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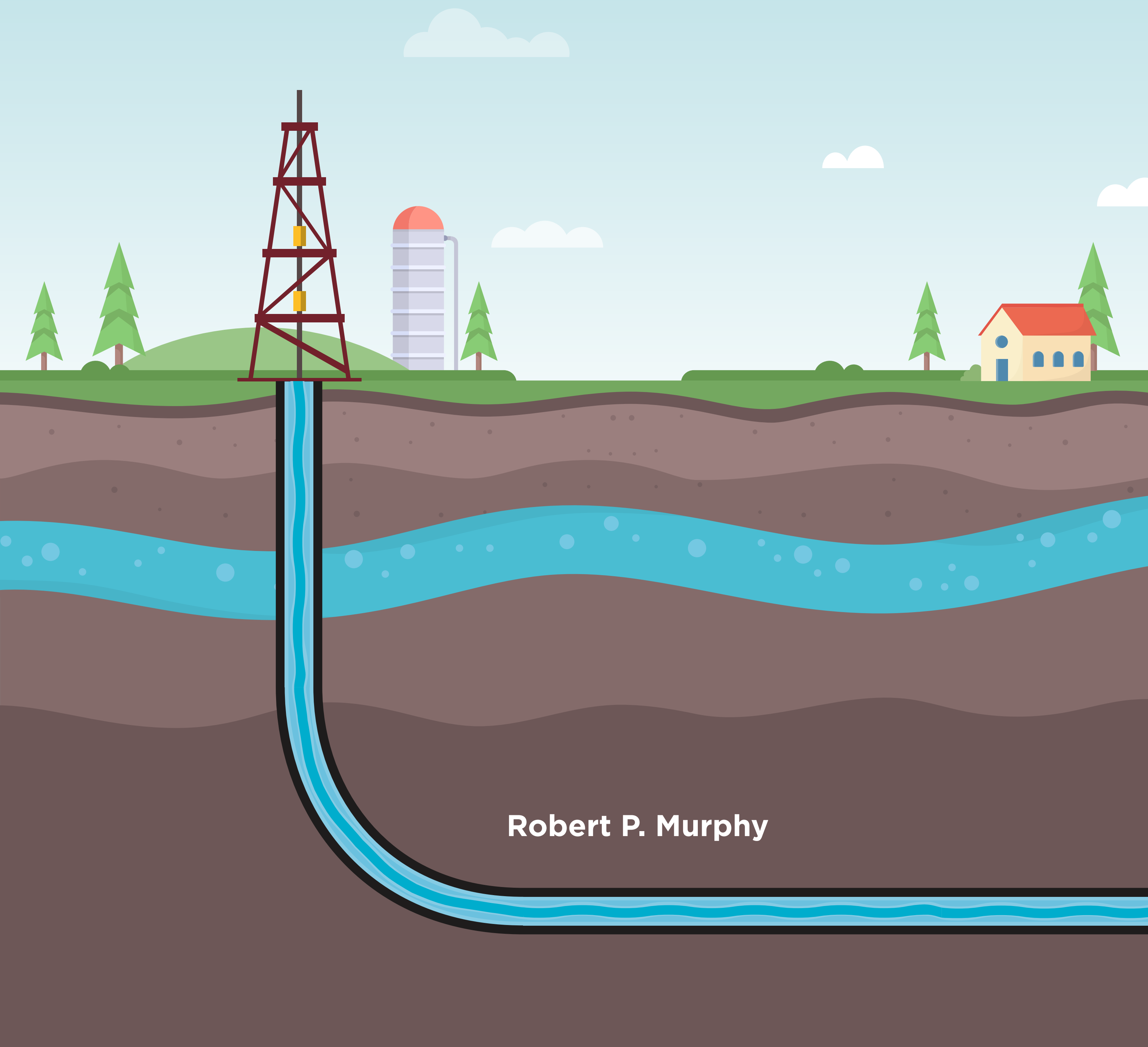
Managing the Risks of Hydraulic Fracturing, 2020



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Fraser Institute

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by Robert P. Murphy

Contents

Executive Summary

The practice of hydraulic fracturing—or "fracking"—in conjunction with horizontal drilling techniques has allowed for an enormous increase in oil- and natural-gas production in Canada. The modern practices associated with fracking can allow for much more extensive development of natural gas and other hydrocarbons located in shale and "tight sand" formations. As Canada is blessed with some of the largest deposits of shale oil and gas resources in the world, continued use of fracking would foster a large flow of economic benefits to Canadians (and the rest of the world).

However, there are potential risks to fracking. In December 2014 the Fraser Institute released a comprehensive report by Kenneth P. Green, which summarized the findings of nine studies and reviews. Green's 2014 study acknowledged that there "is no question that the technology poses risks to water quality, air quality, and ecosystem health" but concluded that "continuing to allow hydraulic fracturing while improving on the current system of governmental and industry self-regulation would seem to be indicated". In December 2015, Green and co-author Taylor Jackson provided an update, incorporating the findings of five new studies and reviews, and argued that "[a]dditional research on the safety of hydraulic fracturing confirms that while there are indeed risks from this process … they are for the most part readily managed with available technologies and best practices".

The present update continues this process, evaluating new studies and reviews that have been published since the update provided in Green and Jackson (2015). The most significant review is the EPA's final 2016 comprehensive report on fracking's potential impact on drinking water. This update also summarizes the findings of nine additional studies and reviews, focusing on fracking's potential impact on drinking water quality and availability, methane emissions, induced seismicity (earthquakes), and noise pollution.

Our conclusions mirror those of the previous publications published by the Fraser Institute. The scientific understanding of the mechanisms through which fracking may affect human welfare—specifically through impacts on drinking water and seismicity—has improved over time, and researchers may view these particular impacts as more serious now than was the case for the 2015 literature update. Even so, actual demonstrated harm to human welfare from fracking is still extremely modest, despite the enormous boom in fracking operations and the passage of many years to allow for an assessment of its effects.

In particular, the latest research shows that fracking actually reduces methane emissions once we adjust for the volume of natural gas produced, and especially if we consider the displacement of coal-fired power plants. The noise pollution from fracking on nearby residences has been documented, but appears to be comparable to the noise generated by a refrigerator.

More important, fracking's potential impacts on drinking water and seismicity are not the result of fracking in itself, but rather to certain procedures in wastewater storage

and disposal. Amending operations (such as the lining of storage pits, and the depths to which wastewater is injected) can reduce these risks. The potential strain on water availability in some local communities can be ameliorated through the introduction of flexible pricing for water, to avoid waste and ensure that the available water supply is channelled to its high-valued uses.

Although there are some genuine risks associated with fracking, the existing research leads us to conclude that they are manageable. Explicit government bans (or moratoria) at this point are a gross overreaction to the actual concerns documented in the literature.

1 Introduction

The practice of "fracking"—formally, hydraulic fracturing—in conjunction with horizontal drilling techniques has allowed for an enormous increase in the production of oil and natural gas in Canada, as well as the United States. The modern practices associated with fracking can allow for much more extensive development of natural gas and other hydrocarbons located in shale and "tight sand" formations. There are thus enormous potential economic benefits to Canadians from the continued use of fracking.

