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To Whom It May Concern:

I am delighted to provide material for consideration by the Panel as it deliberates the environmental and health impacts and risks associated with hydraulic fracturing. By way of introduction, I have studied and written extensively on the topic, focusing on the epidemiologic issues that must be considered before hydraulic fracturing of onshore unconventional gas development is approved. While it is impossible to expect that the process would be risk-free, it is the Panel's charge to weigh the potential benefits against the potential harms and risks. There is now a large body of evidence that has examined the impact of unconventional gas development in the United States. The findings warrant that caution be exercised, as once drilling and extraction commence, it is too late to repair the damage to the environment.

I have served as an outside expert reviewer of Health Protection Scotland's White Paper on assessing the potential benefits and potential harms of unconventional gas development. I have been an invited speaker at the European Commission's Technical Workshop on Public Health Impacts and Risks Resulting from Oil and Gas Extraction to discuss the epidemiological and Public Health perspective of unconventional gas development. I have been an invited speaker at a conference on the topic held in Sydney Australia, and have provided expert consulting to numerous organizations in the United States and Europe. My book, The Human and Environmental Impact of Fracking (Praeger Press, 2015), is a comprehensive presentation of the impact fracking on air quality, water quality, human and animal health, climate change, and community. I am happy to send a copy to the Panel.

As the Panel deliberates the potential benefits and potential risks associated with hydraulic fracturing, it is important to have a very clear understanding of the issues. Australia is the driest continent on earth. Where are you going to get the millions of gallons of water required for the drilling and extraction process? What effect will extraction of water from aquifers have on the water table? Where are you going to store the flow back fluids that are composed of water and chemicals used in the drilling and extraction process? How much will it cost to transport the shale gas from the well site to market? What is the reserve capacity of the natural gas? Is there sufficient gas to make the drilling, extraction, and transportation of gas economically worthwhile? What other sources of energy should be considered? Australia is blessed with intense and immense sun for most of the year--would solar panels, for example, make more economic sense?

While assessing the scientific evidence of the environmental and health impacts and risks associated with hydraulic fracturing is extremely important in decision-making, it is also imperative that baseline health data be collected in order to empirically determine the impact on human health going forward. Environmental and Health Impact Assessments must be conducted, and the findings analyzed carefully before going forward.

Further, there must be a plan in place before drilling to deal with the potential for groundwater and surface water contamination. Based on my study of the potential harms and risks of unconventional gas development, it is my opinion that one should proceed very cautiously before embracing this energy source. The harm to the climate and environment have been shown in studies done in the United States. Granted Australia is quite different from the U.S. geographically, the issues are the same. How are you going to safeguard the environment, and at what cost?

Respectfully submitted,

Prof. Finkel

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Environmental and health impacts of 'fracking': why epidemiological studies are necessary

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Over the past decade, there has been a surge in drilling for natural gas and oil in shale rock. Natural gas and oil extraction using high-volume, slickwater hydraulic fracturing from clustered multiwell pads using long, directionally drilled laterals (known by its popular name 'fracking'), is an unconventional extraction process that is currently the focus of controversy. The process involves the injection of millions of gallons of water, chemical additives, and a proppant (sand and/or silica) at high pressure into a wellbore in order to create small fractures in the rock formations to allow natural gas (or oil) to be released. But for the lack of effective technology, this source of energy would have been tapped long ago.

While there are some positive aspects of high-volume hydraulic fracturing (eg, reduction in the dependence on foreign oil and gas; becoming a net exporter of natural gas and oil; possible reduction in unemployment in areas where wells are drilled), there are serious concerns including its impact on climate change and the potential harm to the environment and human health.

The process of drilling, extracting and transporting oil and gas is a dirty, messy and polluting process if not done correctly, cleanly and carefully. Well venting, flaring and burning gas on release account for the largest sources of air emissions. Volatile organic compounds and diesel particulate matter, for example, result in elevated air pollution concentrations that exceed US Environmental Protection Agency (EPA) guidelines for both carcinogenic and non-carcinogenic health risks. Truck traffic and diesel truck exhaust contribute to airborne emissions of fugitive dust and high benzene concentrations.

The structural integrity of wells can and does fail over time; for example, cement cracks and steel casing barriers corrode. Wells have blowouts, spills are common, and methane is leaked and vented into the atmosphere at all stages of the extraction process. By far, one of the most critical issues is the management (storage, treatment and disposal) of water produced in the gas or oil extraction process. The flowback water contains thousands of gallons of toxic chemicals, the vast majority of which are not identified. Moreover, an undetermined number of the chemical compounds used in the drilling and fracturing processes lack scientifically based maximum contaminant levels, which makes it difficult to assess their public health risks. The mixture of chemicals used by drilling companies is considered to be proprietary, and in many states companies are not mandated to disclose information about the quantities, concentrations or identities of the chemicals used in the process despite calls for such action.

While many states actively support this technology (eg, Pennsylvania, Texas, Louisiana, North Dakota, Wyoming), a growing number of states and municipalities are more hesitant to embrace it. For example, whereas Pennsylvania embraced an aggressive drilling agenda, neighbouring New York took a more cautious route. Both states sit atop the Marcellus Shale.

Several years ago the governor of New York placed a de facto ban on high-volume hydraulic fracturing pending an assessment by the Department of Health (DOH) of the potential health and environmental risks of high-volume hydraulic fracturing. On the basis of the findings compiled in a comprehensive report issued by the DOH, Governor Cuomo, in mid-December 2014, announced that this procedure will be banned in New York State because of the risks to health and the environment. The report concluded that until there is sufficient scientific information to determine the level of risk to public health, and until there is a plan to adequately manage potential risks, high-volume hydraulic fracturing should not proceed in New York. To a certain degree, the governor's decision reflects that of the majority of Americans across the country who are very concerned about high-volume hydraulic fracturing's impact on the environment, as well as on human health.

The available science raises substantial questions about the potential for harm to health. Naturally occurring radioactive materials (NORMs), toxic flowback water, and production brine are brought to the surface during the extraction process. NORMs consist of uranium, thorium, and decay products including radium and radon. Exposure to any of these can be a public health concern if exposure occurs at sufficiently high levels.

People living near drilling sites are presenting with symptoms (eg, skin rashes, nausea, abdominal pain, respiratory difficulties, headaches, dizziness, eye irritations, throat irritations, nosebleeds, anxiety, stress) that demand further investigation. Anecdotal reports of health problems (ranging from the mild to the more serious) do not advance knowledge in a meaningful way. High-volume hydraulic fracturing is generally taking place in rural, poor areas where poor healthcare status is not uncommon. Yet, can one truly and confidently state that but for the gas or oil extraction activity an individual would be healthy? Epidemiological studies must be conducted to assess the strength of association among risk factors and health.

Without baseline morbidity and mortality data, without accounting for bias and confounding, without applying Hill's criteria (especially taking into account dose-response relationships, temporality, consistency across a range of studies), findings may not reflect a true association of risk factors and health outcomes. Clearly, there is a need for well-designed, methodologically sound studies.

While there has been a dramatic increase in the number of peer-reviewed published studies on the topic, there are few well-designed studies to quantify the connections between risk factors and health outcomes, especially among populations living in close proximity to shale gas operations. There have been numerous small-scale health outcomes studies conducted, but these studies are limited in their ability to show that exposure to risk factors caused a health outcome. The findings are suggestive, but do not demonstrate cause and effect.

Ecological descriptive studies, while useful, only generate hypotheses, they do not test hypotheses. They can suggest a relationship between a risk factor and health outcomes; they cannot show cause and effect. Hypothesis testing studies have advantages as well as disadvantages: Prospective cohort studies are expensive

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and take a long time; case–control studies are cheaper and quicker to conduct, but care must be taken in selecting both cases and controls. Regardless of the type of study design used, drawing conclusions about causal association is not so simple from an epidemiological perspective.

That being said, a few important studies are currently underway that hopefully will add to the body of knowledge:

- The Marcellus Shale Initiative Study is a National Institute of Health-funded project focusing on asthma control and pregnancy outcomes among patients at the Geisinger Health System in Pennsylvania.
- The University of Colorado at Boulder Sustainability Research Network, a National Science Foundation funded study, is focusing on the impact of high-volume hydraulic fracturing on air and water.
- A long-awaited EPA study on hydraulic fracturing, and the potential impact on drinking water resources is underway, with the full study expected to be completed in 2016.
- The Pennsylvania Department of Environmental Protection Comprehensive Oil and Gas Development Radiation Study focuses on radioactivity levels in produced and flowback waters, wastewater recycling, levels of radon in natural gas, and potential exposures of workers and residents near drilling sites.

