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Special Issue

SCIENTIFIC, ECONOMIC, SOCIAL, ENVIRONMENTAL, AND HEALTH POLICY CONCERNS RELATED TO SHALE GAS EXTRACTION

Guest editors: Robert Oswald and Michelle Bamberger

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Editorial

AN ENERGY POLICY THAT PROVIDES CLEAN AND GREEN POWER

CRAIG SLATIN
CHARLES LEVENSTEIN

The oil and gas industry's current promise of cheap natural gas supplies for the next century sounds remarkably like the promises of the 1950s about nuclear power. We were to gain cheap, abundant, and safe electricity for our homes, to expand industry for jobs, and to advance modern living. Nuclear electricity generation, however, has brought us the burden of subsidizing the high cost of nuclear facility construction and liability insurance, denial of ongoing radioactive releases, additional cancer burden, decades of fights over the transport and disposal of radioactive wastes, secrecy and lies from the industry and its government regulators, and multiple actual and near meltdowns.

Now shale gas extraction conducted through the technological process commonly referred to as "fracking" is touted by the oil and gas industry as the next great energy boon. They tell us that gas will be so plentiful that it will answer all of our energy-related problems. Best yet, it will end the unemployment crisis that lingers past the Great Recession, leading to millions of jobs over the next several decades. Its promoters claim that we can have energy independence and a fuel that burns cleaner than coal—while they spread denial that the threat of catastrophic climate change is real or has much to do with human activity.

Let's not be deceived: shale gas extraction will neither fulfill the prophesies nor be useful in the transition to just, democratic, and ecologically sustainable economies across the globe. It is business as usual [1]. It is owned and operated by industries with more than a century's legacy of greed, corruption, war provocation, pollution, illness, injury and death, environmental degradation, and a steady stream of propaganda and lobbying to limit its regulation by

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governments. The U.S. Energy Information Agency (EIA) had touted the Marcellus Shale deposit as containing an estimated 410 trillion cubic feet of recoverable natural gas. In 2011, however, the U.S. Geological Survey (USGS) reported that the deposit "contains about 84 trillion cubic feet of undiscovered, technically recoverable natural gas and 3.4 billion barrels of undiscovered, technically recoverable natural gas liquids" [2]. Though an increase from the 2002 USGS estimates, this figure was 80 percent less than the EIA estimate that the industry had used to sell expansion of the shale gas extraction projects. This revision came while some members of the U.S. Congress were calling for investigation of the EIA's use of consultants with ties to industry to produce estimates of shale gas [3].

The subterfuges are likely to continue. In December 2012, the *Boston Globe* reported that Phil Flynn, a Chicago commodities trader for Price Futures Group, was confident that shale gas extraction was a key to U.S. energy independence. He stated that it would create:

> . . . millions upon millions of jobs for the next 10 to 30 years. What is going to drive us in this next decade? What is going to create good, high-paying jobs? Really fracking and natural gas have been an answer to our prayers, so hopefully we're going to embrace it and move in that direction [4].

In response to a journalist's question about whether or not abundant natural gas could jeopardize development of renewable technologies, he replied:

> If they can't compete, maybe they shouldn't. Fracking and new production have made a lot of these other technologies obsolete. You can throw billions of dollars at some of these technologies and they'll never be able to compete, unless you're going to subsidize them for the next 50 to 100 years. We've got over 100 years of [natural gas] supply, maybe more [4].

Keep in mind that this interview was reported at a time when the gas industry sought to obtain permission to establish a pipeline from the Marcellus Shale to New England, which it hopes will be a prime consuming region of this gas. Mr. Flynn neglected to note that U.S. oil and gas industries have received federal government subsidies dating back to 1916 [5]. The point isn't for renewable energy technologies to compete with natural gas. Rather, it is to replace gas and all fossil fuels if we are to have any chance of avoiding catastrophic climate change.

Another end-of-2012 news report from Bloomberg.com criticized U.S. Senator Ron Wyden (D–OR) for suggesting that the U.S. government should ". . . direct trade in energy according to its determination of the national interest" [6]. The editorial criticized Wyden for "protectionism" because of his suggestion that liquefied natural gas exports would lead to domestic gas price increases. Bloomberg.com stated:

> Natural gas is hardly a private product, in Wyden's understanding, but rather a national resource whose price, quantity and use are best determined by the federal government. What's so troubling about Wyden's view, however, is the potentially enormous cost to economic efficiency from substituting market mechanisms with political decision-making.
>
> Wyden is wrong: The federal government should not be exercising a heavy hand in this case. Liberal capitalist democracies [*sic*] should not allocate resources through regulatory determinations of the national interest. They should encourage free trade. If the domestic manufacturing and chemical industries require natural gas, they should place competitive bids for it [6].

Pennsylvania, a prime area above the Marcellus Shale and a state that produces a significant percentage of the nation's shale gas, passed Act 13 in early 2012. The law imposed a tax, an impact fee, on shale gas production. Although it toughened some safety standards to protect the environment and public health, the limited fee is primarily to compensate communities for the prior and ongoing damages that result from shale gas extraction operations. Several pro-industry provisions of the law are being challenged in the courts, including limitations on local zoning of drilling operations and protection of industry chemical use disclosure. These are hardly reasonable trade-offs for limited reparations funding, but "[b]y October (2012), $204 million from gas industry payments were being distributed to state agencies and counties and municipalities that host gas wells" [7]. Pennsylvania and Ohio have both passed laws allowing state institutions of higher education to receive a percentage of revenues from shale gas sales when gas companies are given the right to set up wells on school premises [8]. Shale gas extraction fees/taxes will increasingly be proposed to offset the impact of 30 years of cutting taxes at all levels of government and the resultant reduction and privatization of public services and infrastructure. In the case of public higher education facilities, these revenues will also create disincentives against critical examination of the consequences of using shale gas for fuel. This will be the latest phase of the blackmail of working-class communities—the offer of jobs and public services at the cost of safe and clean natural resources of water and air that sustain good health.

Since its inception, *New Solutions* has been a forum for discussions of a "just transition" toward ecologically sustainable modes of production and consumption. The well-being of workers and communities is at stake when industries and operations that threaten environmental and ecological destruction as well as human illness and injury are closed and in some cases transformed. Communities long suffering environmental injustices and often poverty due to racist and classist policies that placed polluting facilities in their midst must be made whole and provided priority status in this planned transition. Yes, planned, not the free market model of "liberal capitalist democracies" touted by Bloomberg.com.

With this special issue of *New Solutions*, so excellently organized by guest editors Robert Oswald and Michelle Bamberger, we address a range of social, economic, environmental, and public health risks that have emerged from energy companies' push to extract shale gas. The industry claims that the benefits of shale gas extraction far outweigh the costs, and that harms are mostly imagined by the usual collection of NIMBY environmentalists and public health police. We believe, however, that enough evidence has been provided in support of taking extraordinary caution during all phases of shale gas operations. Though this special issue barely addresses the health and safety concerns for workers in this industry, the hazardous exposures involved in this work are another key factor that requires taking extraordinary caution. We can no longer afford to have industry use deeply hazardous technologies—with government encouragement—while public health is consigned to surveillance of the sick and dead.

Whatever short-term assistance the American economy gains from the continued use of fossil fuels, the highest priority must be placed on establishing a national energy policy, coordinated with an international set of energy policies, that aims for immediate measures to avert catastrophic climate change and establish a transition toward producing and delivering clean, green, and sufficient energy as part of the foundation for sustainable development. Attention to the health and welfare of workers and communities affected by these changes must be an essential priority of this new energy policy.

