Hydraulic Fracturing Risk Determination for US Counties

Final Report

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Introduction

In the United States, exploitation of shale gas and other unconventional hydrocarbon resources has greatly expanded over the past few years due to the recent combination of two oilfield technologies: horizontal drilling and hydraulic fracturing, often referred to as "fracking." This activity has enabled economical production of resources that were previously inaccessible, due to the ability of fracturing to expose large areas of shale reservoirs and the relatively minimal well construction requirements afforded by horizontal drilling. The basic idea of hydraulic fracturing – in the US, specifically – involves injecting a fluid known as "slickwater" into a formation with very low permeability (often shale, but formations with different mineralogy are also exploited) at high flow rates and high pressure, causing the hydrocarbon-bearing rock to crack and form complex fracture networks. Once the fluid is flowed back from the subsurface, gas is free to flow out of the formation rock to surface production infrastructure.

The recent explosion in fracturing activity, juxtaposed with the US goal of energy independence and the environmental risks associated with fracturing, has garnered much attention in academia, industry, and mass media, and led to much debate about the risks versus gains. Economically, the development of shale gas reserves has proven fruitful for the US energy sector, keeping natural gas prices low while reducing dependence on hydrocarbon imports. It is estimated that there is as much recoverable gas in US tight shale reservoirs as the total amount of conventional gas discovered in the past 150 years (Engelder, 2011). Many industry experts have asserted that, if managed and regulated properly, the fracturing industry can allow the US to achieve greater energy independence and economic security with minimal environmental risk.

Conversely, the environmental risks and challenges resulting from fracturing are myriad, and include air pollution (from both methane leaks and flaring, as well as truck traffic), habitat fragmentation, and many water-based issues: large volumes of high-salt content flowback and produced water (and difficulty of treatment/disposal), potential aquifer contamination from methane leaks in well casings, overflowing of surface impoundments that could affect ground and surface waters, and the large draws of fresh water necessary to undertake operations. As mentioned before, the vast majority of US fracturing operations use slickwater, which consists of over 99.5% water by fluid volume (Jenkins, 2012). The remainder of the clean (no proppant/sand added) fluid is made up of chemical additives that aid in the treatment, including friction reducers, clay stabilizers, and corrosion inhibitors.

In addition to the variety of risks that fracturing produces, these are all exacerbated when the activity is based near population centers, thus putting many more people at risk from potentially deleterious consequences. Figure 1 shows a brief schematic of fracturing risks (Howarth, 2011).

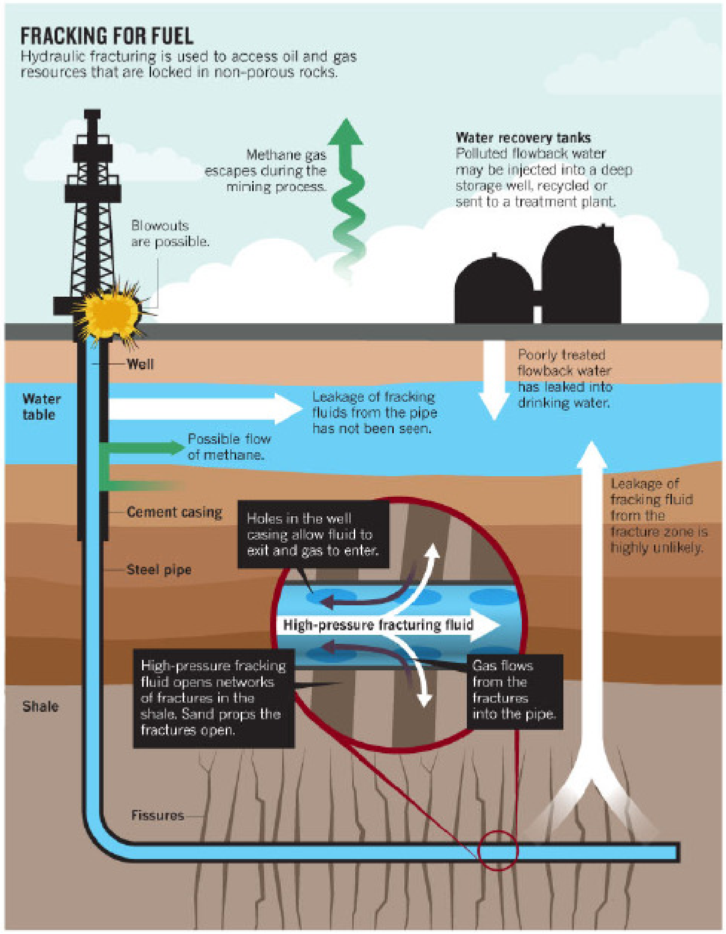

Figure 1 - Schematic of Fracturing Risks (from Howarth 2011)

Since the boom in hydraulic fracturing activity has happened so quickly, legislators and regulators are still in the process of determining how best to control the industry based on economic and environmental studies. Therefore, since not all new necessary legislation can happen simultaneously, it would be prudent to concentrate efforts in regions that would be the most at risk.

Objectives

The main objective of this project is to determine which regions in the US are the most at-risk from the boom in hydraulic fracturing activity, given a set of criteria that can determine the risk based on the most plausible and concerning environmental hazards. Preferably, this determination should be done on a large scale across the country, as well as giving the ability to single out individual counties with the highest potential risk. Once these areas have been highlighted, the legislation in place there would be assessed to address whether improvement is needed in these target regions and counties. As to the factors that were selected to determine this risk, the most important were deemed to be proximity to depleted aquifers, activity density in the shale play, and proximity to centers of high population density.