High-volume hydraulic fracturing is relatively new (approximately 10 years), and diseases, such as cancer, can take many years to present. In the meantime, it would be instructive to examine trends in morbidity and mortality in areas with gas and oil extraction and compare the data to neighbouring areas without such activity. For example, many respiratory and reproductive conditions are known to be impacted by environmental insults as are many cancers (eg, bladder, thyroid, leukaemia). Trend data at the municipal level, or at the county level, are far more precise than that for an entire state. Such data can shed light on health in a particular area at a particular point in time. However, it is important to look at the data years before gas or oil extraction began, as it would be unusual to see any appreciable changes in morbidity and mortality in the short term. While some symptoms may appear fairly quickly, other symptoms will take more time to develop.

Certainly, the potential for harm will vary by proximity to drilling sites, the nature of the exposure, exposure pathways, route of exposure, and length of time exposed. There needs to be particular attention paid to when the drilling started, for how long individuals lived in proximity to the drilling site, and the health status of the individuals prior to drilling. There must be an understanding of potential confounding factors, especially behavioural factors, such as tobacco smoking, diet and health insurance status.

Well-designed epidemiological studies are absent, but given the available evidence from published studies looking at air and water-quality impacts, including groundwater contamination, it is prudent to proceed cautiously. There are significant uncertainties about adverse health outcomes that may be associated with high-volume hydraulic fracturing, and that should give us cause for concern.

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The Rush to Drill for Natural Gas: A Five-Year Update

Follow-up on: Finkel ML, Law A. The rush to drill for natural gas: a public health cautionary tale. Am J Public Health. *2011;101(5): 785–85.*

Five years ago, *AJPH* published our article[1] discussing the potential harm to the environment and human health from horizontal drilling and high-volume hydraulic fracturing of shale (e.g., fracking; hereafter referred to as unconventional gas development or UGD). At that time, the United States was importing oil and gas to meet its energy needs, gasoline prices at the pump were at record high levels, and UGD was proceeding at a rapid pace. There was a paucity of empirical data to confirm or refute the potential for harm from the process of drilling, extracting, and transporting natural gas and oil trapped in formations of low permeability (e.g., shale). We concluded that much remained unknown about the potential for harm from UGD and advocated that preventive, cautionary action should be taken in the face of uncertainty. Given the lax regulatory climate at the time, we felt that the burden of proof should be shifted to the industry to minimize degradation and damage to the public's health and the environment.

Since 2011, there has been not only a surge in drilling for natural gas and oil in the United States (e.g., California, Colorado, Louisiana, North Dakota, Pennsylvania, Texas) and in other countries (e.g., Australia), but also a huge increase in the number of published studies focused on environmental and public health impacts associated with UGD. Nearly 700 peer-reviewed publications, most published since 2013, provide empirical evidence of the various environmental, health, and societal effects of UGD. Potentially serious consequences associated with UGD have become more clearly defined.

Environmental and health impacts are evident at every stage of UGD, including construction of well pads, drilling the wells, extracting the gas, storing the byproducts of the extraction (e.g., flowback fluids), transporting the natural gas by diesel trucks, construction of compressor stations, and building pipelines. Well blowouts, spills, and release of methane into the atmosphere occur to the detriment of the environment. Of particular concern is the use of chemicals, many known to be carcinogens, in the extraction phase. Industry is legally protected from disclosing the composition of chemical mixtures, making it very difficult to determine the consequences of exposure in the short and long term.

Management (storage, treatment and disposal) of flowback wastewater containing thousands of gallons of toxic chemicals is often lax, creating a situation of potential danger to those living in areas where UGD is active as well as to those living out of the region. Proper disposal of flowback fluids is critically important to the protection of both surface and ground water. Flowback wastewater can be stored in containment pits or tanks on site, but there are problems with this option. The failure of a tank, pit liner, or the line carrying fluid ("flowline") can result in a release of contaminated materials directly into surface water, shallow ground water, and soil. Streams and aquifers have been polluted from flowback wastewater.

Although some drill operators recycle flowback wastewater to be used again in the extraction phase, another option is to transport the wastewater to water treatment facilities authorized to treat and discharge flowback wastewater. However, the majority of these facilities are not equipped to treat the total dissolved solids in flowback fluids, which can reach extremely high levels of both concentration and variability. Flowback wastewater also has been sprayed on local roads, which, while perhaps expedient, is not the most prudent way to dispose of the fluid.

There is now ample empirical evidence to link shale gas development to surface and groundwater contamination.[2,3] Furthermore, there is strong evidence of an association between the injection of flowback fluids into underground injection wells and an increase in the frequency of earthquakes.

Air pollutants, such as hydrogen sulfide, nitrogen oxides, volatile organic compounds (e.g., benzene and formaldehyde), particulate matter, sulfur dioxide, and ground level ozone, are emitted or produced and released during all of the drilling and extracting phases.[4] Especially worrisome is the release of airborne pollutants during well venting, flaring, and burning gas on release. Truck traffic and diesel truck exhaust also contribute to airborne emissions of fugitive dust, fine particulate matter, and high benzene concentrations. Fugitive methane (emissions that are not captured for use) has considerable climate implications, as does the contamination of well water. Unconventional gas is predominantly methane, which is estimated to have a global warming potential 25 times greater than carbon dioxide over a 100-year period.[5]

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Alarmed by "increasingly harmful environmental trends," the Rockefeller Foundation–Lancet Commission on planetary health was formed to address changes to the environment, including climate change, ocean acidification, land degradation, and water scarcity, on human health.[6]

A less well-known harm to the environment is the despoliation of farmland as a result of silica sand mining (frac sand), which is a necessary ingredient in the hydraulic fracturing process. Illinois, Wisconsin, and Minnesota have some of the richest agricultural land areas in the United States, areas that sit atop huge deposits of fine silica sand (St. Peter sandstone). Silica is used to keep the fissures in the rock open (a proppant) so that the locked-in oil and gas can escape. Silica sand mining has led to the destruction of large areas of Midwestern farmland. From a Public Health perspective, inhaling crystalline silica can lead to serious, sometimes fatal illnesses, including silicosis, lung cancer, tuberculosis (in those with silicosis), and chronic obstructive pulmonary disease.

In addition to the potential for harm to the environment, epidemiological studies are providing evidence of potential harm to health. Exposure to ozone, particulate matter, silica dust, benzene, and formaldehyde is linked to adverse respiratory health effects, particularly in infants and children.[7] Recent empirical evidence shows an increase in adverse birth outcomes (e.g., preterm birth, low birth weight) in areas with active drilling, especially among women living close to gas wells.[8] Also documented is an increase in hospital utilization rates (admissions for cardiac and neurologic conditions in particular) among those living in proximity to wells,[9] and mental health problems have been shown to be associated with proximity to drilling sites.[10] Adverse effects must be understood in context of proximity to drilling sites, the nature of the exposure, exposure pathways, route of exposure, and length of time exposed. There must be an understanding of potential confounding factors, especially behavioral factors, such as tobacco smoking, diet, and occupation history.

Although some symptoms and diseases may appear fairly quickly, others will take more time to develop. Diseases with long latency periods (e.g., cancer, chronic respiratory illness, impaired cognition, neurologic impairment) will not be evident for years and will depend on the nature and duration of the exposure. For example, to what extent will the chemicals used in UGD have the potential to negatively affect the endocrine system? Colborn[11] evaluated hundreds of chemicals used in the drilling and extraction process and found that more than one third of these chemicals were endocrine disruptors, which could produce adverse developmental, reproductive, neurologic, and immune effects in humans. The hydraulic fracturing process releases toxic and cancer-causing chemicals such as benzene, toluene, and xylene (BTEX). To what extent will exposure lead to reproductive, metabolic, neurologic, and other diseases, especially in children and pregnant women?

Since our article was published, oil and natural gas prices have plummeted to record lows. There is a global glut of oil and gas, and the United States has become a net energy exporter thanks to the shale gas boom. Yet, there are valid, nagging concerns about UGD, prompting many countries (e.g., Bulgaria, France, Germany, Netherlands, Scotland, Spain, Wales) and states (e.g., Maryland, New York, and municipalities in areas of California, Colorado, Texas) to issue a moratorium on hydraulic fracturing, citing the need for more empirical evidence about the consequences of UGD.

As nations debate the merits of UGD, there needs to be a strong Public Health and environmental presence in the debate. Baseline health data need to be collected before drilling to assess changes in disease incidence over time. Biomonitoring studies to document ambient air quality during the drilling and extraction phases of UGD need to be done to assess the impact on air pollution. Chemicals used in the process must be disclosed to assess the potential for harm to human health. There needs to be a better way to manage flowback wastewater so as not to pollute water sources.