Indeed, according to the latest International Energy Outlook from the US Energy Information Administration (EIA), global consumption of natural gas is expected to increase 40% from 2018 to 2050 (with most of the increase occurring in non-OECD nations), while global consumption of petroleum and other liquid fuels increases more than 20% (US-EIA, 2019: 118, 133). As noted in Green and Jackson (2015), the EIA in 2013 released a study of global "technically recoverable" resources, and found that Canada's supplies of shale oil ranked tenth in the world and supplies of shale gas, fifth.

However, there are risks to human welfare associated with fracking, including groundwater contamination, greenhouse gas emissions, and even earthquakes. These risks have made "fracking" a dirty word among some environmental activists and political officials in Canada and the United States. The following quotations give a flavour of this popular hostility to fracking:

> We live in an era of tough choices. Scientists worldwide have amassed overwhelming evidence that we have little time to shift from excessive fossil fuel use if we are to avert climate chaos. But our economic systems demand constant growth and resource exploitation in the name of profits and job creation, regardless of consequences. As easy sources of coal, oil and gas become depleted, industry and governments are moving as quickly as possible to exploit "unconventional" reserves through oilsands extraction, deep-sea drilling, Arctic exploration and fracking.
>
> This is neither sustainable nor rational. (Suzuki, 2019)
>
> Some countries are already moving in the right direction. French President Emmanuel Macron has introduced a bill to phase out all oil and gas exploration and production in France … by 2040; the Scottish government has banned fracking altogether; and Costa Rica now produces the vast majority of its electricity without oil. (Berman and Fuhr, 2017)
>
> Accelerate the end of fossil fuels by immediately…phasing out fracking." —Senator Cory Booker [1]

[1] This and following quotations from US officials (spelling adjusting to Canadian conventions) from Global Energy Institute, 2019: 4.

> On my first day as president, I will sign an executive order that puts a total moratorium on all new fossil fuel leases for drilling offshore and on public lands. And I will ban fracking—everywhere. —Senator Elizabeth Warren
>
> When we are in the White House we are going to ban fracking nationwide. —Senator Bernie Sanders
>
> There's no question I'm in favour of banning fracking. —Senator Kamala Harris
>
> I favour a ban on new fracking and a rapid end to existing fracking. —Mayor Pete Buttigieg

In light of such calls for outright bans coming from some quarters, it is essential that policy makers and citizens have credible information on both the potential benefits but also the genuine risks associated with the practice of fracking. In 2014, the Fraser Institute published a report assessing the literature, and then updated the literature review in 2015 (Green, 2014; Green and Jackson, 2015). The present update continues the process, summarizing the findings of newly published research on the risks of fracking.

2 A Summary of Previous Reports from the Fraser Institute on the Safety of Fracking

In December 2014 the Fraser Institute released a comprehensive report by Kenneth P. Green entitled *Managing the Risks of Hydraulic Fracturing*. The report acknowledged that there "is no question that the technology poses risks to water quality, air quality, and ecosystem health" but concluded that "continuing to allow hydraulic fracturing while improving on the current system of governmental and industry self-regulation would seem to be indicated" (Green, 2014: iii–iv).

In *Managing the Risks of Hydraulic Fracturing*, Green summarized the findings of nine studies and reviews, including the comprehensive report by the Canadian Council of Academies (CCA, 2014). Green broke its analysis into a discussion of the risks fracking posed in the areas of (1) water pollution, (2) conventional air pollution, (3) greenhouse gas emissions, and (4) earthquakes.

In December 2015, Green was joined by co-author Taylor Jackson to provide an update, incorporating the findings of five new studies and reviews on fracking safety that had been published after Green's review in 2014. Most notably, the new studies included the initial 2015 draft of a comprehensive study on water quality by the United States Environmental Protection Agency (US-EPA, 2015). Green and Taylor in their 2015 update of the literature on fracking risks concluded:

> The additional research on the safety of hydraulic fracturing reviewed since the publication of Green (2014) results in many of the same conclusions. ***Additional research on the safety of hydraulic fracturing confirms that while there are indeed risks from this process as there are with all industrial activities, they are for the most part readily managed with available technologies and best practices***. Some of the latest research, such as EPA (2015), which found that hydraulic fracturing does not pose widespread or systemic effects to drinking water, cleared up much of the uncertainty which was present in the earlier comprehensive reviews.
>
> Green (2014) also analyzed the regulatory environment in Canada, finding that Canada has a robust regulatory process that covers the entire range of hydraulic fracturing processes at both federal and provincial levels. In addition, the industry, through its trade association, has stringent self-regulation that exceeds regulatory requirements. More research is needed into the potential environmental impacts of hydraulic fracturing as well as the risks it may pose to human and ecological health—and of course that research is continuing both in Canada and around the world.
>
> ***Calls for bans and moratoria are passionate, and no doubt heartfelt by those who fear the technology or oppose the product of that technology (hydrocarbons), but policymakers should ignore the siren song of the simplistic solution.*** (Green and Jackson, 2015: 13-14)

The present update continues this process, evaluating new studies and reviews that have been published since the update provided in Green and Jackson (2015). The most significant review is the EPA's final 2016 comprehensive report on fracking's potential impact on drinking water (US-EPA, 2016a). This update also summarizes the findings of nine other studies and reviews, focusing on fracking's potential impact on the quality and availability of drinking water, methane emissions, induced seismicity (earthquakes), and noise pollution.

Although researchers' understanding of the nature and mechanisms of fracking's potential impact on human welfare have of course increased since Green and Jackson's 2015 update, the conclusions in the 2020 update will largely mirror those of the Fraser Institute's prior publications.

3 The EPA's 2016 Comprehensive Report on Fracking's Impact on Water Quality and Availability

The present update will concentrate most heavily on the December 2016 report issued by the United States' Environmental Protection Agency (EPA) on the impacts of fracking on the quality and availability of drinking water. For those concerned about drinking water, the EPA's comprehensive report is arguably the single most persuasive line of evidence: it references more than 1,200 sources (of "data and information") and more than half of the articles it cites were published in 2010 or later (US-EPA, 2016b).

The 2015 update on fracking safety from the Fraser Institute (Green and Jackson, 2015) made mention of the EPA report, which at that point—more than a year ahead of the ultimate release date—was still forthcoming although a draft version was available on the internet. Between the 2015 early release and the full 2016 version of its study, EPA added more than 200 citations, and nearly 400 chemicals involved with fracking were added to its analysis.

3.1 The significant change from the EPA's 2015 initial draft to the 2016 official publication

At the outset, we should highlight one important change [2] that affects the assessment provided in the Fraser Institute's update of 2015. In that update, the authors quoted from the EPA's then-draft report, which first acknowledged that there were various "mechanisms by which hydraulic fracturing activities had the potential to impact drinking water resources" but then gave the fairly definitive statement:

> ***We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States.*** Of the potential mechanisms identified in this report, we found specific instances where one or more mechanisms led to impacts on drinking water resources, including contamination of drinking water wells. The number of identified cases, however, was small compared to the number of hydraulically fractured wells. (US-EPA, 2015: ES-6, quoted in Green and Jackson, 2015: 4; emphasis added by Green and Jackson.)