AUTHORS' BIOGRAPHIES

CHARLES LEVENSTEIN is Editor Emeritus of *New Solutions*; Professor Emeritus of Work Environment at the University of Massachusetts Lowell; and Adjunct Professor of Occupational Health at Tufts University School of Medicine. Write him at chuck_lev@comcast.net

CRAIG SLATIN is a professor in the Department of Community Health and Sustainability, University of Massachusetts Lowell. He is an editor of *New Solutions: A Journal of Environmental and Occupational Health Policy*. His book, *Environmental Unions: Labor and the Superfund,* was published in 2009 by Baywood Publishing Co., Inc. He is the principal investigator of The New England Consortium, a hazardous waste worker/emergency responder health and safety training network supported by the National Institute of Environmental Health Sciences' Worker Education and Training Program. Contact him at craig_slatin@uml.edu+

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Direct reprint requests to:

Craig Slatin
Department of Community Health and Sustainability
University of Massachusetts Lowell
205 Riverside St.
Pinanski Hall, Room 301
Lowell, MA 01854
e-mail: craig_slatin@uml.edu

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Introduction

SCIENCE AND POLITICS OF SHALE GAS EXTRACTION

MICHELLE BAMBERGER
ROBERT E. OSWALD

ABSTRACT- Please supply 50-100 word abstract

Keywords: Please supply 3-5 key words

Although humans have exploited natural resources to produce energy throughout recorded history, the modern age of fossil fuels didn't begin until the first half of the 19th century, when oil and natural gas wells were used to extract hydrocarbons for heating in China and for illumination in the northeast United States. Our addiction to oil and gas began in earnest with the introduction of the internal combustion engine for cars and trucks, and the switch from coal to gas in heating our homes in the 1950s. In the 1940s, hydraulic fracturing was introduced to stimulate the production of gas and oil trapped in rocks with

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limited porosity; such stimulation opened up a whole new avenue for the extraction of oil and gas. Conventional wells were drilled to search for pockets of hydrocarbons buried deep within the earth; with hydraulic fracturing, oil and gas could be coaxed out of even very dense rock, such as shales. The initial applications for hydraulic fracturing were on vertical wells where relatively small quantities of water and comparatively low pressures were used to stimulate the flow of oil or gas. The problem with this is that the shale layers are relatively thin (50 to 200 feet in thickness), so that even with hydraulic fracturing, only a small amount of hydrocarbons could be extracted from vertical wells. The solution was to drill down and then turn the bit horizontally and continue drilling. The horizontal length of the well can then be hydraulically fractured, and much more oil or gas can be extracted. This process requires much larger quantities of water (approximately 5 million gallons for each fracturing), which contains sand to keep the fractures open (i.e., sand is used as proppant) and a variety of chemicals, some benign and some highly toxic. The transition from a conventional vertical well to a horizontal well that is hydraulically fractured is a huge step from a relatively minor insult to the rural landscape to major industrialization of the landscape.

Although concerns about this process had been raised in Colorado [1] and Alberta [2], among other places, the realization [3] that a large portion of the heavily populated and farmed areas of the eastern United States rests above large deposits of shale oil and gas (the Marcellus and Utica Shales) has sparked an enormous interest in the consequences of drilling near homes and on farmland. Historically, Pennsylvania is the origin of the U.S. oil industry, with the first well in Titusville in 1859, and New York is the origin of the natural gas industry, with the first well in Fredonia in 1821. Tens of thousands of gas wells have been drilled throughout Pennsylvania and New York over the last 150 years, with little protest. The advent of high-volume hydraulic fracturing of horizontal wells has been perceived as a qualitatively and quantitatively different process that has transformed the landscape and communities. Notably, this recent concern is not limited to the eastern United States; high-volume hydraulically fractured horizontal wells are proposed for shale plays throughout the world, and grassroots organizations have sprung up to question the wisdom of large-scale industrialized drilling. It was in this context that this special edition of *New Solutions* was conceived. A paper in a previous issue of *New Solutions* [4] explored the use of animals as sentinels for the health effects of large-scale drilling and outlined the reasons for the lack of strong evidence to prove or disprove the safety of the process. This issue casts a wider net and explores a range of topics associated with unconventional gas drilling. The intention was to describe important public health, economic, and socio-ecological issues, to present available data, and to define topics that need further study. In the call for papers, all points of view were welcomed. After extensive peer review, a range of topics was included in this issue.

Entitled *Scientific, Economic, Social, Environmental, and Health Policy Concerns Related to Shale Gas Extraction*, the issue opens with an editorial by Charles Levenstein and Craig Slatin discussing the broader need for sustainable production and consumption—in particular, the need to make sure that our energy policies and plans help us move to a greener economy that eliminates poverty, promotes public health, and establishes the primacy of renewable and non-toxic energy sources. Next, Katrina Korfmacher and collaborators provide a comprehensive discussion of exposure pathways and describe a resolution on the use of hydraulic fracturing in shale gas extraction that was approved by the American Public Health Association at its meeting in San Francisco in November of 2012. This resolution proposes a number of commonsense recommendations and a series of action steps to minimize the public health effects of this process.

In the Scientific Solutions section, Simona Perry describes an ethnographic approach to studying the community health implications of unconventional oil and gas development. The work concentrates on hard-to-monitor factors (e.g., psychological, sociocultural) that are associated with chronic stress. A great deal of emphasis has been placed on measuring environmental impacts using air and water testing, but little has been done to monitor scientifically the psychological and sociocultural changes transforming individuals and communities living and working near large-scale industrial gas drilling. Dr. Perry explores how ethnography, with its rigorous methods of fieldwork and analysis, is useful in not only evaluating and monitoring psychological and sociocultural changes within these communities, but also in describing and assessing the short- and long-term environmental health and social justice implications of these changes.

Also in the Solutions section, Nadia Steinzor, Wilma Subra, and Lisa Sumi report on a survey of perceived health effects coupled with water and air monitoring in the Marcellus Shale regions of Pennsylvania. They find that perceived health effects were greater for individuals living within 1,500 feet of a well pad relative to those living beyond that distance. Their findings demonstrate the utility of community-based research designs, especially when industrial and commercial interests inhibit public health and environmental impact studies that could jeopardize profitable gas and oil drilling.

The Features section begins with an economic analysis by Janette Barth. Dr. Barth considers the conventional wisdom that hydrocarbon gas extraction will bring economic prosperity to state and local governments and critically reviews the literature on the subject. Her analysis includes both the positive and negative drivers and looks at both the long- and short-term effects. She concludes that, despite many uncertainties, the long-term economic impacts from shale gas extraction may not be positive for most communities.

Ronald Bishop then addresses the important public health and safety, ecological protection, and greenhouse gas emission concerns related to abandoned oil and gas wells. Using the example of New York State, he shows that the majority of abandoned wells in New York have not been plugged, that the number of unplugged wells has increased since 1992 due to inadequate enforcement, and that no program exists to monitor the integrity of those that have been plugged. Because of the potential for abandoned wells to disintegrate and leak, stronger regulations and additional resources are required not only to complete plugging of the current inventory of abandoned wells but also to provide adequate regulation for the expected increase in the number of new wells within the next few years.

