development. The first is to reuse the wastewater as hydrofracture fluid (Kargbo et al., 2010). This solution, while reducing water usage and overall pollution, is problematic due to the high concentration of elements (barium, calcium, iron, magnesium, manganese, and strontium) that easily form scale as well as precipitates that can block fractures (Kelster, 2009). Another option is the use of treated water from acid mine drainage from old coal mines, of which there is a large amount, and which eliminates the problem of where to dispose of the treated water (ProchemTech International, 2009). Kargbo et al. (2010) strongly encourages the creation of best management practices (BMPs) for the conservation of water during shale gas drilling, such as those developed in Texas by companies drilling in the Barnett Shale.

### *4.4 Increased Local Air Pollution*

Gas companies have begun to employ a variety of measures to reduce emissions of methane and VOCs (Kargbo et al., 2010). These include switching from diesel fuel to natural gas (85% reduction in VOCs), the use of high paraffinic (reduced toxicity) fluids instead of diesel in hydrofracking fluids, various gas detection methods to find and fix any leaking wells and pipelines, and the extension of pipeline networks to reduce trucking (Fefer, 2003; Kargbo et al., 2010).

## 5.0 CONCLUSION

It is clear from the available research that there is still much work to be done in terms of investigating the safety of shale gas drilling/production. There are a variety of health and environmental risks associated with shale gas development including exposure to radionuclides, air and water pollution, and water overuse, as well as the geological risks of subsidence, gas blowout, or induced seismicity. In addition to the measurement of baseline groundwater values (so that any future detrimental changes due to drilling can be easily recognized), clear and reasonable regulations should be in place before drilling begins. The cementing of well casings should be checked at various points during drilling to ensure the prevention of gas (or hydrofracture wastewater) leakage into drinking water aquifers. The radioactivity of wastewater and of pipes/equipment with TENORM scale should be monitored, and the health of oil and gas workers taken into consideration. The development of new, safer gas production technologies should be encouraged, as well as the use of less toxic ingredients in hydrofracture fluid mixtures. Finally, the components of hydrofracture fluids should be made available to the EPA as well as wastewater treatment facilities so that any leaked contaminants can be monitored and remediated.

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