In our 2011 article, we called for a balance between the need for energy with the protection of the public's health. Five years later, mounting empirical evidence shows harm to the environment and to human health from UGD, and we have no idea what the long-term effects might be. We again stress the importance, indeed urgency, to focus on fair and sensible energy policies, and to be mindful of the implications that such policies have on our environment and on population health. Ignoring the body of evidence, to us, is not a viable option anymore. AJPH

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The Rush to Drill for Natural Gas: A Public Health Cautionary Tale

Efforts to identify alternative sources of energy have focused on extracting natural gas from vast shale deposits. The Marcellus Shale, located in western New York, Pennsylvania, and Ohio, is estimated to contain enough natural gas to supply the United States for the next 45 years.

New drilling technology—horizontal drilling and high-volume hydraulic fracturing of shale (fracking)—has made gas extraction much more economically feasible. However, this technique poses a threat to the environment and to the public's health. There is evidence that many of the chemicals used in fracking can damage the lungs, liver, kidneys, blood, and brain.

We discuss the controversial technique of fracking and raise the issue of how to balance the need for energy with the protection of the public's health. (*Am J Public Health*. 2011;101:784–785. doi:10.2105/AJPH.2010.300089)

Madelon L. Finkel, PhD, and Adam Law, MD

LONG BEFORE THE DISASTROUS oil spill in the Gulf of Mexico, there have been calls for the United States to wean itself from foreign oil by exploring alternative energy sources. Nuclear power and coal have their own sets of problems; therefore, natural gas is increasingly viewed as a viable alternative to meeting US energy needs. There are trillions of cubic feet of recoverable natural gas in the Marcellus shale, for example, more than enough for the next 45 years.[1] Relying on natural gas will make it easier to meet federal air quality standards for conventional pollutants such as smog and mercury. But for the lack of effective technology, this source of energy would have been tapped long ago. However, natural gas extraction has its own set of health and environmental problems that must be assessed carefully before wholesale drilling is embraced.

Over the past decade, there has been a surge in drilling for natural gas in shale rock. For example, the Marcellus Shale, a black shale formation that lies up to 10 000 feet below ground surface extending over 54 000 square miles primarily in New York and Pennsylvania, contains between 168 trillion to 516 trillion cubic feet of natural gas.[2] The economic benefit of drilling for natural gas is potentially huge for landowners, states, and industry. There are estimates of more than $500 billion in recoverable gas in Pennsylvania alone.[3] Whereas in the past the thinness of the formation and tightness of the shale made drilling for and extraction of natural gas difficult and expensive, new technologies that allow for horizontal drilling and high-volume hydraulic fracturing of shale (fracking) have made extraction much more economically feasible.

Hydraulic fracturing relies on pumping as much as five million gallons of surface water mixed with tons of chemicals and solids (e.g., sand) under high pressure to create fractures and open joints in the shale, thus releasing the flow of gas. From 2000 to 2008, the number of active gas wells drilled in New York State nearly doubled from 6845 to 13 687, and over the next decades an additional 80 000 wells could be drilled.[4] The rush to drill without sufficient health and environmental impact studies, however, has caused concern. In response, the New York State Department of Environmental Conservation stopped issuing drilling permits so that impact studies could be conducted.[5] Although New York State issued a moratorium, drilling continues at a fast pace in neighboring Pennsylvania, where there are more than 350 000 active and inactive gas wells. Industry estimates indicate that over the next 20 to 30 years an additional 300 000 new wells could be drilled by using fracking technology.[6]

As drilling companies are not legally required to list the chemical compounds used in fracking, it is difficult to assess the full scope of the contents of fracking fluids. However, toxic mud and fluid byproducts from the drilling and fracking as well as spills of oil and gas wastes are not uncommon. Of the more than 8600 abandoned wells in Pennsylvania in 2009 alone, taxpayers paid to plug 259 because of leaking natural gas, oil, and acid mine drainage into the groundwater, surface water, and air.[7] Postmineral extraction cleanup costs are substantial, including restoration of damaged or contaminated streams and soil, improper handling of wastewater disposal, and improper disposal of radioactive material and hazardous waste. In August 2010, the Environmental Protection Agency (EPA) sent letters to nine drilling companies requesting detailed information about the chemicals contained in fluids used in fracking. Such information is deemed essential to understand better the potential health and environmental effects of hydraulic fracturing.

Additionally, fracking has raised concerns regarding the way it may damage underground water supplies. No state has adequate regulations on drilling, particularly the disposal of the polluted water. Although drilling companies are expected to submit water management plans to the appropriate state agencies that oversee environmental protection, often there is little state oversight; companies are expected to self-report violations, which they do not do voluntarily. In Pennsylvania, several drilling companies have been charged with illegal water withdrawals and others have been found to be operating without permits. The state does not have a comprehensive underground water monitoring system in place, and no comprehensive data exist on spills.

Soil contamination also has not been addressed fully. Drilling sludge (a mixture that includes drilling mud and rock cuttings containing hydrocarbons, radioactive material, and heavy metals) is brought to the surface during the drilling phase. Flowback waste fluids, a byproduct of the fracking phase, must be disposed of safely because they can potentially contaminate air and soil. Radioactive hazardous waste needs to be taken to special disposal sites. However, clandestine dumping is widely suspected, thus further jeopardizing both soil and watersheds.

Little research has been done on the potential adverse health effects of fracking. Witter et al. reviewed the available literature, which showed evidence of risk to human health ranging from the comparatively benign to the more serious.[8] One study, based on Pennsylvania Department of Environmental Protection and the Susquehanna River Basin Commission Material Safety Data Sheets for 41 products used in fracturing operations, assessed the chemicals used in fracturing and found that 73% of the products had between 6 and 14 different adverse health effects including skin, eye, and sensory organ damage; respiratory distress including asthma; gastrointestinal and liver disease; brain and nervous system harms; cancers; and negative reproductive effects.[9] Some of the negative health effects appeared fairly immediately after exposure whereas others appeared months or years later, as was the case with some cancers, harm to the reproductive system, or developmental effects. Of concern is that endocrine-disrupting chemicals may alter developmental pathways, manifesting decades after exposure or even transgenerationally by altering epigenetic pathways. Hydrofracking fluid and flowback fluids contain candidate endocrine disruptors, but because of the lack of disclosure by the drilling companies of the individual chemicals with their unique Chemical Abstracts Service registry numbers used in fracking fluids, it is difficult to truly assess their potential adverse effects, and so the cumulative exposure impact is not known.

Because fracking has the potential for environmental and health harm, we advocate using the precautionary principle, which asserts that the burden of proof for potentially harmful actions rests on the assurance of safety in areas of scientific uncertainty (analogous to and partially derived from primum, non nocere [first, do no harm]). Inherent in the principle is that preventive action should be taken in the face of uncertainty, the burden of proof should be shifted to the proponents of an activity, alternatives to possibly harmful actions need to be explored, and there should be increased public participation in decision-making.[10]

In March 2010, the EPA announced that it would conduct a detailed study of the environmental and health impacts of fracking. We hope that before drilling in the Marcellus Shale becomes harmful, legislators and the natural gas industry will follow the EPA's and New York State's lead and pause to reflect on recent and past oil and gas disasters by agreeing to a moratorium on hydraulic fracturing. We argue that it would be prudent to invoke the precautionary principle before further degradation and damage to the public's health and the environment occur. The stakes are high as the disaster in the Gulf, the worst oil spill in US history to date, so visibly demonstrates. ■

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Both authors contributed equally in the writing of the article.

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Review Article

Modern Natural Gas Development and Harm to Health: The Need for Proactive Public Health Policies

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High-volume horizontal hydraulic fracturing of shale formations has the potential to make natural gas a significant, economical energy source, but the potential for harm to human health is often dismissed by proponents of this method. While adverse health outcomes of medical conditions with long latency periods will not be evident for years and will depend on the exposure, duration of exposure, dose, and other factors, we argue that it would be prudent to begin to track and monitor trends in the incidence and prevalence of diseases that already have been shown to be influenced by environmental agents. The dirty downside of modern, unconventional natural gas development, as well as the potential for harm, is discussed.

1. Introduction

A modern form of natural gas development has become a global "game changer" in the quest for energy. Natural gas, abundant around the world, has a clean reputation compared to other fossil fuels since it burns less carbon when used. It is easy to transport, reasonably economical, and requires comparatively quick construction timelines and low capital costs.

Traditionally, natural gas was extracted using a method that bores a vertical well in single gas reservoirs close to the surface (conventional natural gas drilling). However, drilling for natural gas in shale rock was not particularly economical, primarily because shale typically has insufficient permeability to allow significant fluid flow to a well bore. With technological advances and unconventional methods (i.e., horizontal hydraulic fracturing), gas extraction from tight formations (e.g., shale) is now feasible.