The shale layers containing oil and gas also harbor naturally occurring radioactive material that can be brought to the surface along with the hydrocarbons. Alisa Rich and Earnest Crosby analyzed the radioactive materials found in two reserve sludge pits and found radioactive elements of the thallium and radium decay series. The health effects of the individual radionuclides, along with the regulation (or exemption from regulation) of technologically enhanced naturally occurring radioactive materials (referred to as TENORMs) in federal and state regulations, are discussed.

To understand the impacts of gas drilling on water resources, extensive predrilling testing should be performed. The nonprofit Community Science Institute, headed by Stephen Penningroth, has developed an innovative program that partners with community volunteers to sample streams in 50 locations across the Marcellus and Utica Shale regions in New York State. This is combined with more detailed testing of individual water wells by the Institute's certified water quality testing laboratory. This unique approach to water sampling is a small step toward understanding changes in water quality from a variety of sources and will be useful in understanding impacts from both agriculture and industrial drilling in New York State.

In the next piece, Madeleine Scammell and collaborators review the regulations surrounding the disclosure of the chemical additives in hydraulic fracturing fluid. Since disclosure is not mandated by the federal government except on federal lands (and then only after well completion), it is regulated by laws that vary from state to state. The shortcomings cited in this paper include permitted nondisclosure of proprietary chemicals and mixtures, insufficient penalties for inaccurate or incomplete information, and timelines that allow disclosure after well completion. The authors suggest that lax and varying regulations on disclosure leave lawmakers, public health officials, and regulators uninformed of the potential hazards and ill-prepared to take steps to protect public health. Exemptions from federal regulations and efforts to mandate chemical disclosure are discussed.

The question of whether industrialized gas drilling has affected our food supply is an important unresolved issue. One of the reasons for our lack of information about this issue is that farming is by definition a decentralized process without detailed public recordkeeping. Madelon Finkel and collaborators have used what data are available to study the changes in the dairy industry in Pennsylvania, comparing those counties with extensive gas drilling to those with little or none. Using data from the United States Department of Agriculture's National Agricultural Statistics Service and the Pennsylvania Department of Environmental Protection, the authors showed that both milk production and numbers of dairy cows began decreasing in 1996, but that larger decreases were seen between 2007 and 2011 in those counties with intensive gas drilling compared to those with little drilling. Although causal relationships are difficult to establish in studies such as this, the paper emphasizes the importance of considering the effects on the dairy industry when hydrocarbon extraction impacts large portions of a particular region of the country (e.g., the Marcellus and Utica Shales in the northeast United States).

The next section of the issue, Voices, includes an interview of Anthony Ingraffea by Adam Law. Both are founding members of Physicians, Scientists & Engineers for Healthy Energy. Dr. Law is a practicing endocrinologist in Ithaca, New York, and approaches the subject from a medical perspective. Dr. Ingraffea, an engineering professor at Cornell University, is one of the world's foremost experts in fracture mechanics; his simulations have provided important insights into hydraulic fracturing. Ingraffea and Law discuss the importance of studying the process of gas drilling and hydraulic fracturing from a variety of perspectives, including geological engineering, hydrology, and medicine. This interview was originally done as a part of a project funded by the Heinz Endowment, and the transcript is included here with permission of the Endowment. The original interview can be viewed at: http://www.heinz.org/grants_spotlight_entry.aspx?entry=982.

Health practitioners in communities that may suffer health effects of large-scale gas drilling need to obtain accurate medical histories from individuals with potential exposures. In the Movement Solutions section, Pouné Saberi, a practicing physician, describes the process of taking an environmental exposure history in areas that are being intensively drilled, and the issues surrounding detection of possible environmental exposure clusters.

This special issue of *New Solutions* cannot establish firm conclusions, largely because the data are not available to make firm conclusions. Rather, our goal is to add to and review current knowledge and to point out areas where data are lacking and where regulations are lax or nonexistent. In the United States, gas drilling with high-volume hydraulic fracturing is regulated by a patchwork of state laws, varying from comparatively little regulation in Pennsylvania to an outright ban in Vermont. Regulations are largely based on political considerations rather than on sound scientific evidence. However, what passes for "sound scientific evidence" is sometimes in the eye of the beholder. On one hand, an oft-stated refrain is that in the 60-odd years since the introduction of hydraulic fracturing to extract hydrocarbons, no drinking water has been proven to be contaminated. This statement parses the issue into a small part of the process (hydraulic fracturing) and ignores the complete life cycle from drilling to production to consumption. It perpetuates misplacement of the burden of proof, with disdain for the precautionary principle. Ample evidence exists from more than a century and a half of a fossil-fueled industrial economy that it is wrong to assume that the technological processes related to extracting, processing, and using these substances are safe unless proven otherwise by those impacted. In the case of high-volume hydraulic fracturing we are all best served, in the short and long terms, by demanding proof of safety prior to expanding the practice to new areas. The uncertainties and existing evidence make a strong argument for caution and for strong, well crafted, and strictly enforced regulations.

AUTHORS' BIOGRAPHIES

MICHELLE BAMBERGER is a practicing veterinarian and a member of the Ulysses Gas Drilling Advisory Board, which is a committee to advise local government on issues surrounding shale gas drilling. Contact her at mjb57@cornell.edu

ROBERT E. OSWALD is Professor of Molecular Medicine at Cornell University and faculty fellow of the Atkinson Center for a Sustainable Future, also at Cornell. His research interests include central nervous system pharmacology and toxicology. E-mail him at reol@cornell.edu

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Direct reprint requests to:

Robert E. Oswald
Department of Molecular Medicine
Cornell University
Ithaca, NY 14853
e-mail: reo1@cornell.edu

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Comment and Controversy

PUBLIC HEALTH AND HIGH VOLUME HYDRAULIC FRACTURING

KATRINA SMITH KORFMACHER
WALTER A. JONES
SAMANTHA L. MALONE
LEON F. VINCI

ABSTRACT

High-volume horizontal hydraulic fracturing (HVHF) in unconventional gas reserves has vastly increased the potential for domestic natural gas production. HVHF has been promoted as a way to decrease dependence on foreign energy sources, replace dirtier energy sources like coal, and generate economic development. At the same time, activities related to expanded HVHF pose potential risks including ground- and surface water contamination, climate change, air pollution, and effects on worker health. HVHF has been largely approached as an issue of energy economics and environmental regulation, but it also has significant implications for public health. We argue that public health provides an important perspective on policy-making in this arena. The American Public Health Association (APHA) recently adopted a policy position for involvement of public health professionals in this issue. Building on that foundation, this commentary lays out a series of five principles to guide how public health can contribute to this conversation.

Keywords: environmental health, hydrofracking, public health

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The recent growth of high-volume horizontal hydraulic fracturing (HVHF) to extract natural gas from unconventional gas reserves has been framed largely as an issue of economics and environment. Proponents emphasize the potential to bring prosperity to economically depressed communities and to vastly increase domestic natural gas production, decrease dependence on foreign energy sources, and replace dirtier energy sources, such as coal. At the same time, concerns have been raised that HVHF could result in ground- and surface water contamination, contributions to climate change, and increased air pollution. These concerns have focused attention on the inadequacy of existing regulations to protect the environment in the face of dynamic energy extraction technologies and practices.