In the December 2016 final version of the EPA study (US-EPA, 2016a), its staff had removed the definitive sentence italicized in the block quotation above (and which had been highlighted by the Fraser Institute's update of 2015). In an online Q&A regarding the report, EPA staff explained their decision:

[2] For a complete explanation of how the EPA's 2016 final report differed from the 2015 draft, see US-EPA, 2016b.

> ***Q: Why did EPA remove "no evidence of widespread, systemic impacts" from the assessment?***
> A: EPA's scientists included the following sentence in the 2015 draft assessment report: "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States". That sentence was included in a section of the draft assessment report that also highlighted various limitations due to uncertainties and data gaps.
>
> After receiving comments from the SAB [Science Advisory Board], EPA scientists concluded that the sentence could not be quantitatively supported. Contrary to what the sentence implied, uncertainties prevent EPA from estimating the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle. Additionally, EPA scientists and the SAB, came to the conclusions that the sentence did not clearly communicate the findings of the report. (US-EPA, 2016b)

This is an important change but note that the EPA's explanation for the change was *not* that new information concerning drinking water hazards had come to light since the original 2015 draft report. Rather, the EPA was afraid that the original, definitive statement implied more certainty than the actual situation warranted. So to be clear, according to their own explanation, it is not the case that EPA had come to believe that there *were* "widespread, systemic impacts on drinking water". Rather, the EPA decided that the original language—namely, that *it had found no evidence to support* such a claim—might mislead the public, because (presumably) the notion of a "widespread, systemic impact" was hard to quantify.

To anticipate our conclusions from later in this section, we believe the full EPA 2016 report does *not* offer any major departure from the 2015 draft version, with respect to the conclusions drawn in the Fraser Institute's update of 2015 based upon it.

3.2 The EPA's succinct takeaway

As noted, the EPA report is quite extensive; the full version is more than 650 pages, while even the Executive Summary is 50 pages. In a later subsection (4.3), we will delve into one of the key papers covered in the study but it may help the average reader if we here reproduce how the EPA itself summarized its findings. In the Executive Summary of the 2016 EPA report we read:

> The hydraulic fracturing water cycle describes the use of water in hydraulic fracturing, from water withdrawals to make hydraulic fracturing fluids, through the mixing and injection of hydraulic fracturing fluids in oil and gas production wells, to the collection and disposal or reuse of produced water. **[3]** These activities can impact drinking water resources under some circumstances. Impacts can range in frequency and severity, depending on the combination of hydraulic fracturing water cycle activities and local- or regional-scale factors.

[3] Note that in this context, "produced water" refers to naturally occurring water that flows out of the ground during oil and gas extraction. It is distinguished from "flowback water," which is the portion of the "frac fluid" that may return to the surface after injection during fracking (American Geosciences Institute, 2020).

> The following combinations of activities and factors are more likely than others to result in more frequent or more severe impacts:
>
> - Water withdrawals for hydraulic fracturing in times or areas of low water availability ... ;
> - Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources;
> - Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity ... ;
> - Injection of hydraulic fracturing fluids directly into groundwater resources;
> - Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources; and
> - Disposal or storage of hydraulic fracturing wastewater in unlined pits ... .
>
> The above conclusions are based on cases of identified impacts and other data, information, and analyses presented in this report. Cases of impacts were identified for all stages of the hydraulic fracturing water cycle. Identified impacts generally occurred near hydraulically fractured oil and gas production wells and ranged in severity, from temporary changes in water quality to contamination that made private drinking water wells unusable.
>
> ***The available data and information allowed us to qualitatively describe factors that affect the frequency or severity of impacts at the local level. However, significant data gaps and uncertainties in the available data prevented us from calculating or estimating the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle.*** The data gaps and uncertainties described in this report ***also precluded a full characterization of the severity of impacts.***
>
> ***The scientific information in this report can help inform decisions by federal, state, tribal, and local officials; industry; and communities. In the short term, attention could be focused on the combinations of activities and factors outlined above. In the longer term, attention could be focused on reducing the data gaps and uncertainties*** identified in this report. Through these efforts, current and future drinking water resources can be better protected in areas where hydraulic fracturing is occurring or being considered. (EPA 2016a: ES-3–ES-4; emphasis added)

As the above excerpt illustrates, the EPA report is surprisingly vague in its conclusions. All the reader can definitely conclude is that there were *some examples* of fracking affecting drinking water, though the report (see passages with emphasis) refrains from "estimating the national frequency of impacts on drinking water" and the uncertainties involved also made EPA unable to provide "a full characterization of the severity of the impacts".

For another example of this surprising vagueness, consider the following excerpt from EPA's online Q&A associated with the report:

> ***Q: How many documented impacts have you found and where are they?***
> A: EPA's study was not designed to identify or quantify all impacts. EPA used cases of impacts (and other data, information, and analyses) to identify combinations of hydraulic fracturing water cycle activities and local- or regional-scale factors that are more likely than

> others to result in more frequent or more severe impacts on drinking water resources. Data gaps and uncertainties prevented EPA from calculating or estimating the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle.

Again, even when the EPA has its hypothetical questioner specifically ask for the number of documented cases of impacts, the staff refuse to give a specific answer.

Returning to the long quotation from the Executive Summary that we provided above, note that when it came to discussing government policy, the report did *not* outline specific and immediate changes needed to ensure adequately safe drinking water. Instead, the EPA report merely points policy makers to the listed activities and factors of concern, and concluded with a call for more research in the future.

3.3 Concluding remarks on EPA's 2016 study

As we have documented in this section, although the full EPA 2016 study hedged by removing some of the definitive language in its 2015 draft, we see little in the study that would justify such a move. (The possible exception to this conclusion is discussed in Section 4.4 below.) To repeat, the original 2015 draft claimed that EPA "did not find evidence [of] widespread, systemic impacts on drinking water resources" from fracking, and that the number of actual identified cases of contamination "was small compared to the number of hydraulically fractured wells". As far as we can tell, the full EPA 2016 study does *not* contain evidence of widespread, systemic impacts, nor does it update the number of identified cases of contamination such that they are no longer "small" compared to the total number of fracked wells.

In short, the original 2015 EPA draft language still seems appropriate, as does its assessment in *Managing the Risks of Hydraulic Fracturing: An Update* (Green and Jackson, 2015). Although there have been some documented problems with fracking, the extreme claims from some activists [4] that it represents a widespread and serious threat to the quality of drinking water is not borne out by the evidence, at least as covered in the 2016 EPA report. Policy makers may consider reviewing the relevant regulations in light of the documented cases of contamination, but at most this would represent a tweaking of the existing framework, not a major change in policies.