Heavy Water Usage

Slickwater fracturing – though often less expensive than traditional gel fracturing treatments and more effective when injecting into low permeability reservoirs – requires large quantities of water due to the high injection rates that must be used to allow proppant (sand) to be carried. It is this aspect of the treatment design (as well as the multiple stages and treatments in each well) that requires so much fresh water; brackish or recycled water generally cannot be used due to the inability of friction reducers (critical additives) to function properly (Aften, 2010). Due to this, fracturing operations in water-scarce regions can contribute to the depletion of fresh water aquifers. In addition to the depletion of fresh water, flowback and production water stored in surface impoundments has the potential to overflow in a storm event, thus contaminating any underlying unconfined aquifers. Therefore, any fracturing that takes place within a stressed aquifer's area can be considered to be both an environmental and public health risk.

High Activity

Though some shale plays are newly developing and have only seen a few fracturing treatments (such as the Antrim basin in Michigan), the more established basins have variable activity over their areal extent. For example, the shale formations on the east coast – including the Marcellus and Devonian basins – have very heavy activity in states where fracturing is permitted, but no activity at all in New York and minimal work in West Virginia and Ohio. This factors in to the risk that is prevalent in various counties: simply having a shale play does not necessarily mean that the area has a potential for environmental damage. Therefore, a higher focus is given for high-activity shale plays.

Population Density

As stated before, one of the reasons for the controversy surrounding fracturing is its often close proximity to areas of higher population density that have not recently experienced such rapid industrial growth. Western Pennsylvania, the Dallas-Fort Worth metroplex, and Denver have experienced quick growth in the industry, and when combined with the close proximity to large populations reliant on clean ground and surface water, this creates a risky situation. Basically, if a surface impoundment were to overflow in western Wyoming, very few people would be affected – however, contamination of the Ohio River in the Marcellus shale area would have a much greater effect.

Methodology

Data Sources

To assess what regions of the US are most at risk from hydraulic fracturing activity, I mapped the various risk factors across the country – dense population proximity, depleted aquifers, and high-activity shale plays. The aquifer data was obtained from the US Geological Survey (USGS); both aquifer areal extent polygons and well level data points were used. For shale gas information, I used polygonal delineations of US shale gas plays as determined by the USGS; I could have used polygons for tight gas, tight oil, and general hydrocarbon formations, but this would have actually covered most of the US. I instead opted for just the shale gas polygons, understanding that the Bakken shale in North Dakota would not be represented. I will address concerns for this area later in the report, but adding it as part of a data set was not practical for this exercise, since it is not considered a shale gas play. For population density determinations, I used the TIGER database for US county delineations and populations.

Information on where and when fracturing treatments take place is available through the FracFocus project, which aims to provide greater transparency of the fracturing industry. However, this requires registration and is technically only for organizations to sign up for, so that route was not possible in this project. Instead, the SkyTruth website contains data from FracFocus and organizes it for use in ArcGIS. From this source, I was able to download the location of every fracturing job for the past three years in the continental US, as well as the date it was performed. Only this time period was used because it represents the bulk of the most pertinent fracturing jobs, and because prior to this time period most operators did not report this data.

GIS Processing

The first task in this project was to transform the data into the correct coordinate system (1983 North American GCS) and visualize the extent of the various factors. First, the aquifers and USGS monitoring wells were projected onto a topographical base map. To pare down the amount of aquifers shown, I used the Spatial Join tool to combine these into a single feature class, and then determined a first-order "aquifer health" based on the monitoring wells' deviation from the normal water level. Basically, if a well's water level is higher than it has been the past few years (which is how USGS codes each well's data value), it is considered a healthy aquifer, and therefore would be on the "high" end of the scale, as