Until recently, the public health perspective on this issue has received relatively little attention. Goldstein et al. [1] analyzed state and federal advisory committees related to HVHF in the Marcellus Shale region of the United States and concluded that public health was "missing from the table." But what would it mean to have public health voices "at the table," and what would they say? The American Public Health Association took an important first step by adopting a policy position on HFVH in October 2012, and has finalized a resolution as this article goes to press in January 2013 (http://www.apha.org/advocacy/policy/policysearch/default.htm?id=1439). Other public health organizations such as Physicians, Scientists, and Engineers for Healthy Energy (http://www.psehealthyenergy.org) are currently working on similar actions. In this commentary, we lay out a framework for the role of public health in decisions related to HVHF in the United States.

The public health framework for addressing issues that affect people's health is holistic, multidisciplinary, and oriented toward prevention. Bringing this perspective to the issue of HVHF may help identify areas of concern that are not encompassed by existing environmental regulations. In contrast to the lack of public health expertise among the membership of HVHF advisory committees, Goldstein et al. note that in one public hearing, nearly two-thirds of speakers mentioned health [1]. Thus, framing HVHF as an issue of public health may also help decision-makers address the public's concerns. Perhaps most importantly, the public health perspective has the potential to guide policy and management despite the persistent uncertainties about impacts of HVHF. Principles of public health emphasize the need for transparency in research and policy, a precautionary approach in the face of uncertainty, baseline and continued monitoring, and adapting management as understanding of risks increases.

This commentary considers the entire life cycle of, and processes involved in, the expansion of HVHF, including site preparation, drilling and casing, well completion, production, processing, transportation, storage and disposal of wastewater and chemicals, sand mining, and site remediation. The rapid socioeconomic changes, scale of development, and pace of extraction made possible by HVHF could affect health directly or indirectly through changes in vehicular traffic, community dynamics, unequal distribution of economic benefits, demands on public services, health care system effects, impacts on agriculture, and increased housing costs. At the same time, economic growth resulting from HVHF may contribute to improvements in individual health status, health care systems, and local public health resources. The public health perspective also requires assessing the long-term and cumulative impacts of this dispersed-site extractive industry, as well as the distribution of these impacts, particularly within low-income rural populations.

HEALTH AND HVHF: OVERVIEW OF THE POTENTIAL IMPACTS

As discussed in this special issue of *New Solutions*, high-volume horizontal hydraulic fracturing in unconventional gas reserves (often referred to as "fracing" or "fracking") has expanded rapidly since 2007 [2]. HVHF is a technology that injects water, solids, and fluids into wells drilled into the earth's crust as a means to enhance the extraction of natural gas from deep geologic formations, primarily shale, tight sands, and coal seam gas that underlie many regions of the United States [3]. Important unconventional natural gas reserves in the United States include: Barnett (Texas), Fayetteville (Arkansas), Haynesville (Louisiana and Texas), Antrim (Minnesota, Indiana, and Ohio), Marcellus (New York, Pennsylvania, and West Virginia), Bakken (North Dakota), Woodford (Oklahoma), and Eagle Ford (Texas). The basic technology of hydraulic fracturing has existed since the 1860s. However, its recent expansion arose from technological innovations that allowed for horizontal drilling, facilitating greater access to gas in certain shale formations than do conventional vertical wells. HVHF also uses vastly greater quantities of water and chemicals than conventional operations. These horizontal wells are often hydraulically fractured in a number of stages, greatly expanding the potential duration and scale of impacts at each individual site [4, 5].

The rapid expansion of HVHF, both in communities with a long history of natural gas development and in those with limited natural gas industry experience, has the potential to impact public health in numerous ways [1, 6]. These impacts range from direct health impacts for workers or residents who are exposed to harmful chemicals in air, surface water, or groundwater, to indirect effects such as those resulting from rapid community change (e.g., increased traffic and demand for housing), as well as off-site impacts, such as mining the sand required for the HVHF process. Some of these impacts may be positive—for example, from economic growth resulting in better nutrition and health care—while others may be negative.

The distribution of these health impacts varies by proximity to drilling operations, involvement in the industry (worker, property owner, neighboring community member), individual characteristics (children versus adults, asthmatics, etc.), and income (e.g., low income people may be more adversely affected by inflation of housing rental rates). Unequal distribution of benefits may contribute to community conflict and stress, thus indirectly affecting health [7]. Below, we summarize some of the potential health impacts of HVHF in greater detail to set the stage for considering the role of public health in anticipating and managing risks.

Surface and Ground Water Quality

Impacts on water quality and quantity are some of the most highly publicized environmental effects of HVHF with potential human health consequences [8, 9]. HVHF increases the amount of fresh water used by each natural gas well by as much as 100 times the quantity used in conventional drilling [10]. Additionally, wells can be hydraulically fractured more than once, each time using up to 5 million gallons of water [11, 12]. Between 25 and 100 percent of the fluids used in drilling may return to the surface; these "flowback" or "produced" fluids may contain hydraulic fracturing chemicals, as well as heavy metals, salts, and naturally occurring radioactive material (NORM), from below ground [13]. Therefore, this water must be treated, recycled, or disposed of safely [14].

The chemicals and proppants that are added to the water used in HVHF have raised public health concerns related to surface water and groundwater quality [2, 15]. Chemical additives used in fracturing fluids typically make up less than 2 percent by weight of the total fluid [16]. Over the life of a well this may amount to 100,000 gallons of chemical additives. These additives include proppants, biocides, surfactants, viscosity modifiers, and emulsifiers. The chemicals vary in toxicity. Some are known to be safe. However, others are known or suspected carcinogens, endocrine disruptors, or are otherwise toxic to humans—including silica, benzene, lead, ethylene glycol, methanol, boric acid, and gamma-emitting isotopes [16]. Manufacturers of hydraulic fracturing fluids are allowed to protect the precise identity and mixture of the fluids under "proprietary" or "trade secret" designations. From a public health perspective, this prevents effective baseline monitoring prior to hydraulic fracturing, as well as documenting of changes over time. In addition, without this information, it is difficult to apprise workers and the public of potential health hazards.

The manner in which wastewater from HVHF is handled and treated is another water quality concern. The disposal methods used for the "produced water" and brine extracted from the shale have the potential to affect the water quality of lakes, rivers, and streams, damage public water supplies, and overwhelm public wastewater treatment plants [17]. Surface water may be contaminated by leaking on-site storage ponds, surface runoff, spills, or flood events. Even if contaminated surface water does not directly impact drinking water supplies, it can affect human health through consumption of contaminated wildlife, livestock, or agricultural products [18].

Disposal through class II injection wells has traditionally been the primary option for oil- and gas-produced water [19]. Several recent earthquakes near Youngstown, Ohio, were linked to deep injection of HVHF wastewater, raising concerns about this practice under certain geologic conditions [20]. Produced water has also been treated in self-contained wastewater treatment systems at well sites, through local municipal wastewater treatment plants, and by commercial treatment facilities [14]. Because most municipal wastewater treatment plants cannot adequately treat wastewater from HVHF, some states (such as Pennsylvania) require treatment at industrial waste treatment plants [21]. However, the quantity of wastewater needing treatment and the capacity of existing plants to properly treat these wastes may be an issue in some areas [17]. For example, brine in Pennsylvania is permitted to be sprayed for road maintenance purposes, raising concerns about contamination of surface waters [21].