This type of unconventional natural gas development relies on clustered, multi-well pads and long, horizontal laterals. Wells are drilled vertically (often thousands of feet) and horizontally in multiple directions. The method entails injecting large volumes of fluid consisting of chemicals, water, and sand into the well to fracture the shale rock that releases the natural gas. The internal pressure of the rock formation also causes a portion of the injected fracking fluids to return to the surface (flowback fluids); these fluids are often stored in a tank or pit before being pumped into trucks for transport to a disposal site. Flowback has been shown to contain a variety of formation materials, including brines, heavy metals, radionuclides, and organics, which can make wastewater treatment difficult and expensive [1]. Further, other studies found that 20% to 85% of fracturing fluids may remain in the formation, which means the fluids could continue to be a source of groundwater contamination for years to come [2]. By 2009, there were more than 493,000 active natural gas wells across 31 states, almost double the number in 1990, of which approximately 90 percent have used hydraulic fracturing to extract gas [3].

Whereas shale gas has the potential to become a significant, economical energy source, the potential for harm and the potential of giving a false sense of energy security are often dismissed by its proponents. The process is potentially polluting and damaging not only to human and animal health but also to the environment, as a result of clearing of land for well pads, drilling the wells, extracting the gas, storing the byproducts of the extraction, transporting the gas by diesel trucks, and the final capping of the well. The potential for harm to children is especially worrisome. This paper focuses on a literature review of unconventional natural gas development and its potential impact on human health.

2. Discussion

Canaries in coal mines were used as an early-warning signal for toxic gases, primarily carbon monoxide. The birds, being more sensitive, would become sick before the miners thus providing advanced warning of a danger. Animals and children also can be viewed as sentinel species. A 1993 report, now viewed as a watershed moment for health and environmental policy, documented that children are more vulnerable and sensitive than adults to chemicals in the environment [4]. Early development (in utero and during the first few years after birth) is particularly sensitive to disruption by exposures to chemicals in the environment and to imbalanced nutrition, with potentially adverse consequences for health later in life [5]. A child's ability to metabolize toxic chemicals is different from an adult's. Children receive proportionately larger doses of chemical toxicants than adults, and these exposures occur at a time in the life cycle when organs and tissues are rapidly growing and developing.

Endocrine disrupting chemicals (EDCs) present a particularly concerning hazard during human growth and development. EDCs can affect the reproductive system and often effect epigenetic mechanisms leading to pathology decades after exposure. Given the potential for harm, it would be a prudent course of action that chemicals used in the hydraulic fracturing process be evaluated for their EDC potential and screening assays be developed to test flowback fluids.

Landrigan et al. [6], looking at children's vulnerability to toxic chemicals, found strong evidence that toxic chemicals are important causes of disease in children. For example, benzene, being toxic to all humans, has been shown to contribute a disproportionate risk of leukemia to young children [7]. Neural tube defects, spina bifida being the most common [8], and decreased fetal growth [9] also have been shown to occur disproportionately higher in children exposed to toxic chemicals, including benzene. Further, because of the long latency period of some diseases, toxic exposures in childhood are more likely to result in disease in adulthood compared to exposure in adulthood [10].

Trasande and Liu [11], building on Landrigan et al.'s analysis of the costs of environmental pollutants and disease [12], estimated that costs of environmentally mediated diseases in American children totaled $76.6 billion (in 2008 dollars) and called for federal policy action to limit children's exposure to known chemical hazards, including exposures to toxic chemicals. Given the staggering human and economic costs of environmentally mediated diseases, a wise course of action would be to empirically document trends in specific diseases among children living in close proximity to unconventional natural gas operations compared to those living in areas where drilling is not occurring.

We acknowledge that adverse health outcomes of medical conditions with long latency periods will not be evident for years and will depend on the exposure, duration of exposure, dose, and other factors. A higher incidence of asthma, cancer, heart disease, and the effects of endocrine disruption on developing fetuses and children, due to contaminant exposure, only become evident over time. However, baseline measurements should be recorded and updated over time. As of this writing, the extent of health risks associated with unconventional natural gas operations among children is unknown.

In an effort to assess the impact of hydraulic fracturing on children's health, we are advocating that local and state governments work together to establish a system to track the incidence and prevalence of diseases that have been shown in the literature to be causally related or exacerbated by exposure to environmental agents. In Pennsylvania, for example, there has been active, on-going unconventional natural gas development since the late 2000s. There are currently 6,773 horizontal wells drilled or under development and over 9,600 drilling permits have been issued [13]. As of May 2011, 320 daycare facilities, 67 schools, and 9 hospitals were located within two miles of natural gas wells [14]. What effect will this activity have on the development of disease among children living in counties with active drilling as compared to children living in counties with little or no drilling activity? Trends in childhood cancers, especially acute lymphoblastic leukemia, birth outcomes including birth defects, premature and low birth weight births, neurodevelopment disorders, and, respiratory disease, especially asthma, should be monitored.

The limited information available on the chemicals that are used in the drilling hampers efforts to empirically assess the potential for harm. Oil and gas companies are legally permitted to withhold information on their proprietary mixtures, and the federal government has granted oil and gas companies exemption from many environmental law restrictions such as the Clean Water Act, Clean Air Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, Toxic Release Inventory under Emergency Planning and Community Right-to-Know Act, and the National Environmental Policy Act. By default, states have the responsibility for enacting regulations; however, many states have weak or no regulations. As of February 2012, only four of 31 states have significant drilling rules; of these, 5 adopted disclosure rules, although they still allow for "proprietary trade secrets" [15].

3. Harm to Health

The production process creates a huge pressure cooker of organics and inorganics, and even if every single compound pumped into the well is harmless by itself (which is not the case), the pressure would create hundreds if not thousands of different compounds that are highly toxic. Of the few studies that have looked at the chemical cocktails used in the process, findings have identified chemicals that are known to cause cancers, mutations, and diseases of the nervous, immune, and endocrine systems, the kidney, gastrointestinal tract and liver, heart, and skin [16]. Colburn identified almost 1,000 chemical products and nearly 650 individual chemicals used in natural gas operations, many of which have the potential to cause adverse health effects as well as to potentially cause deleterious effects on the environment [17]. Specifically, the researchers documented that the hydraulic fracturing process releases toxic and cancer-causing chemicals such as benzene, toluene, xylene (BTEX), and methylene chloride among other health-hazardous air pollutants. These health-hazardous pollutants are released from a number of sources including blowouts, flaring, condensate tanks, construction activity, engines, and venting. Methane, a powerful greenhouse gas, also is emitted throughout the oil and gas development process. Methane interacts with sunlight to produce tropospheric ozone, which is a strong respiratory irritant associated with increased respiratory morbidity and mortality [18].

Witter et al. were one of the first to present a detailed assessment of health trends in Garfield County, CO, that documented the negative impact of drilling on air, soil, water, and human health [19]. Building on those findings, McKenzie et al. estimated health risks for exposures to air emissions from a natural gas development project also in Garfield County and found that residents living less than one-half mile away from wells were at greater risk for ill health effects than those living farther away [20]. Although these studies focused on Garfield County, CO, the researchers maintain that the exposure pathways and related health risks would be similar wherever oil and gas development is occurring.

4. Water Contamination

Whereas the conventional method of natural gas production utilizes about 20,000 to 80,000 gallons of fluid, the unconventional method utilizes up to 5 *million gallons* of fluid per hydraulic fracturing event, which includes not only water and sand, but also numerous toxic chemicals. The potential for contamination of aquifers by the residual fracking fluids that remain underground must be considered. The likelihood of spills throughout the entire lifecycle of development also must be taken into account. Blowouts (uncontrolled release of natural gas from a gas well after pressure control systems have failed) allow gas and/or highly contaminated produced waters to flow to the surface; hoses come undone, gaskets fail, pits or tanks that hold the fracking fluids leak raising the serious risk of ground and water contamination. Even small quantities of the toxic fracking fluids can contaminate shallow aquifers with hydrocarbons, toxic chemicals, heavy metals, and radioactive materials.

Further, improper wastewater disposal, specifically the handling of fracking fluids including flowback wastewater (a byproduct of the process), can lead to contamination of ground and water [21]. The flowback can be taken to sewage plants, but it is widely acknowledged that sewage plants are not equipped to handle the contaminants. There have been reports of untreated wastewater being dumped into rivers and streams and sprayed on rural roads and forests [22].

The New York Times, in its analysis of more than 30,000 pages of federal, state, and company records relating to more than 200 gas wells, found that radioactive wastewater from the process has been discharged into rivers that supply drinking water to millions of people in Pennsylvania and Maryland. At least 12 sewage treatment plants in three states have discharged waste that was only partly treated into rivers, lakes, and streams [23]. There have been well-publicized instances of water contamination in Pavillion, WY, and Dimock, PA [24, 25], and gas has seeped into underground drinking water supplies in five states (Colorado, Ohio, Pennsylvania, Texas, and West Virginia). Further, a study conducted in Northeastern Pennsylvania found that water wells near a fracking site were 17 times more likely to exhibit methane contamination than wells not near drilling sites [26].