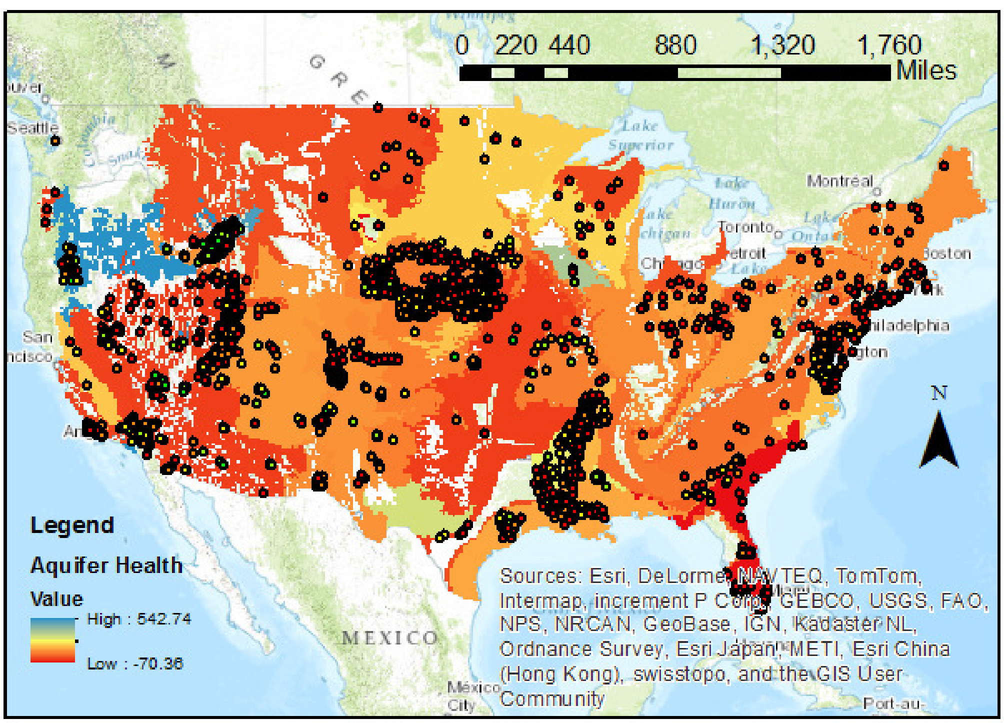

Figure 2 - Aquifer Depletion per USGS

seen in Figure 2. As can also be seen, the vast majority of aquifers that are being monitored are relatively depleted, meaning this is more of a blanket factor and would not necessarily be good for targeting particular regions.

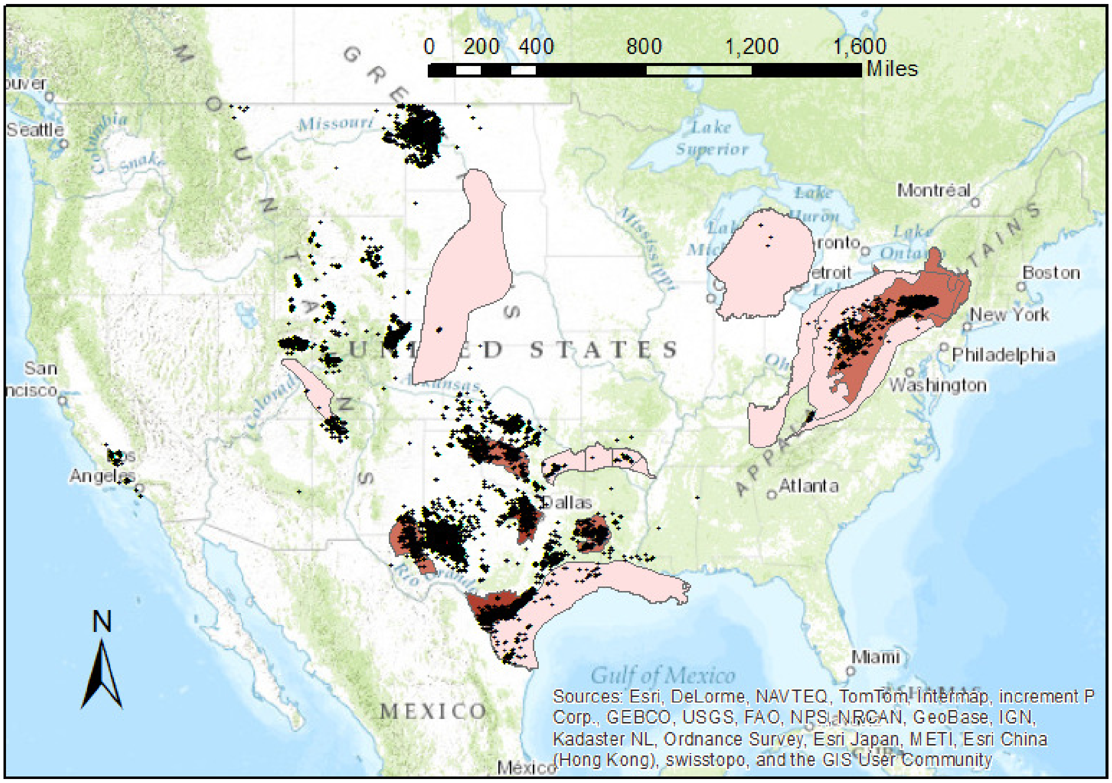

Figure 3 - Shale Gas Activity in the US

The same general process was done for shale gas plays, by joining the SkyTruth wells with the USGS shale polygons. Though it was desired to depict a graduated density of fracturing treatments over each shale play, this essentially is not possible using any known tools. Pictured in Figure 3 is another "first order estimate" of risk, this time depicting shale plays for which there is well data, coded by their density of wells per area; darker colors indicate a higher density of wells. Figure 4 shows a similar picture, but instead codes counties for activity level (darker color indicates higher well density) – I considered this to be a better indicator for where fracturing could have an adverse affect, because it allows all operations to be counted, instead of just the ones that technically took place in a tight gas shale play.

Finally, I calculated the density for all counties in the contiguous US, based on population per polygon area. This was then converted to a raster dataset for eventual combination with the other risk factors. Figure 5 shows this; again, darker colors indicate higher density. Note that no legends are provided on most of the graduated color maps – this is because the true units are not available, as these calculations use an area in longitude and lattitude units, not actual distance units. The gradiations would be the same regardless, so the risk trends can still be observed.