Furthermore, one of the problems documented by the EPA—namely, that fracking operations can strain a region that is already suffering from limited water availability—has an obvious solution of bringing *more* economic freedom (in the form of pricing flexibility for water) rather than increased government regulation. In general, if there is a "water shortage" then the immediate culprit—as with any shortage in a market economy—is an artificially low price, which is allowing the quantity demanded to exceed the available supply. Many economists recommend flexible water pricing as a way of encouraging conservation; see for example Livio Di Matteo (2016) and the book-length treatment from Zetland (2014).

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[4] In addition to concerns about climate change, many environmental activists have a particular disdain for fracking because of its alleged impact on drinking water. For example, the 2010 documentary *Gasland* purported to document the systematic degradation of local communities' drinking water supplies by fracking operations (Fox, 2010).

4 Other Studies on Fracking's Impact on Water Quality and Availability

To supplement the comprehensive EPA assessment on fracking's possible impact on water quality and availability, in this section we review four recent studies that were not included in the EPA's report, as well as a study that *was* included but has received attention as amplifying concerns that the EPA initially downplayed.

4.1 Kondash, Lauer, and Vengosh (2018)—The Intensification of the Water Footprint of Hydraulic Fracturing

Kondash, Lauer, and Vengosh acknowledge that "it has been shown that the overall water withdrawal for hydraulic fracturing is negligible compared to other industrial water uses on a national level". However, on a *local* scale, "water use for hydraulic fracturing can cause conflicts over water availability, especially in arid regions such as western United States, where water supplies are limited".

The specific contribution of the article is to document that the intensity of water usage in fracking operations has increased over the years. The authors analyzed data on drilling and water usage from more than 39,000 individual wells in six US shale-producing regions from 2011 to 2016. In all regions except the Marcellus, the water-use *intensity*—defined as the amount of water needed to produce a unit of energy—increased from 2011 to 2016. The authors state: "The increase in the water footprint of hydraulic fracturing shown in this study has serious implications for local communities, where increased drilling volumes will lead to large instantaneous water demands …".

On this specific concern of water strain, we repeat our commentary from the previous section: when there are competing uses for a scarce resource, the market economy relies on market prices to allocate the available supply. If unconventional oil and gas operations are implicitly being subsidized with access to artificially cheap water, the ideal solution is to reform the water-pricing mechanism, rather than directly regulate enterprises that would like to use more water.

4.2 Wen, Niu, Gonzales, Zheng, Li, and Brantley (2018)—Big Groundwater Data Sets Reveal Possible Rare Contamination amid Otherwise Improved Water Quality for Some Analytes in a Region of Marcellus Shale Development

The authors of this study relied on "[e]leven thousand groundwater samples collected in the 2010s in an area of Marcellus shale-gas development" in order to "assess spatial and temporal patterns of water quality". Although they confirmed "previous observations that methane concentrations in groundwater tend to be naturally elevated in valleys and near faults", they also found "waters with elevated methane that are not otherwise explained by geologic features". However, "[t]hese slightly elevated concentrations occur near 7 out of the 1,385 shale-gas wells and near some conventional gas wells in the study area". So to be clear, the unnaturally high concentrations of methane were only *slightly* elevated, and this only occurred in 0.5%—one half of one percent—of the shale-gas wells in the area under study.

Moreover, the study found that the concentrations of five analytes (TDS, Fe, Mn, sulfate, and pH) showed "small but statistically significant improvement" relative to the pre-1990 period, while the concentrations of five others (As, Pb, Ba, Cl, and Na) showed no statistically significant change. The authors speculated that these improvements in groundwater quality could be "caused by decreased acid rain (pH, sulfate) since the imposition of the Clean Air Act or decreased steel production (Fe, Mn)" (Wen, Niu, Gonzales, Zheng, Li, and Brantley, 2018: Abstract).

4.3 The Academy of Medicine, Engineering and Science of Texas (2017)—*Environmental and Community Impacts of Shale Development in Texas*

The Academy of Medicine, Engineering, and Science of Texas (TAMEST) issued a report of more than 200 pages in 2017 outlining the environmental and community impacts of shale development in Texas. In this section, we will summarize its findings about water quality, while in later sections we will summarize its findings for methane and earthquakes.

From the chapter, Water Quantity and Quality, in the TAMEST 2017 report, here is the opening summary:

> - Water used in hydraulic fracturing processes in Texas represents a small fraction—less than 1 percent—of total water use statewide. In some regions and locales in Texas, however, water used in hydraulic fracturing represents a significantly larger proportion of local water sources.
> - Use of brackish groundwater and produced water [5] for hydraulic fracturing can reduce freshwater use. Increased use of these waters, however, can potentially increase impacts to land and water due to spills and leaks.
> - The depth separation between oil-bearing zones and drinking water-bearing zones in Texas makes direct fracturing into drinking water zones unlikely, and it has not been observed in Texas.
> - Surface spills and well casing leaks near the surface are the most likely pathways for oil and gas activities to lead to contamination of drinking water sources and environmental damage.
> - In Texas, both economics and risk considerations dictate that much of the produced water will continue to be injected in deep wells or used as fracturing fluid to minimize impacts on other water sources. (TAMEST, 2017: 113)

[5] As explained in footnote 3, "produced water" refers to naturally occurring water that flows out of the ground during oil and gas extraction.

In the body of the chapter, the TAMEST 2017 report relies heavily on the EPA's definitive 2016 study (see Section 3), supplemented with individual studies that focus more narrowly on a specific issue (and often based in Texas). For a representative selection, consider the TAMEST discussion of groundwater contamination in Texas as a result of oil and gas operations:

> More often, casing problems result in leaks with less spectacular impacts. If casing designs include multiple layers, leaks may simply lead to communication between annular layers, with no exposure to the surrounding environment. ***In a study of 211 groundwater contamination incidents in Texas associated with oil and gas activity (Kell, 2011), only 10 incidents were associated with well drilling and completion and none were associated with stimulation (hydraulic fracturing). Moreover, many of the noted incidents occurred prior to 1969 and before the RRC*** [Texas Railroad Commission] ***revised regulations on cementing. Continued improvements in cementing and casing pressure monitoring are intended to further reduce the occurrence of these types of incidents.*** However, because of the industrial nature of this activity, there is, and always will be, some probability of casing failure leading to near surface contamination or contributing to surface spills due to flow up the failed casing. [TAMEST 2017: 123; emphasis added.]

Regarding drinking water quality, here are the recommendations from the task force:

> **Subsurface contamination by fracturing or formation fluid**
>
> - ***Direct migration of contaminants from targeted injection zones is highly unlikely to lead to contamination of potential drinking water aquifers.*** The collection and sharing of pressure data relevant to communication between water-bearing and producing strata—including non-commercial flow zones—or across wells could help identify and avoid potential concerns.
>
> **Spills of flowback water, drilling fluid, and formation water at the surface**
>
> - Statewide leak and spill reporting requirements for produced water should be considered. For all spilled substances, reporting requirements should be improved to aid identification of the primary sources of leaks and appropriate management responses.
> - ***Texas regulators and industry should continue to develop and apply best management practices relative to well casing design and construction, and surface management of oil and gas operations, to reduce inadvertent release of fluids.*** (TAMEST 2017: 128–129; emphasis added.)