The potential for HVHF to cause methane to seep into drinking water supplies has received considerable media attention [10, 22]. While many of the assertions regarding flammability of drinking and surface water have yet to be substantiated, a study published in the *Proceedings of the National Academies of the Sciences* indicates that drinking-water wells within a one-kilometer radius of a drilling site have methane concentrations 17 times higher than wells outside of a one-kilometer radius [23]. The potential for health impacts from human exposure to methane released into household air from domestic water use is not well understood [23, 24].

Finally, on a local basis, using large volumes of fresh water for HVHF may consume a scarce commodity needed for agriculture, recreation, wildlife, environmental recharge, and drinking water supplies. Disrupting or displacing these pre-existing uses could have additional indirect public health impacts. Drilling fluids that do not return to the surface and remain below ground are effectively removed from the surface water cycle. Especially in areas with limited water resources, the impact of HVHF on the quantity of surface water available for other uses related to public health is a concern. Technological developments, such as gel-based fracking or closed-loop systems, could reduce water use in the future; however, the current practice of HVHF is water-intensive [25].

Air Quality

Globally, replacing coal with natural gas may result in reduced air pollution. However, combustion connected with extraction processes and fugitive emissions may increase air-quality–related health problems in HVHF production areas. Levels of ozone (including wintertime ozone) and concentrations of particulate matter (PM_{10} and $PM_{2.5}$) have been found to be elevated near gas activity [26]. Wintertime ozone caused by the release of volatile organic compounds (VOCs) mixed with the conditions of sunlight and snow cover has been noted in Utah, New Mexico, and Wyoming. Hydrocarbon emissions from gas drilling activity have also been found to be high in Colorado, where researchers found that twice as much methane was being leaked into the atmosphere from oil and gas activity as was originally estimated [27]. Researchers in Colorado have documented a wide range of air pollutants near an HVHF operation [28]. One study has found that residents living near well pads have a higher risk of health impacts from air emissions than those living farther away [29]. Domestic animals may also be affected [18].

Quality of Life

Noise and light have been cited as health concerns for residents and animals living near drilling operations [30, 31]. Excessive and/or continuous noise, such as that typically experienced near drilling sites, has documented health impacts [32]. According to community reports near these sites, some residents may experience deafening noise; light pollution that affects sleeping patterns; noxious odors from venting, gases, and standing wastewater; and livestock impacts [33]. Both noise and light can contribute to stress among residents.

Expansion of HVHF in rural communities may result in significant rapid population changes. These changes may create health care needs that overwhelm the capacity of existing public health systems to care for existing populations. Similarly, both the number and nature of emergency response resources needed in local communities may increase due to accidents, blowouts, or spills at drilling sites, as well as accidents during the transportation of supplies and waste through rural communities. Some areas have reported inadequate emergency medical services (EMS) training and insufficient communication between drilling operators and emergency responders. Pipeline construction and maintenance may also pose security and safety issues [34].

In addition to these environmental health threats, the rapid socioeconomic changes, scale of development, and pace of extraction made possible by HVHF may impact health. HVHF has the potential to significantly change the nature of communities, particularly in rural areas [34]. There have been reports of increased crime associated with the influx of natural gas workers [35, 36]. A study by the County Commissioners Association of Pennsylvania found that Pennsylvania was experiencing deficits in emergency management and hazardous materials response planning in drilling areas; courts and corrections impacts; human services burdens in areas such as drugs and alcohol, domestic relations, and children and youth; and effects on affordable housing, among others [37]. The stresses of social change, uncertainty, isolation, inadequate housing and infrastructure, and substandard services may combine in ways that significantly affect communities' quality of life [33]. Chronic psychological stress has been linked to respiratory health, both independently and in combination with air pollution exposures [38]. Therefore, social stressors, such as those seen with the changes that natural gas drilling brings to an area, may have a cumulative impact on public health.

Worker Health

Historically, natural gas extraction has been a dangerous occupation [39]. Many of the safety issues involved are well understood and regulated. According to the Bureau of Labor Statistics (BLS), transportation incidents are consistently the leading cause of fatalities, followed closely by contact with equipment [40]. However, the rapid pace and geographic scope of expansion into remote locations inhibits monitoring of worker protection at drill sites [41]. This environment creates significant challenges for protecting oil and gas extraction workers.

The industry is characterized by a high rate of fatal injury when compared to all U.S. industries. Worker safety in this industry is highly variable, both over time and across individual companies. The risk of fatality is higher among workers employed by contractors and small companies [42]. During times of high demand, the number of small companies and inexperienced workers entering the industry increase. The annual rate of fatalities is also associated with the number of drill rigs in operation [42]. This pattern of risk suggests particular attention should be paid to small operations during periods of rapid industry expansion, especially in rural areas with roadways unsuited to industrial traffic.

In addition to risks typical of the oil and gas industry, there may also be unique worker health concerns associated with HVHF, such as the potential for exposure to chemical constituents of hydraulic fracturing fluids, diesel exhaust, BTEX (benzene, toluene, ethylbenzene, and xylenes), particulate matter (PM), glutaraldehyde, and the sand used as a proppant that have not been fully characterized and are still poorly understood [43].

Sand Mining and Transport

HVHF operations typically involve hundreds of thousands of pounds of "frac sand," the sand used as proppant during the hydraulic fracturing process. Transporting, moving, and filling thousands of pounds of sand onto and through sand movers, along transfer belts, and into blenders generates dust containing respirable crystalline silica. Inhalation of fine dusts of respirable crystalline silica can cause silicosis [35]. Crystalline silica has also been determined to be an occupational lung carcinogen [44]. This exposure is of concern for workers and also for other individuals near the mining operations and well pads.

The National Institute for Occupational Safety and Health (NIOSH) recently collected air samples at 11 different HVHF sites in five different states (AR, CO, ND, PA and TX) to evaluate worker risks, including exposure to crystalline silica [43]. At each of the 11 sites, NIOSH consistently found levels that exceeded relevant occupational health criteria (e.g., the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) and the NIOSH Recommended Exposure Limit (REL)). At these sites, 47 percent of the samples collected exceeded the calculated OSHA PELs; 79 percent of samples exceeded the NIOSH RELs. The magnitude of the exposures is particularly important: 31 percent of samples exceeded the NIOSH REL by a factor of 10 or more. This study indicates that hydraulic fracturing workers are potentially exposed to inhalation health hazards from dust containing silica when open air mixing of sand is done on site.

There may also be impacts on workers and communities affected by the vastly increased production and transport of sand for HVHF in other areas of the country. NIOSH concluded that there continues to be a need to evaluate and characterize exposures to these and other chemical hazards in hydraulic fracturing fluids, which include hydrocarbons, lead, naturally occurring radioactive materials (NORM), and diesel particulate matter [26, 43].

Climate Change

Uncertainty remains over the potential for HVFH to affect climate change. Climate change is predicted to significantly affect health in numerous direct and indirect ways [45]. Natural gas is more efficient and cleaner-burning than coal. When burned, natural gas releases 58 percent less carbon dioxide (CO_2) than coal and 33 percent less CO_2 than oil [46]. Because of that, natural gas has been promoted as a transitional fuel to begin a conversion to greener energy such as wind and solar [11, 47]. However, some projections suggest that obtaining natural gas through HVHF actually produces more greenhouse gas emissions than does coal production and burning [48]. The impacts of HVHF on overall greenhouse gas emissions depend on actual fugitive emissions, the quantity of fossil fuels combusted during production processes (by compressors, trucks, machinery, etc.), and whether natural gas produced by HVHF reduces the use of other more greenhouse-gas–intensive fuels. Burning natural gas obtained through HVHF will result in a net increase of greenhouse gas emissions over time if it simply delays the burning of coal reserves.