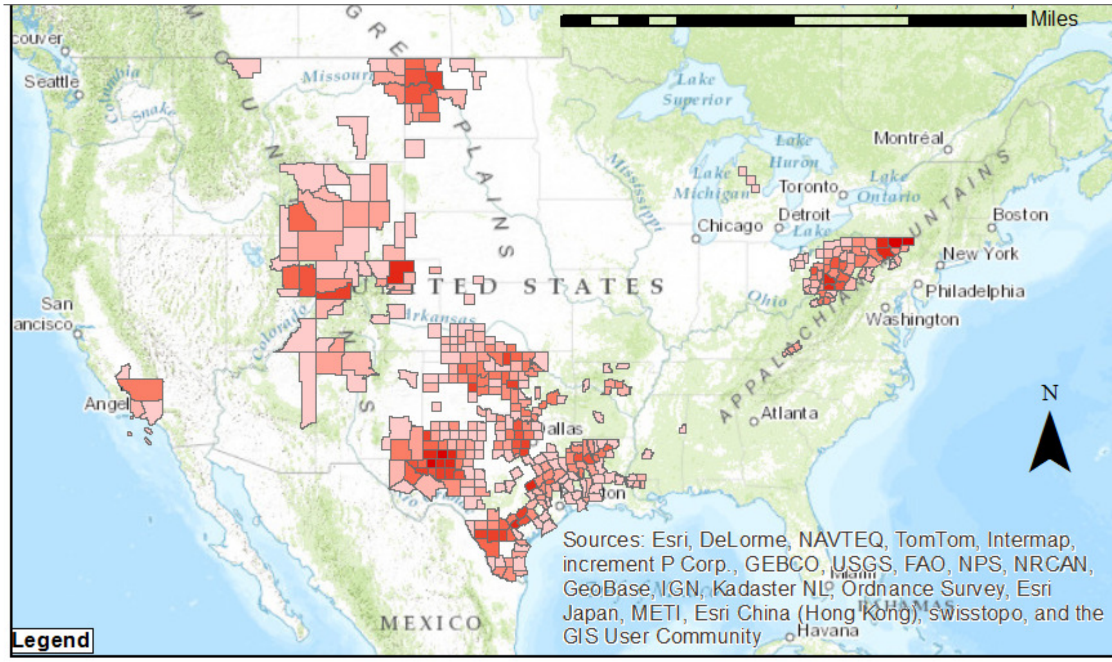

Figure 5 - Frac Activity by County

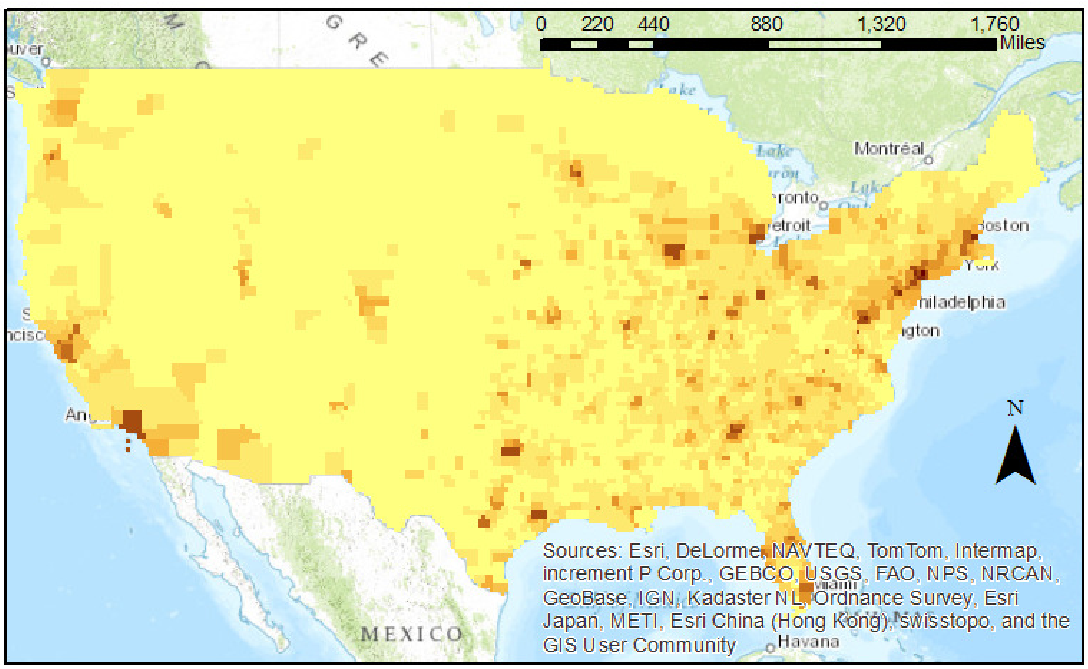

Figure 4 - Population Density

Once all three of the selected risk factors were mapped across the US, the regions with the highest risk could be determined. This was done in two different ways, both of which involved taking each risk factor – aquifer depletion, fracturing activity, and population density – as a percentage of its maximum value, then taking an average of these three percentages to determine a “risk percentage.” The areas with the highest percentages were then singled out for further scrutiny. The two ways this was calculated was via polygon calculations and raster algebra. The formulas to calculate each of the risk factor percentages are as follows.

- Aquifer Depletion: $1 - \frac{DepletionValue+Minimum}{Value\ Range} = Depletion\%$
- Fracturing Activity $\frac{\ln(Activity)}{\ln(Maximum)} = Activity\%$
- Population Density $\frac{\ln(Density)}{\ln(Maximum)} = Density\%$

Note that the second and third factors are calculated with natural log conversions. This is because under the normal method of calculating a percentage (i.e. value/maximum), the range of values in this category is so wide as to have a dramatically skewed distribution. By taking the natural log of both the value and the maximum, I was able to create a clearer graduation of values.