To summarize, the TAMEST 2017 task force found that the primary threat to water quality did not come from fracking itself, but instead from inadequate well casing and surface-management practices (that could allow spills). Moreover, even these risks were relatively modest, with contamination incidents being relatively rare over the course of decades of heavy oil and gas development.

4.4 Claire Botner, Townsend-Small, Nash, Xu, Schimmelmann, and Miller (2018)—Monitoring Concentration and Isotopic Composition of Methane in Ground Water in the Utica Shale Hydraulic Fracturing Region of Ohio

In this study, the researchers took measurements of natural gas methane (CH_4) concentrations and other variables in groundwater in the Utica Shale drilling region in eastern Ohio. From January 2012 to February 2015, they collected 280 groundwater samples. In order to isolate the possible cause of high groundwater concentrations, air samples were also collected.

As the Abstract explains, "[p]revious studies have shown that natural gas methane (CH_4) is present in groundwater near shale gas wells in the Marcellus Shale of Pennsylvania, but did not have pre-drilling baseline measurements". The authors therefore set out to determine whether these previous studies were documenting causation rather than mere correlation and concluded:

> Contrary to our hypothesis, ***we did not see an increase in CH_4 concentration or change in isotopic composition of CH_4 in groundwater in regularly monitored wells over the study period, despite a large increase in the number of producing shale gas wells in our study area.*** In fact, we saw a decrease in CH_4 concentration in some of our regularly monitored wells, although the number of samples in our time series is relatively small. The low numbers of significant correlations indicate there may be natural variability in concentrations of biogenic [biologically generated] CH_4 in ground water in our study area (contrary to expectation,) and/or we may simply lack statistical power to uncover a robust signal. (Claire Botner et al., 2018: 9 [offprint]; emphasis added.)

This study is interesting because the authors had *expected* to see the increase in shale gas production lead to an increase in the concentration of natural gas methane in groundwater wells, and yet they found an actual decrease. They determined that "high levels of biogenic CH_4 can be present in groundwater wells independent of hydraulic fracturing activity and affirm the need for isotopic or other fingerprinting techniques for CH_4 source identification" (Claire Botner et al., 2018: Abstract). In other words, they were cautioning researchers not to simply assume that a high level of natural gas methane in groundwater near shale gas operations was *a result of* the operations, because other sources could be at work.

4.5 DiGiulio and Jackson (2016)—Impact to Underground Sources of Drinking Water and Domestic Wells from Production Well Stimulation and Completion Practices in the Pavillion, Wyoming, Field.

This study is noteworthy in the public-policy debate over fracking, because—as the story goes—one of the authors (DiGiulio) had been an EPA investigator but felt the agency was reluctant to publicize the harms of fracking (Vaidyanathan, 2016). On this interpretation, DiGiulio and Jackson (2016) is effectively the truth about fracking. It is worth emphasizing, however, that, although the work of DiGiulio was not contained in the EPA's 2015 draft, it was cited and discussed in the final EPA report that came out in December 2016.

In any event, we here reproduce the study's Abstract:

> A comprehensive analysis of all publicly available data and reports was conducted to evaluate impact to Underground Sources of Drinking Water (USDWs) as a result of acid stimulation and hydraulic fracturing in the Pavillion, WY, Field. Although injection of stimulation fluids into USDWs in the Pavillion Field was documented by EPA, potential impact to USDWs at the depths of stimulation as a result of this activity was not previously evaluated. Concentrations of major ions in produced water samples outside expected levels in the Wind River Formation, leakoff of stimulation fluids into formation media, and likely loss of zonal isolation during stimulation at several production wells, indicates that impact to USDWs has occurred. Detection of organic compounds used for well stimulation in samples from two monitoring wells installed by EPA, plus anomalies in major ion concentrations in water from one of these monitoring wells, provide additional evidence of impact to USDWs and indicate upward solute migration to depths of current groundwater use. Detections of diesel range organics and other organic compounds in domestic wells <600 m from unlined pits used prior to the mid-1990s to dispose diesel-fuel based drilling mud and production fluids suggest impact to domestic wells as a result of legacy pit disposal practices. (DiGiulio and Jackson, 2016: Abstract)

As far as what response these discoveries warranted, here is the discussion from the EPA's 2016 report:

> Following complaints by area residents about changes to their water quality in the mid-2000s, state and federal agencies began a series of investigations, centering on various aspects of the site and supporting differing conclusions about the source and mechanism of the water quality changes.
>
> Twenty-five pits that were used to dispose of drill cuttings, drilling mud, and spent drilling fluids near some of the water wells were also investigated as a potential source of the groundwater contamination. Based on these evaluations, soil and/or groundwater remediation was performed at approximately six of the pits, no further action was recommended at approximately twelve pits, and the remaining pits are receiving further investigation. (EPA 2016: 6-48 ; citations omitted)

This particular study is the most concerning of those reviewed in this update. (Indeed, it may be the reason that the comprehensive EPA 2016 report dialed back some of its sweeping statements in the 2015 initial draft concerning the apparent lack of evidence of fracking's systemic impact on drinking water.)

Even so, the overall significance of the findings is unclear, as some of the detected chemicals have not been sufficiently studied to determine which level should be deemed safe for household use. The lead author of the study told the press: "Right now, we are saying the data suggests impacts, which is a different statement than a definitive impact ... We are saying the dots need to be connected here, monitoring wells need to be installed" (Vaidyanathan, 2016).

Finally, as the study and the EPA 2016 discussion suggest, the possible impact on underground drinking water seems attributable to unlined storage pits for waste products and "shallow fracking" operations. If this diagnosis is correct, then even these admittedly concerning problems could be handled through adjusting procedures, rather than an outright ban.

4.6 Summary of impact on water quality and availability

Since the Fraser Institute's update of 2015, there have been several new studies of the possible impact of fracking on water quality and availability. Although there have now been more documented impacts than was the case in 2015, the overall harms still appear relatively modest. Amending storage procedures to reduce spills and limiting drill depths to avoid contaminating groundwater supplies would reduce the risk to water quality. In those areas where water consumption strains available supplies, the relevant authorities could introduce flexible pricing to ration the available water among competing uses, just as businesses must pay the market price for other inputs.

5 Methane Emissions

In this section we review the issue of methane emissions into the atmosphere, drawing on the large report from The Academy of Medicine, Engineering and Science of Texas (TAMEST) and an additional study.