The list of potential public health impacts outlined above is not comprehensive. However, it provides an overview of the diversity, extent, and nature of the issues that might be addressed by taking a public health perspective on HVHF. It is clear that while natural gas extraction is a long-standing and important part of our nation's energy portfolio, the rapid implementation of large-scale HVHF in many parts of the country has presented a new industrial, environmental, and land use development pattern with significant potential for public health effects.

PUBLIC HEALTH RESPONSE

In 2008, Howard Frumkin and colleagues set forth a framework for public health responses to the challenge of climate change [45]. Both climate change and HVHF are usually considered issues characterized by tradeoffs between economic growth and environmental protection. As a policy problem, climate change is similar to the rapid expansion of HVHF in several key ways, including wide-ranging uncertainties, the potential for impacts in diverse sectors, and the need to address the issue through multidisciplinary investigation and at local, state, and federal levels (as well as internationally). For both issues, public health brings an important perspective, and public health professionals have an important role to play. Here, we adapt Frumkin's framework for climate change to the issue of HVHF to provide guidance for a constructive role for public health in future practice and policy.

Frumkin et al. describe five public health perspectives that inform responses to the challenges of climate change [45]:

- prevention;
- risk management;
- co-benefits;
- economic impacts; and
- ethical issues.

These perspectives are also salient for the many challenges facing public health professionals in addressing HVHF. Below, we discuss each perspective in turn as a source of guidance for what public health voices can add to the ongoing public dialogue about managing HVHF to promote the public good.

Central to each of these perspectives is the uncertainty surrounding the potential impacts of HVHF. Uncertainty is frequently cited as one of the primary barriers to determining whether—and if so how—HVHF can be managed in a manner that promotes public health. While instances of health problems have been reported in various communities where HVHF has occurred across the country, to date there has been little peer-reviewed literature on the nature or extent of these impacts [18]. This dearth of research is due to the limited number of years HVHF has been practiced, as well as to fundamental challenges in studying its health impacts. These include the lack of identified unique health indicators, latency of effects, limited baseline and monitoring data, cumulative impacts, low population densities, and, in some cases, industry practices and non-disclosure agreements that limit access to relevant information. Understanding of health effects is further complicated by the variations in HVHF operations geographically and over time. Many of these significant uncertainties are unlikely to be overcome in the foreseeable future. However, the public health community has extensive experience in situations that are rife with unknowns. The precautionary principle is often invoked to guide decision-making, so as to prevent suspected environmental or health risks when there is significant uncertainty. The theme of taking action despite remaining uncertainties carries through each of the principles discussed below.

Prevention

As Frumkin et al. [45] point out, public health professionals distinguish between primary prevention (taking action to avoid a harm) and secondary prevention (anticipating and taking action to reduce existing impacts). Principles of prevention suggest that public health professionals should urge federal, state, and local environment, health, and development agencies to adopt a precautionary approach in the face of uncertainty regarding the long-term environmental health impacts of HVHF. Such an approach might include:

- discouraging the use of chemicals or chemical mixtures with unknown health effects, particularly those with the potential for long-term or endocrine-disrupting potential, and favoring safer substitutes;
- requiring gas development companies to disclose and receive approval of the chemicals proposed in each HVHF operation, before drilling and completion;
- conducting baseline monitoring of air quality, water quantity and quality, land resources, and human health before drilling begins, throughout the extraction process, and after active operations cease;
- modeling and predicting cumulative environmental health impacts under various extraction scenarios;
- conducting health impact assessments that address multiple health effects at a local and regional scale prior to expansion of HVHF;
- insisting on the use of commonly accepted industry best practices to lower worker exposures, for example, dust controls, traffic control plans, closed chemical delivery systems, reduced worker exposure to produced water, and employer provision of personal protective equipment (PPE), training and monitoring;
- proceeding at a scale and pace that allow for effective monitoring, surveillance, and adaptation of regulation to anticipate/prevent negative health effects; and
- should negative health or environmental effects be observed, ceasing extraction until further evidence indicates that operations may resume safely.

Geological, geographic, climatological, technological, economic, social, and political differences between communities in which HVHF occurs result in widely varied potential for health impacts. The public health community should advocate for planning and policy approaches that take into account this variability.

Risk Management

The framework of risk management guides the systematic identification, assessment, and reduction of risks. Public health professionals should advocate for and participate in efforts to manage the risks of HVHF. These efforts should examine the full life cycle of the process at local, regional, and global levels.

This implies explicitly modeling the cumulative impacts of HVHF over time. For example, individual drilling operations are unlikely to produce enough pollution to trigger regulation under existing environmental laws. However, the cumulative impacts of emissions from drilling-associated activities at multiple sites may create significant public health threats for local communities or regions. Therefore, projections of aggregate emissions under expected extraction scenarios should be the basis for regulation of individual sources. Overall density and projected development over time should be considered.

Air pollution is just one type of impact to which the risk management approach should be applied. Health impact assessment (HIA) provides a framework for identifying and prioritizing multiple impacts. Only one HIA of HVHF has been conducted to date, and public health professionals and others have advocated for additional HIAs to be conducted in other areas [30].

Co-Benefits

Frumkin et al. invoke the principle of co-benefits to guide a public health response to climate change [45]. Co-benefits result when actions yield benefits in multiple arenas. Focusing on actions with co-benefits is particularly appropriate when resources are limited and uncertainties are high.

Public health professionals can look to the list of 10 essential services of public health, developed by the Public Health Functions Steering Committee in 1994 (see Figure 1) to help identify actions within their purview that may both reduce risks from HVHF and benefit health in other ways [49]. For example, monitoring private drinking water wells for baseline data prior to the onset of HVHF may identify pre-existing drinking water quality problems that would otherwise have gone undetected. Community partnerships forged to address the issues raised by HVHF may also be able to confront other local environmental public health problems. Training public health professionals, health care providers, and emergency responders to deal with potential spills, explosions, or accidents related to HVHF may improve local capacity to respond to other types of public health emergencies.

Economic Impacts

Public health planning aims to protect the public at the lowest possible cost. In the case of HVHF, this suggests the following:

- Both long- and short-term costs and benefits should be considered. The history of environmental health includes many examples long-term remediation costing more than prevention.
- The timing of HVHF has major implications for the economics of shale gas extraction because of expected changes in the price of natural gas. Policies regarding HVHF should explicitly compare tradeoffs between the economic, strategic, public health, and global climatological implications of energy alternatives under different extraction scenarios over the long term.
- The distribution of costs and benefits from HVHF is highly variable. While HVHF undoubtedly brings economic growth, the benefits do not accrue

1. Monitor health status to identify and solve community health problems.
2. Diagnose and investigate health problems and health hazards in the community.
3. Inform, educate, and empower people about health issues.
4. Mobilize community partnerships and action to identify and solve health problems.
5. Develop policies and plans that support individual and community health efforts.
6. Enforce laws and regulations that protect health and ensure safety.
7. Link people to needed personal health services and assure the provision of health care when otherwise unavailable.
8. Assure competent public and personal health care workforce.
9. Evaluate effectiveness, accessibility, and quality of personal and population-based health services.
10. Research for new insights and innovative solutions to health problems.