Generally speaking, the raster version is better for looking at general trends across regions of the US, while the county-level determination allows for closer inspection of exact counties that are the most affected by fracturing activity; both results are presented subsequently.

Results and Discussion

Risk Distribution

The results from the determination of fracturing risk are presented as a raster grid in Figure 6. The legend, which indicates the Risk Percentage, is an average of the three aforementioned risk factors I analyzed over the contiguous US:

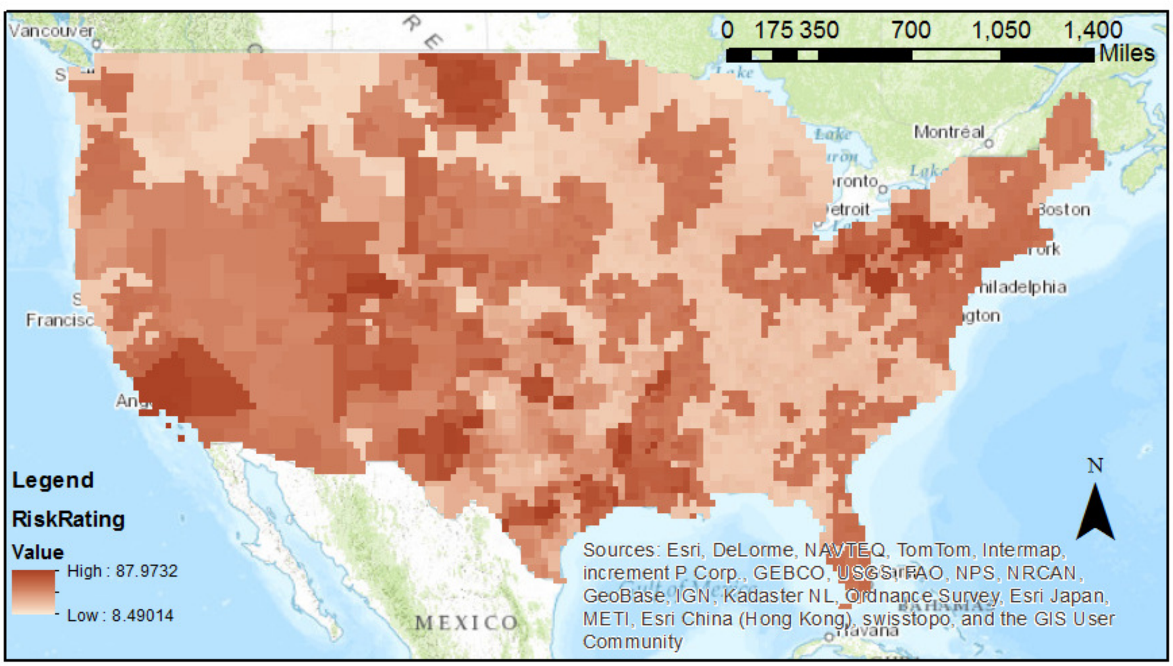

Figure 6 - Raster Grid of Risk Across US

$$Risk\% = \frac{Density\% + Activity\% + Depletion\%}{3}$$

The benefit of this presentation style is the ability to see clear trends in the risk across the US, as evidenced by the swaths of darker color. For instance, certain "hot spots" in Texas emerge; this makes sense since there are many shale plays throughout the state, including the Permian basin in the west (near Midland), the Eagle Ford Shale (south of San Antonio), and the Barnett Shale (near Fort Worth). Much larger shale basins are fairly easy to distinguish, looking at the upper Appalachian mountain region (Marcellus Shale) or northern Great Plains (Bakken Shale). Finally, it must be noted that the risk is not all from fracturing activity, but also because of proximity to population centers and depleted aquifers – this is why southern California has a large area of dark color.