5.1 The Academy of Medicine, Engineering and Science of Texas (2017)—*Environmental and Community Impacts of Shale Development in Texas*

After a discussion of the "global warming potential" (GWP) of carbon dioxide compared to methane, TAMEST concluded that "using natural gas instead of other fossil fuels produces a climate benefit as long as the methane emissions along the full supply chain, as a percentage of the methane in the natural gas produced, are less than 1 percent (for transportation uses) to less than 3 percent (for electricity generation)" (TAMEST 2017: 94). The report then admitted that the estimates of methane emissions varied over a wide range. However, the crucial insight was that most of the emissions came from relatively few sites, even when adjusting for production levels:

> A study that analyzed data taken downwind of natural gas supply chain sites in the Barnett Shale region defined functional super-emitting sites as those with the highest proportional loss rates—that is, the amount of methane emitted relative to methane produced or methane throughput. Using this definition, ***77 percent of the methane emissions were accounted for by 15 percent of the sites with the highest normalized emissions, with more than 50 percent of the emissions coming from only 2 percent of the sites …***
>
> An issue that is still unresolved is why some sources become high emitters. Analogies with vehicles can, again, provide some insights. Vehicle testing reveals that vehicle type, maintenance, and operation all play a role in determining whether a vehicle becomes a high emitter … In a similar way, in the oil and gas sector, there are some sources that are more likely than others to become high emitters, but operational practices also play a role. For example, in the source category of gas well liquid unloadings, mature wells with low reservoir pressure and high rates of liquid production are more likely to have high unloading emissions. Differences in operational practices, in contrast, can lead to differences in emissions from pneumatic controllers and compressors. (TAMEST 2017: 98; citations removed, emphasis added)

In light of the above considerations, the TAMEST 2017 report concluded its treatment of methane emissions in this way: "***Overall, emissions in many categories associated with shale resource production are dominated by a small sub-population of high-emitting sources. Development of inexpensive, robust, reliable, and accurate methods of rapidly finding high-emitting sources has the potential to reduce emissions***" (TAMEST 2017: 99; emphasis in original).

5.2 Omara, Sullivan, Li, Subramanian, Robinson, and Presto (2016)—Methane Emissions from Conventional and Unconventional Natural Gas Production Sites in the Marcellus Shale Basin

This paper used data from "facility-level CH_4 [methane] emission rates" made at 18 conventional natural gas production sites (consisting of 19 individual wells) and 17 unconventional (involving fracking and horizontal drilling) natural gas production sites (consisting of 88 individual wells) in Pennsylvania and West Virginia, over the period from June 2014 to February 2015. The researchers sought to measure the absolute methane emissions from the two types of operations, as well as emissions adjusted for total output.

The study found that the "mean facility-level [methane] emission rate among [unconventional natural gas] well pad sites in routine production ... was 23 times greater than the mean [methane] emissions from [conventional natural gas] sites". However, the absolute level of methane emissions from fracking sites could be misleading, because the large disparities "were attributed, in part, to the large size (based on number of wells and ancillary [natural gas] production equipment) and the significantly higher production rate of [unconventional natural gas] sites." Indeed, the conventional (that is, non-fracking) natural gas production sites "***generally had much higher production-normalized [methane] emission rates ... compared to [unconventional natural gas] sites ... likely resulting from a greater prevalence of avoidable process operating conditions*** (e.g., unresolved equipment maintenance issues)" (Omara et al., 2016: 2099; emphasis added).

More specifically, the paper attributed the higher production-normalized emissions from the conventional sites to these factors: "(i) variability in the rate of total [natural gas] production, (ii) facility age, (iii) the engineering design of the facility (e.g., utilization of emission capture/control devices), and/or (iv) well operator practices (e.g., the level and frequency of site inspection and maintenance)" (Omara et al., 2016: 2102).

The researchers also found that even when controlling for production levels, methane emissions were heavily concentrated among a few "superemitters" (which included both conventional and unconventional production sites). Here again, the researchers found that "***the excess [methane] emissions from the functional superemitters appeared to be mainly associated with avoidable process operating conditions***" such as "well casing vents ... and open venting from [a] condensate tank" (Omara et al., 2016: 2104; emphasis added).

5.3 Summary of risk of methane emissions

Readers should keep in mind that the issue of methane *emissions*—as opposed to leakage of natural gas methane into underground water sources—does not affect the air quality of local communities but is instead related to global climate change insofar as methane is a potent greenhouse gas. The TAMEST report and Omara et al. summarized in this section both found that fracking natural-gas operations are associated with methane emissions, but that these emissions varied greatly from site to site, and that (at least in Pennsylvania and West Virginia) the *relative* amount emitted (compared to production volume) was actually lower for unconventional than conventional natural-gas production sites. Both sources also found that most emissions came from a relatively small number of sites where procedures could be altered, if deemed desirable. Furthermore, to the extent that increased natural-gas production displaces coal in electricity generation, there is an offsetting effect on global warming in the form of reduced carbon-dioxide emissions.

6 Earthquakes

In this section, we review the issue of earthquakes, drawing on the large TAMEST report as well as three additional studies. In order to keep the findings in perspective, **table 1** provides information about the effects of earthquakes of various magnitudes.

Table 1: Effects of earthquakes of various magnitudes

Magnitude (Richter Scale)	Effects
Less than 2.5	Usually not felt, but can be recorded by seismograph.
2.5 to 5.4	Often felt, but causes only minor damage.
5.5 to 6.0	Slight damage to buildings and other structures.
6.1 to 6.9	May cause a lot of damage in very populated areas.
7.0 to 7.9	Major earthquake; serious damage.
8.0 or greater	Great earthquake; can totally destroy communities near epicenter.

Source: Michigan Technological University, 2017.

6.1 The Academy of Medicine, Engineering and Science of Texas (2017)—*Environmental and Community Impacts of Shale Development in Texas*

Interested readers can review the details in the report itself, but here are some of the relevant Findings and Recommendations as highlighted by the TAMEST 2017 report in its discussion of earthquakes:

> **Findings**
>
> ...
>
> - There has been an increase in the rate of recorded seismicity in Texas over the last several years. Between 1975 and 2008 there were, on average, one to two earthquakes per year of magnitude greater than M3.0. Between 2008 and 2016, the rate increased to about 12 to 15 earthquakes per year on average.
> - Under certain unique geologic conditions, faults that are at or near critical stress may slip and produce an earthquake if nearby fluid injection alters the effective subsurface stresses acting on a fault.
>
> ...
>
> - To date, potentially induced earthquakes in Texas, felt at the surface, have been associated with fluid disposal in Class II disposal wells, **[6]** not with the hydraulic fracturing process. (TAMEST 2017: 17)

[6] As defined by the EPA, Class II wells "are used only to inject fluids associated with oil and natural gas production". Class II wells fall into these three categories: (1) disposal wells (about 20 percent of the total), (2) enhanced recovery wells (about 80 percent), and (3) hydrocarbon storage wells, which include the underground crude oil storage in salt caverns of the Strategic Petroleum Reserve (US-EPA, 2019).

> **Recommendations**
> - Future geologic and seismological research initiatives should develop improved and transparent approaches that seek to balance concerns surrounding data handling and sharing, and that promote sharing of data.
> - Development of a common data platform and standardized data formats could enable various entities collecting data to contribute to better data integration. It also could facilitate interdisciplinary collaboration directed toward mitigation and avoidance of induced seismicity. (TAMEST 2017: 17)

In the main body of the TAMEST report, one finds the following quotation from the National Research Council (NRC) to highlight the distinction in the actual cause of earthquakes and the scope of the possible problem:

> (1) ***The process of hydraulic fracturing an oil or gas well, as presently implemented for shale gas recovery, does not pose a high risk*** for inducing felt seismic events;
>
> (2) ***Injection for disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells*** in operation; and
>
> (3) Carbon Capture and Storage (CCS), due to the large net volumes of injected fluids, may have potential for inducing larger seismic events. (NRC, 2012, quoted in TAMEST 2017: 63; emphasis added)

To summarize, although the TAMEST 2017 report found that human activity had been increasing the frequency of magnitude 3.0+ earthquakes (which is a very low threshold), the cause was not fracking in itself. Rather, it was the injection of wastewater that was the culprit. We will see this pattern in the other studies summarized below, and how revised procedures for wastewater injection could mitigate the potential problem.