Figure 1. Ten essential services of public health.
Source: U.S. Centers for Disease Control and Prevention, National Public Health Performance Standards Program (NPHPSP), "10 Essential Public Health Services," http://www.cdc.gov/nphpsp/essentialservices.html

equally within communities, nor do the burdens. Because of public health's focus on eliminating health disparities and the close association between economic and health status, the distribution of economic impacts has public health implications.

- The impacts of the boom-and-bust cycle of economics associated with extraction of nonrenewable resources like shale gas has significant implications for community health over the long-term.
- Many economic costs are not included in simple calculations of jobs and economic growth generated by new industry. These externalities may include losses to existing businesses (tourism, agriculture, etc.), damage to roads and increased costs of road maintenance, and days of work or school missed by asthmatics who suffer more when air pollution increases.

For these reasons, public health professionals should advocate for economic analyses that account for long-term costs, identify externalities, and clarify the distribution of costs and benefits. Such analyses may provide a basis for designing fee structures, prioritizing research needs, creating monitoring systems, and developing public health programs that reflect the true costs and benefits of HVHF.

Ethical Issues

The ethics of public health have been codified into 12 "principles for practice." In addition, Frumkin et al. [45] point to several ethical foundations that may inform public health responses in a given situation. Building on these principles, ethical considerations relevant to the public health perspective on HVHF include:

- *Future generations:* As noted above, the potential long-term costs of environmental and health damage should be considered. Given the long latency of diseases like cancer, intergenerational impacts of endocrine disruptors, and slow migration of groundwater, it is appropriate to advocate for a long-term perspective on health effects of HVHF.
- *Vulnerable populations:* Some individuals or populations may be more vulnerable to environmental health impacts of HVHF. Children, the elderly, and those with existing disease (for example, asthma) may be more susceptible to impacts such as air pollution. Workers (both on-site and in related industries) are another population that may be particularly affected due to their proximity to operations.
- *Environmental justice:* Public health ethics point to protection of those who have fewer resources to avoid or mitigate impacts, already bear disproportionate environmental risks, or have historically lacked a voice in policy decisions. By this definition, isolated and economically disadvantaged rural communities are of concern as a whole, and lower-income members of these communities may need particular consideration.
- *Public participation:* Informed, ongoing, and meaningful participation by affected communities is often advocated as a strategy to promote ethical decision processes and outcomes. Public health professionals have the tools and experience to communicate information, develop partnerships, and process the public's input in a meaningful way. The extent of public concern about health in discussions of HVHF points to the importance of public participation in decisions on this issue.

Public health professionals have a role to play in making sure that these ethical principles are considered in decision-making related to HVHF.

CONCLUSIONS

Natural gas development is regulated under local, state, and federal land use and environmental laws. However, implementing new natural gas extraction technologies on a large scale poses potential public health threats that existing regulatory systems may not adequately anticipate, monitor, or protect against. Therefore, it is essential that public health professionals be included in deliberation of administrative, programmatic, and policy approaches to natural gas extraction at all levels of government. Federal, state, and local commissions and agencies charged with regulating the natural gas industry should include strong representation by professionals with training and experience in public health. In addition, the role of local and state public health professionals in responding to public health concerns arising from HVHF should be recognized and supported accordingly.

Training of local health departments, health care providers, and occupational health centers, as well as open ongoing communication between health professionals and the gas extraction industry, are essential to protecting worker and public health. The implementation of new natural gas extraction technologies, continual changes in the gas development industry, rapid growth of drilling operations in new areas, and variations in operations between companies pose significant challenges for occupational health. Public health professionals should support training for workers and local health care providers to anticipate these challenges and the provision of resources to subsidize these additional needs.

There are clearly many uncertainties surrounding the nature, distribution, and extent of health effects from HVHF. However, as Frumkin et al. [45] note, "Preparedness often occurs in the face of scientific uncertainty." Based on past experiences with emergency response, offshore oil and gas production, nonpoint sources of air and water pollution, and occupational health, public health professionals have a wealth of experience relevant to many aspects of HVHF. Policies that anticipate potential public health threats, use a precautionary approach in the face of uncertainty, provide for monitoring, and promote adaptation as understanding increases may significantly reduce the negative public health impacts of this approach to natural gas extraction.

To help accomplish this goal, the public health workforce should become better educated about natural gas development and its potential for public health impacts. In particular, local public health agencies in areas of active natural gas development should receive adequate resources to support education, outreach, surveillance and monitoring, needs assessment, and prevention activities related to natural gas extraction. Federal and state legislatures should provide funding for the training and staffing of local public health agencies in areas of active natural gas development. Public health professionals should also reach out to health care providers and community partners to increase their capacity and involvement in this area.

Such awareness, education, and support may help public health professionals more actively engage in protecting public health from the potential impacts of HVHF. Policy position statements such as that recently adopted by the APHA provide a platform from which public health professionals can continue to engage in decision-making processes related to HVHF. This special issue of *New Solutions* offers additional information and inspiration for next steps.

AUTHORS' BIOGRAPHIES

WALTER A. JONES is the Associate Director of the Occupational Safety and Health Division for the Laborers' Health and Safety Fund of North America, in Washington, DC. Mr. Jones is a Certified Industrial Hygienist and helps contractors establish and maintain OHS best practices that create healthy work-sites and positive safety cultures. Mr. Jones is a member of NIOSH's Prevention through Design Council and sits on the OSHA Advisory Committee on Construction Safety and Health (ACCSH) and the American National Standards Institute (ANSI) A10 Construction and Demolition Standards Committee. Contact him at wjones@lhsfna.org

KATRINA SMITH KORFMACHER is Associate Professor in the Department of Environmental Medicine at the University of Rochester Medical Center and directs the Community Outreach and Engagement Core of the Environmental Health Sciences Center. Dr. Korfmacher's current research focuses on the use of science in community-based environmental health policy in the areas of healthy homes, hydrofracking, and health impacts assessments. Her email address is katrina_korfmacher@urmc.rochester.edu

SAMANTHA MALONE is the Manager of Science and Communications at the FracTracker Alliance. She provides user and partner support, coordinates organization-wide communications, and conducts and translates environmental health research for the blog. Sam has an MPH degree from the University of Pittsburgh Graduate School of Public Health (GSPH) and is currently a doctoral student in the school's Environmental and Occupational Health department. Contact her at slm75@pitt.edu

LEON F. VINCI, DHA, MPH, BA, RS. His thirty-year public health career has involved him in a variety of aspects of the environmental health profession. He has received national stature in such areas as school health issues, hazardous materials management, Health Reform, Public Health Preparedness, continuing education, institutional sanitation, Bioterrorism/Emergency Preparedness, Environmental Health, and infectious diseases. He is the founder and CEO of Health Promotion Consultants (HPC), a health consulting firm.

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Direct reprint requests to:

Katrina Smith Korfmacher, Ph.D.
601 Elmwood Avenue, Box EHSC
Rochester, NY 14642
e-mail: katrina_korfmacher@urmc.rochester.edu

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USING ETHNOGRAPHY TO MONITOR THE COMMUNITY HEALTH IMPLICATIONS OF ONSHORE UNCONVENTIONAL OIL AND GAS DEVELOPMENTS: EXAMPLES FROM PENNSYLVANIA'S MARCELLUS SHALE

SIMONA L. PERRY

ABSTRACT

The ethnographer's toolbox has within it a variety of methods for describing and analyzing the everyday lives of human beings that can be useful to public health practitioners and policymakers. These methods can be employed to uncover information on some of the harder-to-monitor psychological, sociocultural, and environmental factors that may lead to chronic stress in individuals and communities. In addition, because most ethnographic research studies involve deep and long-term engagement with local communities, the information collected by ethnographic researchers can be useful in tracking long- and short-term changes in overall well-being and health. Set within an environmental justice framework, this article uses examples from ongoing ethnographic fieldwork in the Marcellus Shale gas fields of Pennsylvania to describe and justify using an ethnographic approach to monitor the psychological and sociocultural determinants of community health as they relate to unconventional oil and gas development projects in the United States.