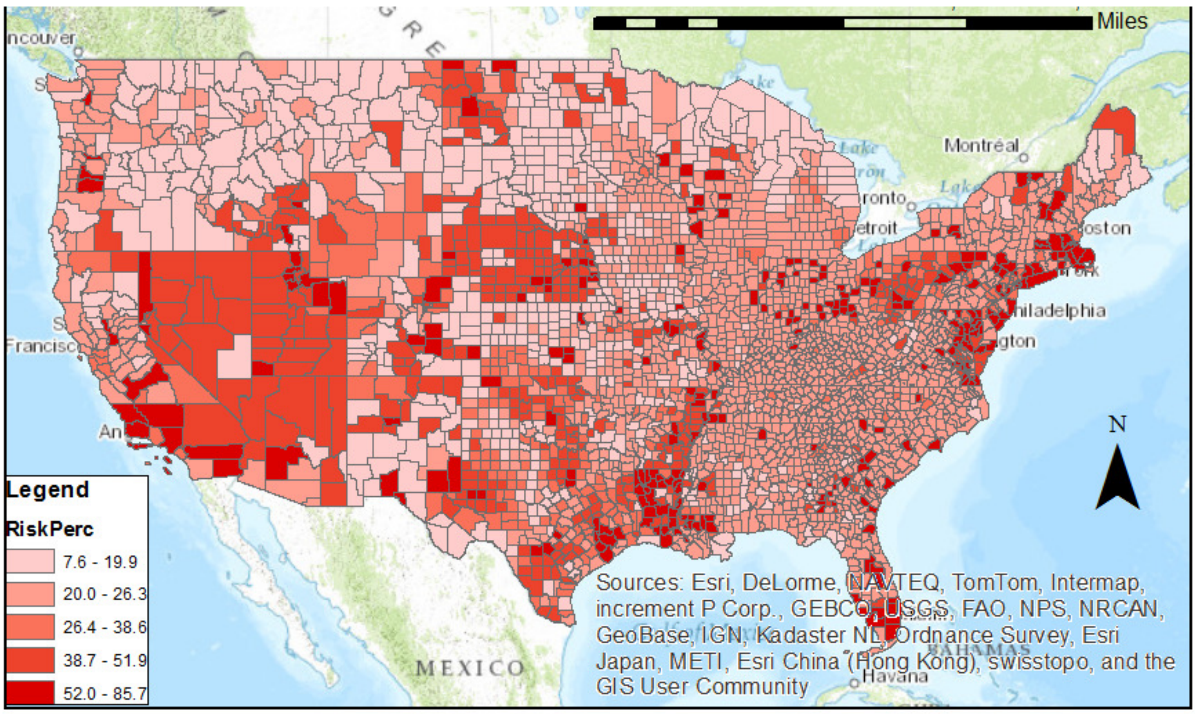

Figure 7 - Polygon-Style Risk Determination across the US

The county-level determination of risk from fracturing activity is presented in Figure 7. The utility of this representation lies in the opportunity to diagnose individual counties that have a high risk rating. From a cursory glance at the map, a few areas [re]emerge: The Bakken Shale in North Dakota, northern Pennsylvania, southern California, and various spots throughout Texas and Louisiana. However, note how there are many other red spots, seemingly at random. This represents a flaw in the risk determination: because the calculation also involves aquifer depletion and population density, counties with high risk may not necessarily have any fracturing activity. Therefore, counties in Florida, Nevada, and Nebraska show up as high risk, despite having absolutely no shale gas fracturing. To get a better understanding of where the risk really is, Figure 8 superimposes the fracturing jobs from SkyTruth on the previous map. Now it is much more obvious where the true fracking-related risk lies: the main shale gas plays of the US, plus the other unconventional basins in North Dakota, Colorado, and Wyoming. From here, I singled out the counties with the highest risk that had fracturing activity with them for further

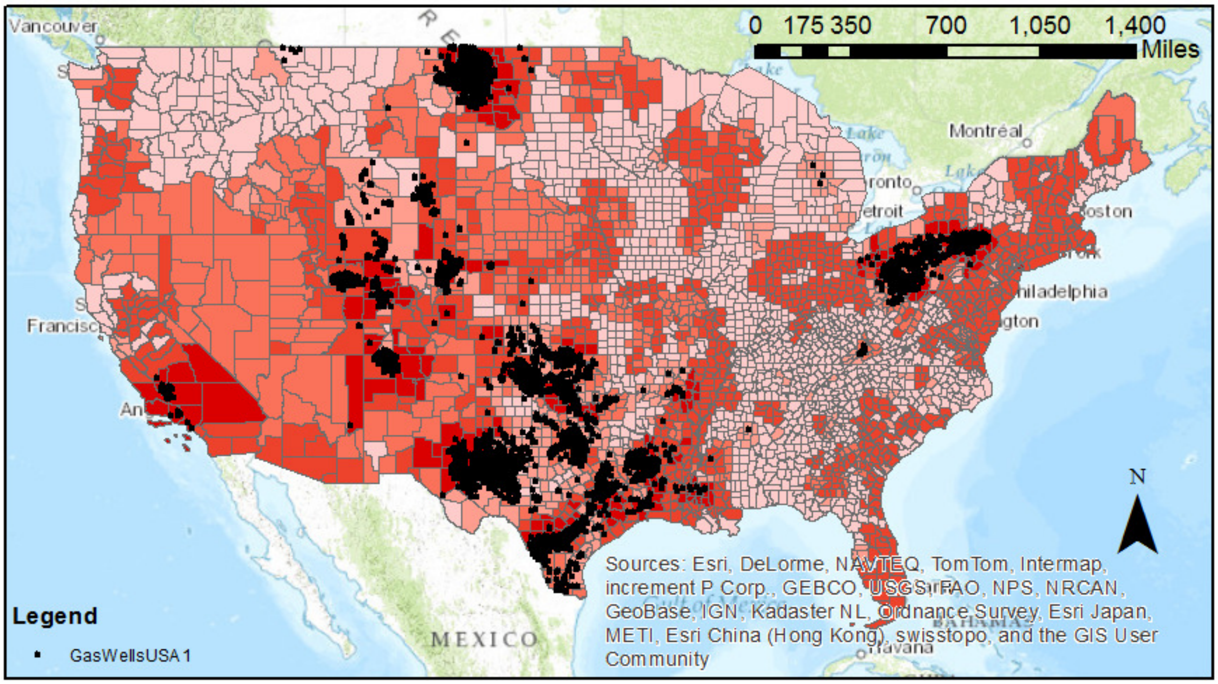

Figure 9 - County Level Risk Determination With Gas Wells

investigation into current laws in place. Figure 9 shows this subset, where only the counties affected by fracturing are shown.