6.2 Hincks, Aspinall, Cooke, and Gernon (2018)—Oklahoma's Induced Seismicity Strongly Linked to Wastewater Injection Depth

An excerpt from the Abstract:

> ***The sharp rise in Oklahoma seismicity since 2009 is due to wastewater injection***. The role of injection depth is an open, complex issue, yet critical for hazard assessment and regulation. We developed an advanced Bayesian network to model joint conditional dependencies between spatial, operational, and seismicity parameters. We found that injection depth relative to crystalline basement most strongly correlates with seismic moment release … Restricting injection depths to 200 to 500 meters above basement could reduce annual seismic moment release by a factor of 1.4 to 2.8. (Hincks, Aspinall, Cooke, and Gernon, 2018: Abstract; emphasis added)

The paper first relays that measured seismicity in Oklahoma has increased ~900 fold since 2009. This prompted "Oklahoma regulators to introduce emergency directives aimed at managing injection," and the new measures "appear to have decreased the earthquake count ($M_w \geq 3$) in the period 2015" to 2018 (when the paper was published).

As the emphasized sentence in the quotation from the Abstract indicates, it is commonly accepted in this literature that the massive increase in Oklahoma's seismic activity is due to wastewater injection. The paper relied on monthly underground injection control (UIC) well data from January 2011 to September 2016 obtained from the Oklahoma Corporation Commission (OCC), as well as earthquake location and magnitude data from the ComCat catalog maintained by the Advanced National Seismic Systems (ANSS). The basement depths at well sites were estimated from 1,232 depth records obtained from the Oklahoma Geological Survey.

The paper is very technical but for our purposes it suffices to say that it sought to quantify what effect injection depth had on seismicity, in addition to the effect of high-rate injection on seismicity already documented (e.g., Weingarten, Ge, Godt, Bekins, and Rubinstein, 2015). In other words, the paper sought to create a more accurate model of the interaction between wastewater disposal practices and induced seismicity, to assess the relative importance of (say) putting limits on injection depth compared to capping the volume flow rate of wastewater injection.

The authors' simulations found that the various factors had a complex, interactive effect on induced seismicity (which is difficult to summarize in this review). In their conclusion they argued:

> Our framework allows regulatory actions to be evaluated on a rational, quantitative basis in terms of seismic effects. The model could be used to identify evolving vulnerability, complementing zoned seismic hazard forecasts of the U.S. Geological Survey (USGS), and provide a basis for targeted management of induced seismicity in Oklahoma and other wastewater disposal regions. We welcome the support of researchers, operators, regulators, and policy-makers in updating and extending our model. (Hincks, Aspinall, Cooke, and Gernon, 2018: 1255)

Thus we see a pattern for Oklahoma similar to that recommended by the TAMEST 2017 study for Texas: more research, of course, but in the meantime a consideration of adjusting wastewater disposal practices to reduce induced seismicity.

6.3 Pollyea, Chapman, Jayne, and Wu (2019)—High Density Oilfield Wastewater Disposal Causes Deeper, Stronger, and More Persistent Earthquakes

This study's abstract states:

> Oilfield wastewater disposal causes fluid pressure transients that induce earthquakes. Here we show that, in addition to pressure transients related to pumping, there are pressure transients caused by density differences between the wastewater and host rock fluids. In

> northern Oklahoma, this effect caused earthquakes to migrate downward at ~0.5 km per year during a period of high-rate injections. Following substantial injection rate reductions, the downward earthquake migration rate slowed to ~0.1 km per year. Our model of this scenario shows that the density-driven pressure front migrates downward at comparable rates. This effect may locally increase fluid pressure below injection wells for 10+ years after substantial injection rate reductions. We also show that in north-central Oklahoma the relative proportion of high-magnitude earthquakes increases at 8+ km depth. Thus, our study implies that, following injection rate reductions, the frequency of high-magnitude earthquakes may decay more slowly than the overall earthquake rate. (Pollyea, Chapman, Jayne, and Wu, 2019)

The main contribution of this study is that it "challenges the assumption that fluid properties are of negligible importance to pressure accumulation and decay in the seismogenic zone". The authors were trying to solve the puzzle of why annual earthquake frequency declined dramatically along with saltwater disposal (SWD) volume in Alfafa County, Oklahoma after 2015 (which was expected), while the mean annual depth of earthquake hypocenters continued to increase (which was *not* expected).

To explain "systematically increasing hypocenter depths in Alfalfa County" even years after a significant reduction in the volume of salt water disposal from unconventional oil and gas operations, the authors "hypothesize that wastewater produced from the Mississippi Lime formation comprises higher total dissolved solids (TDS) concentration (and thus higher density) than fluids in the Precambrian basement (seismogenic zone)", and that this "density differential drives advective transport of wastewater into the seismogenic zone, thus increasing fluid pressure enough to trigger earthquakes". Using data from the United States Geological Survey's National Produced Waters Geochemical Database, the authors confirmed their hypothesis.

To assess the importance of this finding, the authors then develop two types of models, one that accounts for the difference between wastewater and host-rock fluids and "an identically parameterized model that neglects thermal and compositional variability between the wastewater and host-rock fluids". They conclude:

> Pressure recovery rates predicted by [the] variable density models are substantially different than pressure recovery in the constant-density models, the latter of which recovers rapidly to pre-injection conditions … Our complete set of results … reveal that high-density wastewater can become effectively trapped within the seismogenic zone thus maintaining elevated fluid pressure over 10- to 15-year timescales. In aggregate, our results show that the density-driven pressure accumulation and decay process is robust to a wide range of permeability scenarios when there is a large density contrast between SWD and basement fluids. (Pollyea, Chapman, Jayne, and Wu, 2019)

The excerpt above contains much technical language but, in plain English, the authors concluded that *it was important* to model the fact that the wastewater being injected into the ground may have a different density than the fluids originally present. (Other researchers had neglected this real-world complication.) This effect can linger even 10 to 15 years after the initial injection of the high-density wastewater.

The 2019 study by Pollyea, Chapman, Jayne, and Wu illustrates the current knowledge of the connection between fracking—or more accurately, wastewater disposal techniques associated with fracking—and earthquake intensity and frequency. The field is still evolving rapidly, with experts continuing to refine their views on the relative importance of different factors. This evolving understanding in turn affects the recommendations for how best to adapt wastewater disposal regulations and/or industry standards in order to minimize human-induced seismic activity. In particular, this study shows that it is *not* merely the volume of flow that matters (as previous researchers noted), but also—in some regions—the difference in density between the injected wastewater and the fluids already present in the host rock.