5. Air and Soil Contamination

Unconventional natural gas development causes air pollution from multiple sources. Many particulates and chemicals are released into the atmosphere, including sulfuric oxide, nitrogen oxides, volatile organic compounds (VOCs), benzene, toluene, diesel fuel, hydrogen sulfide, and radon gas, all of which can have serious health implications. Further, the venting or flaring of wells during drilling and production contributes to local air pollution.

The drilling sludge, which is brought to the surface during the drilling process, contains fracking fluid, drilling mud, and radioactive material from the subsurface land formation, hydrocarbons, metals, and volatile organic compounds. Sludge, often left to dry on the surface in waste pits, may be removed to waste disposal sites (but not always to hazardous waste sites) or may be tilled into the soil in "land farms." These practices raise the risk of contaminating soil, air, and surface water, as a result of the fine dust becoming airborne thus affecting local air quality and raising the risk of respiratory disease. Based on concerns about the exposure to dust containing silica sand, the US Occupational Safety and Health Administration, along with the National Institute of Occupations Safety and Health (NIOSH), released a joint hazard alert on fracking silica in June, 2013 [27].

Unconventional natural gas development requires many diesel trucks for the transportation of the products used in drilling as well as the removal of flowback fluid. Diesel emissions contain nitrogen oxides and volatile organic compounds, which can react to sunlight to produce ozone, a strong respiratory irritant associated with increased respiratory morbidity and mortality [28].

6. Conclusion

The health impacts related to unconventional natural gas development may not be evident for years, as medical conditions with long latency periods will present over time. While the potential long-term, cumulative effects will not be known for years, we argue that it would be prudent to begin to track and monitor trends in the incidence and prevalence of diseases that already have been shown to be influenced by environmental agents. Meanwhile, the natural gas industry needs to address the risks to human and animal health and take steps to limit, preferably to eliminate, the exposure pathways. We need far greater transparency and full chemical disclosure. There needs to be an end to discharging effluent into rivers, streams, and groundwater. There needs to be much more attention paid to curtailing or preferably eliminating spills and leaks of radioactive wastewater. There needs to be an end to the disposal of radioactive sludge from drilling sites in landfills. There needs to be a safer way to develop this resource to limit the exposure to silica, which can cause silicosis, chronic obstructive pulmonary disease, and lung cancer. Banning the practice of burning off the initial flow of natural gas (flaring) needs to be mandated sooner than 2015, the date when EPA ruling goes into effect. And, perhaps most importantly, there needs to be a well-designed epidemiologic study conducted to empirically assess health status among those living proximate to active development compared to those living in areas where development is not occurring.

Conflict of Interests

No author has any conflict of interests or financial conflicts to declare.

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Original Research

Shale gas development and cancer incidence in southwest Pennsylvania

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ABSTRACT

Objective: To what extent does unconventional gas development lead to an increase in cancer incidence in heavily drilled Southwest Pennsylvania?

Study design: Ecological study.

Methods: Data for urinary bladder, thyroid and leukaemia were abstracted from the Pennsylvania Cancer Registry (PCR). Cancer incidence among counties with high, moderate and minimal number of producing wells is compared before drilling activity and thereafter. Observed vs expected cases, standardized incidence ratio and 95% confidence intervals are presented. Data are presented by county, diagnosis and sex for the years 2000–2004, 2004–2008 and 2008–2012. The percent difference between the observed cases from 2000 to 2004 and 2008–2012 was calculated.

Results: The observed number of urinary bladder cases was higher than expected in both sexes in counties with shale gas activity. In counties with the fewest number of producing wells, the increase was essentially non-existent. The number of observed cases of thyroid cancer increased substantially among both sexes over the time period in all counties regardless of the number of wells drilled. The pattern for leukaemia was mixed among males and females and among the counties regardless of the extent of shale gas development activities.

Conclusion: Potential risk factors other than shale gas development must be taken into account to explain the higher than expected cancer cases in counties with and without shale gas wells before and during unconventional shale gas activity.

Introduction

Unconventional oil and gas development has enhanced the ability to extract trapped gas from tight shale formations. The process, using hydraulic fracturing, requires injecting millions of gallons of water combined with a mixture of chemicals (many of which are toxic) and proppants (usually sand or silica) into the drilled well under high pressure. With unconventional natural gas extraction, trapped gas is released along with flowback fluids consisting of the water and the chemicals used in hydraulic fracturing. In the USA, over the decades,

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38,000 oil and gas production wells in at least 25 states were hydraulically fractured, the majority of which are in Texas, Colorado, Pennsylvania and North Dakota.[1]

Studies conducted in the USA have linked shale gas development to surface and ground water contamination,[2–6] and a landmark 2015 Environmental Protection Agency (EPA) report on the impact of hydraulic fracturing estimated that almost 10 million people live within one mile of a fracked well and that hydraulic fracturing and associated activities not only have the potential to contaminate drinking water, ground water and other water resources but actually did in a number of places.[7]

Further, air pollutants, such as hydrogen sulphide, nitrogen oxides, volatile organic compounds (e.g. benzene and formaldehyde), particulate matter and ground level ozone are emitted or produced, are released during all phases of the drilling and extracting phases.[8–11] Well venting, flaring and burning gas on release account for a large source of air emissions.[12] Truck traffic and diesel truck exhaust also contribute to airborne emissions of fugitive dust, fine particulate matter and high-benzene concentrations. Werner et al.[13] comprehensively reviewed the strength of evidence focussing on the environmental health impacts of unconventional natural gas development (UGD), including the potential for harm to air, water, soil and climate change.

Finkel and Law[14] and later Shonkoff et al.[15] were the first to raise the issue of a paucity of well-designed epidemiologic studies on the public health impact of hydraulic fracturing. Anecdotal reports from areas with UGD found that adults and children living near drilling sites were presenting with symptoms such as skin rashes, dizziness, headaches, nausea, respiratory problems, eye and throat irritations, nosebleeds, anxiety. Other health conditions, many potentially serious, will take more time to develop (e.g. cancers; endocrine and reproduction systems disruptions). Hydraulic fracturing fluids contain endocrine disrupting chemicals that may adversely impact organs in the body years or decades after exposure.[16]

The byproducts of hydraulic fracturing, including benzene, fine particulate matter, and other nitrogen oxides, sulphur dioxide and ozone, have been shown to increase the risk of adverse birth outcomes and a variety of health problems among those living in near proximity to hydraulic fracturing activities.[17] Recent empirical evidence shows an increase in adverse birth outcomes (e.g. preterm birth, low-birth weight) in areas with active drilling, especially among women living close to gas wells.[18–20] Also documented is an increase in hospital utilization rates (admissions for cardiac and neurological conditions in particular) among those living in proximity to wells,[21] and mental health problems have been shown to be associated with proximity to drilling sites.[22,23]

While the accumulation of reports enumerating the potential for harm in the short-term are a matter of concern, the long-term effects of living in near proximity to unconventional drilling sites are not known as of this writing. Certainly, the potential for harm will vary by proximity to wells, length of time of exposure and route of exposure. Confounding factors would need to be taken into account as well to understand the extent of the relationship between health outcomes and UGD.

Purpose of study

Many states actively support unconventional natural gas development (e.g. Colorado, Louisiana, North Dakota, Pennsylvania, Texas, Wyoming). Pennsylvania, in particular, has embraced an aggressive policy of drilling and extracting natural gas from the Marcellus Shale, one of the largest shale plays in the USA. Drilling commenced in 2008, and as of May 1, 2015, 9134 unconventional wells have been drilled in Pennsylvania, notably in several counties in the southwest part of the State.[24]

Anecdotal reports of elevated cancer rates in the heavily drilled southwest region of the state provided the impetus to investigate whether exposure to UGD activities impacts the development of cancers that are known to be associated with environmental exposure (e.g. bladder, leukaemia and thyroid cancers). To what extent were the observed number of cancer cases higher than expected in counties with the highest number of producing wells (Washington and Greene) compared to counties with little or no UGD (Fayette and Westmoreland) and to counties with a moderate amount of producing wells (Allegheny and Beaver). Data before UGD commenced (2000–2008) are compared to years during UGD (2009–2012). Key questions that we sought to answer include: to what extent was cancer incidence elevated prior to UGD? To what extent does UGD contribute to cancer development?

Methods

While genetics and lifestyle factors account for many cancers, occupational and environmental exposures also can be major risk factors. Three specific cancers were selected for inclusion in this study: bladder, leukaemia and thyroid. Bladder cancer, for example, is associated with exposure to arsenic in drinking water, and exposure to benzene, cadmium, aromatic amines, tricholoroethylene solvants, silica and lead. Benzene, pesticides, reactive chemicals, dioxin solvents and non-ionizing radiation are linked to leukaemia. Radiation, pesticides and genetics are linked to thyroid cancer. However, cancer causation is complex and multi-factorial. UGD requires hundreds of different chemicals in the fracturing process, many of which have been shown to be carcinogenic.