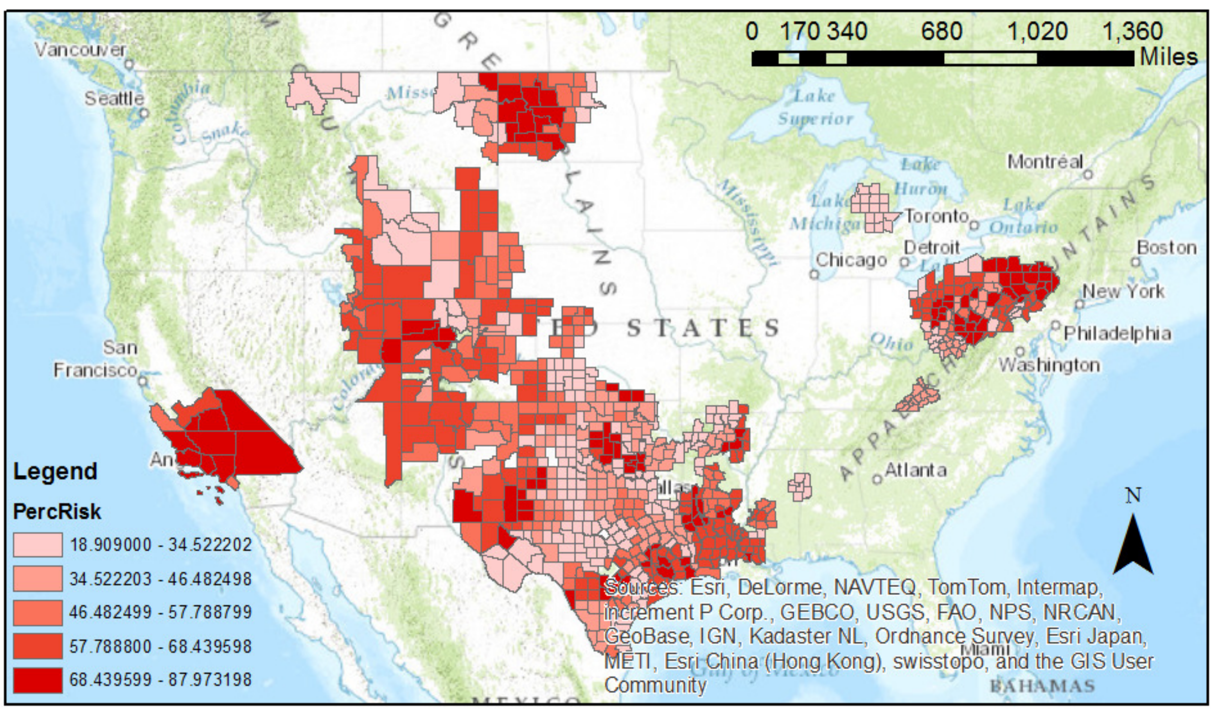

Figure 8 - Selected Counties at Risk from Fracturing

Legislation Investigation

Hydraulic fracturing has come under environmental scrutiny due to the existence of many loopholes in federal regulations. Generally speaking, this is a factual assertion, as many major federal laws exempt fracturing activities (Brady, 2012), including:

- Safe Drinking Water Act: This law normally sets minimum regulatory standards for any fluids injected into or near an aquifer. However, after a [dubiously performed] EPA study in 1997 reported that fracturing does not contaminate overlying aquifers, the 2005 Energy Policy Act included a loophole that exempted fracturing from this law (with the exception of diesel fuel injection).
- Resource Conservation and Recovery Act (RCRA): Oilfield wastes are exempt from this act following a 1988 EPA study which asserted that the industry was adequately covered by state and federal laws. Basically, the only requirement per this law is a lined surface impoundment or tanks for on-site storage of oilfield wastes.
- Emergency Planning and Community Right-To-Know Act: Fracturing treatments are exempted from this because the fracture industry is not listed as a Standard Industrial Classification (SIC) that produces toxic chemicals above threshold quantities. Adding the fracturing industry as a SIC would require approval of the EPA Administrator.
- Clean Water Act: Originally, the EPA oversaw construction of oil and gas well sites, considering runoff sediment as a pollutant. Though the 2005 Energy Policy Act updated this activity to include it under “Oil and Gas Exploration” – which made it exempt under the Clean Water Act – the EPA challenged this and currently still oversees storm water runoff permitting at oil and gas exploration sites.
- Clean Air Act: Since individual well sites do not generally exceed threshold emission rates, they are exempt from needing a Title V permit under the law.
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA): This holds companies responsible for sites that include any hazardous materials (under RCRA), except any “crude oil, natural gas, natural gas liquids,” etc. – therefore, oil and gas industry exploration sites are exempt from most of this law.
- National Environmental Policy Act: Oil and gas exploration activities – especially those on federal land – are essentially exempt from this law, which normally makes all federally overseen projects subject to an environmental assessment.

According to the Interstate Oil and Gas Compact Commission – a multi-party committee that envisions itself as the “leader and driver of national oil and gas policy” – the states are the best suited to regulating the fracturing industry due to experience with oil and gas operations and unique geology and ecology from state to state (Interstate Oil and Gas Compact Committee, 2013). Though this is indeed the opinion of a biased commission, the truth is that state laws are generally much more stringent than existing federal laws, which have many gaping loopholes. A sample of state regulations and activities covered is given in Table 1, summarized from Brady (2012).