6.4 Summary of risk of earthquakes

It is important to emphasize that the term "earthquake" in the context of fracking can be misleading. It is typical in the literature to focus on earthquakes of magnitude 3.0 and higher, but at this level little damage is caused. Indeed, despite the large increase in (apparently) human-induced earthquakes in Oklahoma and Texas after 2009, the United States Geological Survey (USGS) only lists two US fatalities from earthquakes from 2000 to 2012 (the last year posted), and they occurred in 2003 (USGS, 2019).

The research on human-induced seismicity continues to evolve, with experts developing more nuanced models that can be applied to the large swings in saltwater disposal volume that have occurred in the industry. Although recent research suggests that the impact of certain wastewater disposal practices may be longer lasting (at least in certain regions) than previously thought, our general conclusion mirrors that of Fraser Institute's update of 2015: there are definite risks that wastewater disposal techniques may induce seismic activity, but these are not due to fracking in itself. Furthermore, the overall impact has thus far been relatively modest in comparison to the wide scope of activity. The latest research shows that the heightened risk for seismicity from wastewater injection is the result of a complex interaction of several factors, including the volume of flow, the depth of the injection, and the density differential between the wastewater and the fluids already present in the host rock. As our knowledge continues to improve, it appears that the seismic impact can be mitigated by paying attention to these factors and adjusting practices accordingly, depending on the expected benefits (in reduced earthquake risk) and costs (more expensive wastewater disposal).

7 Noise Pollution

In this section we review a study of noise pollution by Richburg and Slagley (2019). The study "measured sound pressure levels in neighborhoods adjoining hydraulic fracturing well pads, compression stations, and processing plants in Southwest Pennsylvania" (2019: 5) and it also surveyed residents (8 males and 15 females) in the area about their hearing and health concerns. The measurements were taken in 13 locations from February 2014 to July 2016.

The results and conclusions in the Abstract of the study are relatively brief and can be quoted in full:

> **Results**
> Daytime instantaneous sound levels ranged between 45.0 and 61.0 dBA. Dosimeter studies recorded day–night levels (L_{dn}) of 53.5–69.4 dBA outside and 37.5–50.1 dBA inside, exceeding United States Environmental Protection Agency guidelines. Respondents indicated the NTGI noise disturbed their sleep, and the majority of respondents (96%) reported being worried about their overall health as a result of the noise.
>
> **Conclusions**
> Health care professionals serving rural areas impacted by hydraulic fracturing (fracking) should be aware of potential noise stressors on the populations they serve.

In order to interpret the above results, **table 2** (based on information provided by the Hearing Health Foundation) will be useful.

Table 2: Decibel levels of common sounds

Sound	Decibel level	Sound	Decibel level
Jet taking off	140 dB	Hair dryer	70 dB
Ambulance siren	120 dB	Normal conversation	60 dB
MP3 players at maximum volume	105 dB	Refrigerator	40 dB
Heavy city traffic	85 dB	Whisper	30 dB

Note: The "dBA" unit in the Richburg and Slagley (2019) means decibels that are "A-weighted" according to how the human ear perceives loudness as a function of frequency. (It is somewhat analogous to a "wind-chill factor" in temperature reports.) For our purposes, we can use the dB levels above interchangeably with the dBA reported in the study.
Source: Hearing Health Foundation, 2020.

Reviewing the study's conclusions in light of the table, we see that residents indoors were subjected to noise levels comparable to (or a bit louder than) a refrigerator but quieter than a normal conversation. This is certainly something that should be monitored, and local communities that are considering the introduction of new fracking operations should be aware of the issue, but such noise pollution does not at this point seem to warrant changes in industry procedures.

8 Conclusion

After reviewing some of the most relevant new research to emerge since the 2015 update on fracking safety from the Fraser Institute (Green and Jackson, 2015), our conclusions largely match those offered by the earlier authors. Our understanding of the mechanisms through which fracking may affect human welfare—specifically through impacts on drinking water and seismicity—has improved, and researchers may view these particular impacts as more serious now than was the case in 2015.

Even so, actual demonstrated harm to human welfare from fracking is extremely modest, despite the enormous boom in fracking operations and the passage of many years to allow for an assessment of its effects. More important, most of the problems associated with fracking are not due to fracking in itself, but rather to certain procedures in wastewater storage and disposal that involve a complex interaction between the volume flow, depth, and density of the fluids. These can be amended to reduce the risks. The potential strain on the availability of water in some local communities can be ameliorated through the introduction of flexible pricing for water, to avoid waste and ensure that the available water supply is channelled to its high-valued uses.

Contrary to the sweeping rhetoric of some environmental activists, the public-policy issue is not the question, "Is fracking safe?" After all, is driving safe? In 2018, Canada suffered 1,922 motor-vehicle fatalities (Government of Canada, 2019) but most Canadians would agree that "banning cars" would be a cure far worse than the disease. Instead, a much more reasonable policy is to allow the practice while always striving to identify and reduce the specific causes of accidents, through better vehicle design, changes in road layout, updated penalties on driving while intoxicated, and so on.

Likewise, the reasonable policy response to the identified risks of fracking is to allow the practice while considering various changes in operations that could minimize such risks. Ideally, the benefits and possible harms of fracking would be limited to the same group of decision makers. For example, if an isolated individual owned land sitting atop extensive shale gas resources, then an ideal scenario would involve the individual making an informed decision as to whether royalty payments from commercial developers were sufficient to compensate for the potential impact of fracking operations on the individual's supply of drinking water, exposure to noise pollution, and so on. In this ideal scenario, no external government regulations would be necessary because fully informed individuals could consider the pros and cons of various offers from outside companies regarding the procedures to be used and the amount of monetary compensation for permission to begin fracking operations.

The real world, of course, is more complicated than this hypothetical ideal scenario. Residents affected by fracking operations do not necessarily all have the same tolerance for risk, and they may not be fully informed about the pros and cons of various production protocols. There is also the complication that some of the benefits and harms of fracking are not fully borne by the landowner when he or she is deciding whether to allow such operations.

Moreover, there are overlapping jurisdictions of pre-existing regulation, making it difficult to distill a set of simple recommendations for government officials. In this context, it is important to note that (1) even absent formal regulations governing fracking itself, victims of demonstrable harm may be able to sue developers through the traditional court system; and (2) on the issue of water usage, many economists would argue that a policy allowing market-based pricing (as opposed to under-priced water leading to shortages) would eliminate some of the documented effects of fracking upon the availability of water.

Because of the complexity of the legal and regulatory frameworks, the present paper will merely state that, in light of the most current research, it still appears that fracking is a tolerably safe practice that confers large economic benefits for Canadians. The documented risks it poses still appear relatively modest, and can largely be mitigated through appropriate changes in industry practice. Whether these changes should merely be urged through voluntary industry “best practices” compliance, through education of local communities who must ultimately give permission for companies to operate, or through changes to government regulation, is a complex topic that lies outside the scope of the present update.

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