Cancer incidence and mortality were abstracted from the Pennsylvania Department of Health (DOH) Bureau of Health Statistics and Research's Pennsylvania Cancer Registry (PCR).[25] The PCR includes the annual number of invasive cancer cases and cancer deaths by age, sex, race, primary site, as well as observed and expected cases by diagnosis. The observed number of cases is based on the number of primary tumours, not the number of individuals diagnosed with cancer. The PCR follows the SEER ICD-0 coding structure used to identify primary sites of cancers. Expected cases represent the total number of primary malignant tumours that would have been reported to the PCR if Pennsylvania's male and female populations had experienced the same age-specific rates of cancer incidence as those reported by the SEER program during the same time period.

The PCR includes the standardized incidence ratio (SIR), which is calculated by dividing the number of observed cases by the number of expected cases and multiplying the dividend by 100. A ratio greater than 100 indicates that there were more cases observed than expected. The 95% confidence interval for the SIR was calculated independently. The percent difference between the observed cases from 2000–2004 to 2008–2012 was calculated.

The following cancer sites were selected for analysis because epidemiologic evidence shows a moderate to strong relationship to environmental pollutants (e.g. chemical exposures): urinary bladder (invasive and in situ), leukaemia and thyroid. Other potential risk factors such as occupational exposures (e.g. diesel fumes, rubber byproducts, paint solvents), tobacco smoking, alcohol consumption, diet and genetic history could not be assessed in this ecologic study.

Based on anecdotal reports of 'high' cancer morbidity and mortality among residents in Washington County, we also include data at the township level. We acknowledge that there is a higher probability of chance variation in an observed number in rural counties with small populations, rather than a real change or difference. There is always the possibility that some events could have occurred by chance.

Results

Of the 67 counties in Pennsylvania, there are 30 overwhelmingly rural counties that sit atop the Marcellus Shale. Table 1 presents a profile of the counties included in this study. The principle products and/or industry in these counties include coal mining (e.g. the Klondike and Pittsburgh coalfields), agriculture, manufacturing (e.g. fabricated metals and electric machinery) and shale gas development.

Table 2 shows the trend in incidence of urinary bladder cancer by county, sex and year grouping. The SIR in each year grouping for all Pennsylvania was above 100 indicating that there were more observed cases than expected. There was a 10% increase in the number of observed cases from 2000 to 2012. In every county and for each of the year groupings, the SIR was above 100 among males and females (with the exception of 2000–2004 in Greene County and 2004–2008 in Westmoreland County where there were fewer number of observed cases of urinary bladder cancer than expected in females). In all of the counties for each of the year groupings, the observed number of cases exceeds the expected in each of the year groupings among males. The increase in the number of observed cases from 2000 to 2012 was notably higher among males in the heavily drilled Washington County (+20.2%), but in heavily drilled Greene County there was a 20% decline in observed cases. The numbers are quite small, which could distort the findings. In moderately drilled Westmoreland County, there was a 19.9% increase in the number of observed cases. In the counties with the fewest number of drilled wells, there was an insignificant change in the number of observed cases over the time period.

Among females, in heavily drilled Washington County, there was a 5.3% increase in the number of observed cases and a 7.7% increase in Greene County. In moderately drilled Fayette County, there was a 22.5% decline in the number of observed cases from 2000 to 2012; however, in Westmoreland County there was a 44.4% increase over this time period. In Allegheny and Beaver Counties, there was a 3.2% decrease and a 4.4% increase in the number of observed cases, respectively. Bladder cancer is generally more prevalent among males, which may be a factor in explaining the differences between the sexes.

Table 3 shows the trend in incidence of thyroid cancer by county, sex and year grouping. The SIR for each year grouping exceeds 100 for the state of Pennsylvania, and there was a huge 91.2% increase in the number of observed cases from 2000 to 2012. The data show that the number of thyroid cancer cases over the time period has been higher than expected, especially among males. While the numbers are small (as apparent by the 95% confidence interval range), the number of observed cases in males and females in all counties almost always exceeded the number of expected cases from 2004 to 2012 regardless of shale gas development activity in the specific county.

Among males in Washington County, there is a 92.9% increase in the number of observed cases of thyroid cancer from 2000 to 2012. The numbers in Greene County are too small to draw any conclusions. In Fayette and Westmoreland counties, there was a 231.3% and 160% increase in the number of observed thyroid cases from 2000 to 2012, respectively. In Allegheny and Beaver Counties, where there has been relatively little unconventional drilling activity, there is a 105.9% and 68.2% increase in the number of observed cases over the time period, respectively.

Table 1 – Demographic profile by county.

Demographic characteristics	Allegheny	Beaver	Fayette	Greene	Washington	Westmoreland
Population (2014 est)	123,125	169,392	134,086	37,843	208,187	359,320
Population (as of 2010)	122,348	170,539	136,607	38,686	207,820	365,169
% Change	0.6%	−0.7%	−1.8%	−2.2%	0.2%	−1.6%
< 5 years of age (as of 2014)	5.3%	5.1%	5.0%	4.9%	5.0%	4.6%
>64 years of age (as of 2014)	17.4%	19.7%	19.4%	17.1%	18.9%	20.7%
% White (as of 2014)	81.0%	91.1%	93.1%	94.7%	94.0%	95.1%
Persons in poverty (as of 2014)	12.9%	11.3%	19.2%	16.3%	10.9%	10.7%
Number of unconventional active wells, 2015	63	30	257	870	1146	251

Source: http://quickfacts.census.gov/qfd/states/42000.html
Source: http://stateimpact.npr.org/pennsylvania/drilling/counties

Table 2 – Urinary bladder cancer incidence by county 2000–2012.

County		Males				Females			
		Observed	Expected	SIR	95% CI	Observed	Expected	SIR	95% CI
Allegheny	2000–2004	1547	1257	123.1+	117, 129.2	589	481	122.5+	112.6, 132.4
	2004–2008	1555	1244	125.0+	118.8, 131.2	561	460	122.0+	111.9, 132.1
	2008–2012	1588	1254	126.7+	120.5, 132.9	570	445	128.1+	117.6, 138.6
	% difference	2.70%				−3.20%			
Beaver	2000–2004	273	193	141.8+	125, 158.6	90	69	131.2+	104.1, 158.3
	2004–2008	242	194	124.6 +	108.9, 140.3	106	67	157.2 +	127.3, 187.1
	2008–2012	273	196	139.0+	122.5, 155.5	94	66	142.0+	102.2, 181.8
	% difference	0%				4.40%			
Fayette	2000–2004	201	151	133.0+	114.6, 151.4	80	57	140.9+	109.9, 171.9
	2004–2008	214	153	139.6 +	120.9, 158.3	57	55	103.0	26.7, 110.6
	2008–2012	223	153	145.8+	126.6, 165	62	52	118.9	89.3, 148.5
	% difference	10.90%				−22.50%			
Greene	2000–2004	50	37	134.3	97.1, 171.5	13	13	99.4	45.3, 153.5
	2004–2008	52	39	135.0 +	36.7, 172.2	13	13	101.8	46.4, 157.2
	2008–2012	40	39	101.8	70.2, 133.4	14	12	113.3	53.9, 172.7
	% difference	−20.00%				7.70%			
Washington	2000–2004	243	211	115.2+	14.5, 130.8	94	76	122.9	98.1, 147.7
	2004–2008	283	215	131.6 +	15.3, 148.4	101	75	135.0 +	108.5, 161.5
	2008–2012	292	227	128.6+	14.7, 145.7	99	76	130.7+	104.8, 156.6
	% difference	20.20%				5.30%			
Westmoreland	2000–2004	452	396	114.0+	10.5, 135.3	144	142	101.4	84.8, 118
	2004–2008	532	404	131.7 +	126, 137.4	137	139	98.4	81.9, 114.9
	2008–2012	542	426	127.3+	116.6, 138	208	141	147.1+	127.1, 167.1
	% difference	20%				44.40%			
All PA	2000–2004	13,496	11,280	119.6+	117.6, 121.6	4917	4120	119.3+	116, 122.6
	2004–2008	14,149	11,620	121.8 +	119.8, 123.8	4831	4060	119.0 +	115.6, 122.4
	2008–2012	14,843	12,290	120.8+	118.9, 122.7	4941	4117	120.0+	116.7, 123.4
	% difference	10.00%				0.50%			

CI, confidence interval; SIR, standardized incidence ratio.
% difference between 2000–2004 and 2008–2012.