Table 1 - Selected State-Level Legislation on Fracturing

State	Administration	Drilling	Flowback Storage	Chemical Disclosure	Disposal
Colorado	OCGA	Permitted, plus water risk assessment	Permitted, exceptions for lining	Full	Permitted
New York	DEC	Not allowed currently, but future regulations indicate relatively strict permitting and requirements			
Pennsylvania	DEP	Permitted	Permitted, lining required	Full	Permitted, covered under various laws
Texas	TRC	Permitted, casings scrutinized	Permitted, only if pollution can be avoided	Full	Permitted for injection, but also spreading over land
Louisiana	DNR	Permitted, including casing and treatment description	Permitted, prohibited in flood plains	Full	Permitted, only at approved facilities
Wyoming	WOGCC	Permitted, include treatment and construction details	Permitted, but only some need lined	None known	Permitted, but not highly scrutinized

As can be seen from the table, states tend to agree on requiring permits to drill, store flowback and produced water, and dispose of waste, but the requirements to obtain these permits vary widely – from the full assessments required in Colorado to the minimal scrutiny in Texas. Interestingly, chemical disclosure is now required in many states (exempting some trade secret chemicals in some places). Finally, the regulation of surface impoundments, or "pits," varies quite a bit from state to state. While some require every pit to be lined in order to prevent any underlying aquifers, other states only require lining in special circumstances. This regulation gap is probably the most pertinent to the map presented in the previous section: we can now directly see where sensitive aquifers would be most at risk. For example, aquifers in Wyoming would have a higher potential for contamination due to low regulation, whereas aquifers in New York would be very well protected (when fracturing eventually commences) due to heavy scrutiny and assessments on potential pollution scenarios.

Note that many other states have their own regulatory schemes, and these vary just as widely as the ones presented in the sample of Table 1. Additionally, there are regulations that do not pertain directly to water contamination that warrant additional scrutiny: air permits regarding flaring of natural gas found with continuous oil, lease and land ownership rules, and traffic agreements that must be reached with local communities.

As a digression – and after reading through several other states' regulations – it would seem that there is a trend of regulation intensity. States with a generally strong environmental record (e.g. Pennsylvania, New York, California) have much more scrutiny over oil and gas exploration activity, as would be expected given their histories. On the other hand, states that either have less stringent environmental regulations or where oil and gas production is a vital part of their economy (e.g. Texas, North Dakota, Wyoming, Oklahoma) have less strict regulation.

Following the evidence presented and the preceding digression, a simple conclusion can be drawn. Since regulation is almost completely covered by state governments, with counties only providing either opposition or support to laws enacted at this level, the focus of new and more stringent regulation should be in states where there are significant at-risk counties. From this, focus should be zeroed in on the states that do not have strong regulation at this point; this brings the roster to the following states: Texas, New Mexico, North Dakota, Wyoming, and Oklahoma. Other states have reasonable protections against flowback impoundment siting and waste disposal (especially in aquifers near population centers), but the listed states have weaker regulations in this area. The specific codes that pertain are listed below:

- Texas: TAC Title 16, Part 1, Chptrs 1-20 (http://www.rrc.state.tx.us/rules/rule.php)
- New Mexico: NMCPR Title 19, Chapter 15 (http://www.emnrd.state.nm.us/OCD/documents/SearchablePDFofOCDTitle19Chapter15created3-2-2012.pdf)
- North Dakota: NDAC, Chptrs 38-43 (https://www.dmr.nd.gov/oilgas/rules/rulebook.pdf)
- Wyoming: WOGCC Rules and Regulations (http://wogcc.state.wy.us/)
- Oklahoma: Chptrs 5, 10, 15, 16, 20, 25, 27-30 (http://www.occeweb.com/rules/rulestxt.htm)

Conclusions

From the data presented, it is evident that quite a large section of the United States is at risk for potential environmental consequences due to hydraulic fracturing activity, whether from sheer amount of fracturing jobs, reliance on depleted aquifers for this water-intensive industry, or proximity to population centers. Most federal regulation that would apply to such activity appears to have exemptions to fracturing, whether by the well sites not meeting certain threshold values or by varying definitions and qualifications of "waste," "injection", and "hazardous." As stated before, this is mostly due to the 2005 Energy Policy Act, which exempted fracturing from many laws that had previously applied to it.

Therefore, since state governments are responsible for most regulation – and since counties only play a minor role in influencing these policies – these laws matter most. Unfortunately, some of the states that have the highest risk of environmental degradation due to fracturing are also some of the least protected; it is there where lawmakers and environmental and social justice lobbyists must concentrate their efforts first.

In addition to the three risk factors assessed, more could be worked into the Average Risk Percentage, likely via use of a process model in ArcGIS. Creating a standard method to add more factors to the equation could allow for simple addition of factors such as:

- Proximity to national parks and forests or wildlife sanctuaries
- Density of injection wells for produced water disposal (as a benefit)
- Proximity to permitted industrial wastewater treatment plants
- Condition of transportation infrastructure
- Density of pipelines in the area

To continue this project, the first step would be to create this process model and incorporate at least these factors into the risk determination. Perhaps, then, an index of the effectiveness of state environmental protection laws could be created (based on how strictly each aspect of the oil and gas industry is regulated), then cross-referenced with the risk areas. Overall, this can be a useful tool to both state and federal legislators and activists (and probably industry supporters, as well) for determining where to focus regulation efforts, and is easily adaptable for changing conditions.

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