Among females, Westmoreland County shows the largest increase in the number of observed cases during this time period (+187.6%), followed by Fayette County (+138.5%) and Allegheny County (+108.2%). The numbers for Greene County are too small to make any meaningful determination. Given the higher than expected number of cases in both males and females in the counties in the years before unconventional drilling, other factors must be taken into account to explain this finding.

Table 4 shows the trend in incidence of leukaemia by county, sex and year grouping. Compared to thyroid and urinary bladder cancers, the data for leukaemia present a different picture. For all of Pennsylvania, the SIR for each year grouping was less than 100, and there was a modest 18.9% increase in the number of observed cases from 2000 to 2012. For each county, as evident by the SIR, for the most part there are fewer observed cases than expected in males and females over the years. The percent increase from 2000 to 2012 is comparatively minimal, and in many instances, there fewer observed cases than expected during this time period in each of the counties and in males and females, regardless of county well status.

The data show that the observed number of urinary bladder cases were higher than expected in males and females in southwest Pennsylvania prior to shale gas development, however, in counties with the fewest number of producing wells (Allegheny and Beaver) the increase from 2000–2004 to 2008–2012 was essentially non-existent. In the counties where drilling was more intense, the percent increase among males was the highest in Washington and Westmoreland Counties and in Westmoreland and Fayette Counties among females. The number of observed cases of thyroid cancer increased substantially among males and females over the time period in all counties (excluding Greene County because of the small number of cases). The pattern for leukaemia was much more mixed among males and females and among the counties regardless of the extent of shale gas development activities.

Focus on Washington County townships

County-level data may mask activity at the small area level (e.g. township level). We focused on Washington County townships primarily because this county, as compared to the neighbouring counties, embraced shale gas development early on and has the most number of active producing unconventional wells. Fig. 1 shows the location of active, producing unconventional wells in Washington County as of 2015. Each well pad contains multiple wells.

Data were grouped by years before shale gas development (2000–2007) and during shale gas development (2008–2012). Table 5 shows the number of cases of urinary bladder and thyroid cancers and leukaemia by selected townships from 2000 to 2012. Townships with 20 or more observed cases of

Table 3 – Thyroid cancer incidence by county 2000–2012.

County		Males				Females			
		Observed	Expected	SIR	95% CI	Observed	Expected	SIR	95% CI
Allegheny	2000–2004	186	147	126.3+	108.2, 144.5	646	461	140.3+	129.5, 151.1
	2004–2008	284	186	153.1+	135.2, 170.9	1074	591	181.9+	171.0, 192.8
	2008–2012	383	230	166.8+	150.1, 183.5	1345	728	184.8+	174.9, 194.7
	% difference	105.90%				108.20%			
Beaver	2000–2004	22	22	100.2		115	65	176.3+	
	2004–2008	39	28	139	58.3, 142.1	145	85	169.8+	144.1, 208.54
	2008–2012	37	34	108.2	95.3, 182.7	131	104	126.2+	142.2, 197.4
	% difference	68.20%				13.90%			
Fayette	2000–2004	16	18	90.6	72.2, 159.5	52	53	98.2	94.9, 146.5
	2004–2008	27	23	115.8	137.2, 283.4	84	70	120.7	138.5, 160.7
	2008–2012	53	28	187.8+		124	83	149.6+	
	% difference	231.30%				138.50%			
Greene	2000–2004	2	5	–		9	13	–	
	2004–2008	6	7	–		26	17	148.8	91.6, 206.0
	2008–2012	13	8	166.1	159, 173.2	4	6		
	% difference	550%				−55.60%			
Washington	2000–2004	28	25	113		84	73	114.5	
	2004–2008	42	33	129.1	71.1, 154.9	129	97	132.4+	89.8, 139.2
	2008–2012	54	41	130.6	90.1, 168.1	163	123	132.3+	109.6, 155.23
	% difference	92.90%				94.00%			
Westmoreland	2000–2004	45	46	97.7	95.8, 165.4	133	134	99.1	112.0, 152.6
	2004–2008	73	60	121.6		206	176	116.8+	
	2008–2012	117	75	155.3+	69.1, 126.3	325	220	147.7+	82.3, 115.9
	% difference	160.00%				187.60%			
All PA	2000–2004	1752	1415	123.8+	93.7, 149.5	5969	4295	139.0+	100.9, 132.8
	2004–2008	2341	1857	126.1+	127.2, 183.4	7950	5706	139.3+	131.7, 163.8
	2008–2012	3350	2372	141.3+		10,237	7260	141.0+	
	% difference	91.20%				71.50%			

CI, confidence interval; SIR, standardized incidence ratio.
% difference between 2000–2004 and 2008–2012.

urinary bladder and thyroid cancers, and 15 or more leukaemia cases, are included in the Table. Given the small number of observed cases, one must interpret the data with caution.

Cecil and North Strabane townships showed the largest percent increase in urinary bladder cancer from 2000–2007 to 2008 to 2012, 141.7% and 81.3%, respectively. Three townships (Monogahela City, North Franklin and Washington City) showed a decrease in the number of urinary bladder cases over the time period. Regarding thyroid cancer, South Strabane and Peters Townships showed a substantial increase in the number of cases between the time periods (157.1% and 153.8%, respectively), whereas North Strabane, Washington City and Cecil Townships showed a decrease in the number of cases. Every township showed an increase in the number of leukaemia cases from 2000 to 2012. Of note is the 220% increase in the number of cases reported for Washington City; a 120% increase in South Strabane Township and a 100% increase in Peters Township.

Overall, Peters and South Strabane Townships showed increases in the three cancers of interest over the time period. Cecil, North Strabane and Washington City Townships had a mixed record; e.g., urinary bladder was especially high in Cecil Township but thyroid and leukaemia cancers either declined or increased modestly. Geographically, the townships with the comparatively larger number of cancer cases are adjacent to each other in the north central part of the county. However, as Fig. 1 shows the location of unconventional wells is primarily in the western portion of the county with a smaller concentration located in the southern part of the county. The wells are not proximate to the townships with elevated cancer cases. For example, Cross Creek, West Middletown, Hopewell, Mount Pleasant and Independence Townships are located in areas with the highest concentration of producing wells but have comparatively fewer cancer cases than townships in areas with few producing wells.

Discussion

It is important to note that Southwestern Pennsylvania is comprised of an ageing, rural, generally poor population. Township population is small, which makes it difficult to draw statistical conclusions. Trying to link shale gas development to higher than expected morbidity is complicated because shale gas development did not begin in earnest in the region until 2008, and the PCR data are available only through 2012. The data show, however, that the number of observed cancer cases exceeds the number of expected cases for each of the counties and for males and females even before shale gas development commenced.

Cancers generally take years to manifest, which make the findings from this study all the more concerning. Given the lead time in the diagnosis of chronic diseases, townships with

Table 4 – Leukaemia Incidence by County 2000–2012.

County		Males				Females			
		Observed	Expected	SIR	95% CI	Observed	Expected	SIR	95% CI
Allegheny	2000–2004	490	540	90.7-	82.7, 98.7	388	451	85.9-	77.4, 94.5
	2004–2008	487	536	90.9-	82.9, 98.9	425	449	94.6	85.6, 103.6
	2008–2012	559	590	94.8	86.9, 98.6	478	475	100.7	91.7, 109.7
	% difference	14.10%				23.20%			
Beaver	2000–2004	74	82	90.7	70.0, 111.4	63	64	98.5-	74.2, 122.8
	2004–2008	73	82	88.7	68.3, 109.1	48	65	75.1-	53.9, 96.3
	2008–2012	91	91	100.3	79.7, 120.9	64	70	91.9	69.4, 114.2
	% difference	23.00%				1.60%			
Fayette	2000–2004	60	65	92.7	69.3, 116.1	66	53	124.7	94.5, 154.9
	2004–2008	55	66	83.4	61.4, 105.4	51	54	95.3	69.1, 121.5
	2008–2012	47	72	65.5-	46.9, 84.1	31	55	56.3-	19.8, 61.9
	% difference	−21.70%				−53.00%			
Greene	2000–2004	19	17	114.7	63.1, 166.3	17	12	136.8	71.7, 201.9
	2004–2008	18	17	105	56.5, 153.5	21	13	166.8	95.4, 238.2
	2008–2012	21	19	100.3	57.4, 143.2	7	7		
	% difference	10.50%				−58.80%			
Washington	2000–2004	101	90	111.8	89.9, 133.7	84	72	117.3	92.2, 142.4
	2004–2008	92	93	99.4	79.1, 119.7	88	73	120.5	95.3, 145.7
	2008–2012	100	106	94	75.6, 112.4	79	80	98.2	76.5, 119.9
	% difference	1.00%				−5.90%			
Westmoreland	2000–2004	149	168	88.5	74.3, 102.7	120	132	90.9	74.6, 107.2
	2004–2008	163	172	95	80.4, 109.6	132	134	98.3	81.5, 115.1
	2008–2012	170	197	86.4-	73.4, 99.4	130	148	87.7	72.6, 102.8
	% difference	14.10%				8.30%			
All PA	2000–2004	4833	4962	97.4	94.7, 100.1	3741	3952	94.7-	91.7, 97.7
	2004–2008	5049	5129	98.4	95.7, 101.1	3874	4063	95.3-	92.3, 98.3
	2008–2012	5747	5902	97.4-	94.9, 99.9	4426	4487	98.6	95.7, 101.5
	% difference	18.90%				18.30%			

CI, confidence interval; SIR, standardized incidence ratio.
% difference between 2000–2004 and 2008–2012.

substantial shale gas activities could be posed to see a large increase in cancer incidence, not to mention other cardiovascular, respiratory, neurological, endocrine and reproductive conditions, over the next few years.

While there was a steady increase (and in some cases a substantial increase) in cancers from 2000 to 2012, clearly risk factors other than, or in addition to, shale gas development activities must be taken into account. To what extent is exposure to shale gas activities synergistic with past exposure to other risk factors for cancer and other diseases? The region has a long history of industry (e.g. coal mining and steel mills) that is associated with elevated morbidity and mortality.

Canonsburg Township located in heavily drilled Washington County, for example, was home to a major uranium milling facility for decades prior to 1957. At one time Cannonsburg was known as 'the most radioactive town in America'.[26] Uranium-238 decays to form radium-226. Long-term exposure to uranium-238 (half-life of 4.5 billion years) and radium-226 (half-life of 1600 years) increases the risk of bone and lung cancer, tumours of the lymphatic and haematopoietic tissues, leukaemia and lymphoma. The Cannonsburg mill site was designated in the 1978 Uranium Mill Tailings Radiation Control Act as eligible for federal funds for clean-up. Also, Cannonsburg is situated along Chartiers Creek, a tributary of the Ohio River, that is highly polluted from acid mine drainage, agricultural and industrial runoff and sewer overflow. It remains one of the most polluted watersheds in Pennsylvania.[27]

Cannonsburg is located adjacent to Cecil, North Strabane Charters and Peters Townships, which have higher than expected cancer rates; yet, none of these townships are located in areas with substantial drilling activity (see Fig. 1).

Allegheny County, which has few producing wells, is home to the Clairton Coke Works Plant, the largest coke manufacturing facility in the USA. Significant quantities of fugitive dust from pet coke storage and handling operations raises the risk of heart and lung disease primarily from the inhalation of particles that are 10 μm in diameter or smaller. These particles, once inhaled, generally pass through the throat and nose and enter the lungs causing damage to tissues.[28]

In heavily drilled Greene County, high concentrations of bromides and radionuclides were found in Ten Mile Creek, a stream that snakes through Greene and Washington Counties passing through areas of shale gas development. Ten Mile Creek feeds into the Monongahela River, the source of drinking water for hundreds of thousands of people in western Pennsylvania. Exposure to bromine can severely impact the thyroid gland[29] and has been linked to an increased risk of preterm delivery.[30] Bromides are found in fracking wastewater. Illegal dumping of fracking waste into streams and ponds has occurred in the county.[31] Also in Greene County, the Hatfield's Ferry power plant, recently closed, was a major

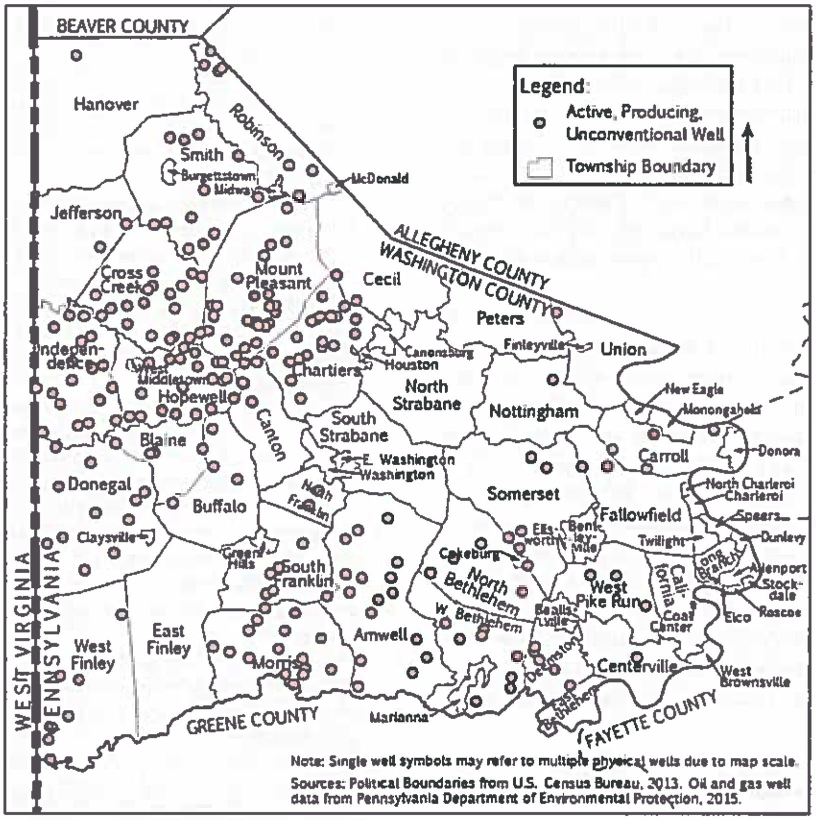

Fig. 1

Table 5 – Selected cancers by township by year, Washington county.

Cancers by township	2000–2007	2008–2012	Total	
Urinary bladder				
Canonsburg	14	14	28	0.00%
Canton	12	18	30	50.00%
Carroll	6	20	26	233%
Cecil	12	29	41	141.70%
Chartiers	12	14	26	16.70%
Fallowfield	9	14	23	55.60%
Monongahela City	12	9	21	−25.00%
North Franklin	14	8	22	−42.90%
North Strabane	16	29	45	81.30%
Peters	20	29	49	45.00%
South Strabane	21	22	43	4.80%
Washington City	19	12	31	−36.80%
Total county	296	390	686	31.70%
Thyroid				
Cecil	11	9	20	−18.20%
North Strabane	12	8	20	−33.30%
Peters	13	33	46	153.80%
South Strabane	7	18	25	157.10%
Washington City	12	9	21	−25.00%
Total county	131	216	347	64.90%
Leukaemia				
Cecil	5	12	17	8.30%
North Strabane	7	9	16	28.60%
Peters	7	14	21	100.00%
South Strabane	5	11	16	120.00%
Washington City	5	16	21	220.00%
Total county	123	177	300	43.90%

source of air and water pollution. There is documented ground water contamination due to coal ash waste.[32] Fly ash is known to contain heavy metals including arsenic and lead.

As the above illustrates, there are multiple sources of potentially toxic, harmful exposures in southwest Pennsylvania, many dating back decades. Shale gas development is a relative newcomer to the region, but there could be a synergistic effect of shale gas activities with past toxic exposures. This link must be more fully explored.

Data limitations include small population counts in these rural counties and townships, and a small number of events, which raises the risk of chance variation. Further, the short period of time between the onset of drilling and the development of cancer must be taken into account. What this study tries to do is illustrate that other potentially confounding factors must be taken into account before one can state with statistical certainty that UGD is the 'cause' of an increased risk of cancer.

Conclusion

As the above illustrates, pollution from industry is not new in southwest Pennsylvania. Multiple sources of air and water pollution, past and present, serve to raise the risk of disease among those living in the area. Given the decades-long exposure to highly toxic pollutants, it perhaps is not surprising that even in counties with minimal shale gas activities there are higher than expected rates of cancer, heart and respiratory diseases and other medical conditions. Data from the PCR show that there were higher than expected cancer rates long before unconventional shale gas activity began in the region. To what extent are the higher than expected cases seen in 2008–2012 a result of exposure to the potentially harmful byproducts of past industrial activity? To shale gas development? To some combination thereof? To what extent do demographic and lifestyle factors contribute to the higher number of observed cancer cases? Given the long lead time for many cancers to develop, the results presented here may be just the tip of the iceberg.

Ecological studies such as this one cannot determine causality, cannot link exposure to risk factors to disease, nor can they take into account confounding factors such as lifestyle, genetics, poverty, age. They can, however, raise 'red flags' to warn of higher than expected morbidity and mortality and should provide the impetus for observational studies such as case-control and cohort studies. Given that shale gas continues to be extracted in many parts of the region, there must be a concerted effort to monitor health indicators on a county and township level in order to better understand what the future holds for individuals living in southwestern Pennsylvania, especially for those living in counties that have been heavily drilled. Clearly, further research should be conducted to better understand the relationship between health and UGD.

Author statements

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Ethical approval

None sought.

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Competing interests

None declared.

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