Keywords: environmental justice, unconventional oil and gas, Marcellus Shale, community health, chronic stress, ethnography, fracking

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The term *onshore unconventional oil and gas developments* refers broadly to the activities and technologies used for extracting hydrocarbon resources from oil and gas shale, tight gas and tar sands, heavy oil reservoirs, and coal beds [1]. As the pace of exploration, drilling, extraction, and processing of shale oil and gas across North America has increased, medical doctors, research scientists, and federal agencies have raised concerns about the public health implications of the environmental and social changes that result from these developments [2-8]. Many of these public health concerns relate to air and water pollution from industrial facilities and accidents related to these developments. However, perhaps just as significant is the risk that such changes may lead to psychological and social (psychosocial) stress that can make individuals more susceptible to disease and chronic health problems [9-11].

Ethnography, the process of observing, interpreting, describing, and writing about local cultures [12], is an important social science method for systematically documenting and describing environmental and sociocultural factors and changes that may impact community health. Ethnographic methods can also be used to inform local public health research agendas, including carrying out health impact assessments and planning for or responding to emergencies, and making culturally appropriate health policy recommendations. Ethnographic methods as part of community health studies can also be used within an environmental justice framework. A hallmark of these environmental justice studies using ethnography is their grounded, systematic description of the persistent environmental inequalities within communities of color and the poor who are exposed to greater environmental hazards at the same time as they experience higher rates of poverty, malnutrition, social isolation, political powerlessness, and discrimination [13-15]. This article expands on this application and describes how ethnography can be used as an important community health monitoring tool in rural, urban, and suburban areas where unconventional oil and gas developments are taking place.

Concrete examples are drawn from an ongoing ethnographic study in Bradford County, Pennsylvania, where Marcellus Shale gas exploration and development is taking place. Data collected from interviews, focus groups, and participant observations in 2009, 2010, and 2011 confirm that rapid environmental and social changes were happening in the county as a result of Marcellus Shale developments. A total of 31 landowners and 68 other residents of the county were interviewed during this time period, and most spoke about experiencing what was later classified during data analysis as psychosocial stress. The majority of this stress was articulated by landowners or observed in the field as resulting from the environmental and social changes taking place over such a short period of time. These psychosocial stress factors were then analytically sorted into three themes with direct relevance to understanding the psychological and sociocultural determinants of community health outcomes: anticipated or perceived changes to quality of life; economic inequalities; and acts of violence.

These themes raise new questions about the risks posed by unconventional oil and gas development and lead to new avenues for investigation of the links among such developments, environmental and social changes, chronic stress, and community health outcomes.

AN ENVIRONMENTAL JUSTICE FRAMEWORK FOR ASSESSING COMMUNITY HEALTH IMPLICATIONS OF UNCONVENTIONAL OIL AND GAS DEVELOPMENTS

The rapid rise in onshore unconventional oil and gas developments has new and serious implications for local communities, particularly in poorer rural areas, making this an emerging environmental justice issue. Compared to the offshore oil and gas developments of the 1970s and 1980s in the Gulf of Mexico [16], these onshore developments, particularly in the Marcellus Shale in Pennsylvania and Ohio, occur in closer proximity to people's water wells, homes, schools, places of work and worship, playgrounds, and historic locations. There is increased competition and direct conflict with existing and future private and public land uses, particularly where new natural gas pipelines are being constructed. Adding to these tensions are unknown risks regarding the use of chemical compounds and other materials labeled "trade secrets" by the industry and used in the drilling, extraction, and production processes. The Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 created environmental and right-to-know regulatory exemptions for hydraulic fracturing and added tax breaks and government subsidies to encourage domestic exploration of unconventional oil and gas resources. In addition, the U.S. Environmental Protection Agency is investigating concerns about the amount and type of waste materials that are generated from drilling and production and their appropriate disposal [17].

This article applies an environmental justice framework that incorporates the public health model of prevention and the precautionary principle [18] to the assessment of the community health implications of onshore unconventional oil and gas developments. The public health model of prevention focuses on eliminating a threat before harm can occur. This approach shifts the focus from treatment to prevention and demands that affected communities not have to wait for conclusive proof of causation before preventive action is taken [18, pp. 19, 20, 26]. The precautionary principle says that if there is scientific uncertainty about the harms posed by an activity, then those proposing that activity have the duty to prevent harm. The burden of proof lies on those who propose to use risky technologies, not those who may be harmed by such technologies [18, pp. 19, 28].

In the United States, the use of ethnography to study environmental pollution as it relates to public health has its roots in the environmental justice movement, looking at the social, geographic, and procedural burdens disproportionately placed on communities of color and the poor, particularly in urban areas [18, pp. 30-31]. The bottom-up, grounded approach that ethnographic fieldwork takes provides information on the cultural context: where people live, work, play, and attend school and how they interact with the physical and natural world on a daily and lifetime basis. Ethnographic analysis, and use of the iterative process of returning to the fieldwork location to verify and check analytical themes, also provides a means to track environmental and social changes and their impact on the psychological, social, and physical health of individuals and communities over time.

THE ROLE OF PSYCHOLOGICAL AND SOCIAL STRESS IN DETERMINING COMMUNITY HEALTH OUTCOMES

Since at least the mid-1950s public health scientists, psychologists, and sociologists have studied how psychological, social, and environmental stressors impact individual and community susceptibility to disease or changes in overall health. In this previous work, a stress or stressor is defined as "any environmental, social, or internal demand which requires the individual to readjust his/her usual behavior patterns" [11, p. 54], having a negative influence on a person's overall well-being and quality of life, and in some cases triggering physiological mechanisms that in turn may determine an individual's or a community's susceptibility to disease, environmental pollution, or toxic substances [11, 18, 21].

In their study of abandoned coal mine communities Liu et al. [22] found that economic deprivation was significantly associated with a greater number of abandoned mines in rural Pennsylvania. And, while they do not draw definitive conclusions regarding the community health implications of their results, they do identify important interactions between sociocultural characteristics and available material and institutional resources that may result in poor overall health outcomes. Namely, they point to problems of industrial and social abandonment and landscape changes in addition to poverty and economic inequality that can limit access to health care, healthy food choices, and recreational spaces [22, p. 7]. Previous studies of the social determinants of health have also identified poverty and economic inequality as significant contributing factors to chronic stress that may lead to adverse health outcomes [23-28]. These economic metrics may sometimes be an inaccurate and culturally inappropriate way to identify and measure overall well-being and quality of life [29]; however, at least in studies conducted in the United States, personal and community economic status does seem to play a key role in determining levels of chronic stress, the overall health of individuals and groups, and susceptibility to disease.

Anecdotal reports by individuals in communities where onshore unconventional oil and gas developments are occurring describe rapid environmental changes related to well pad and pipeline construction, road damage, physical health problems, and deteriorating air and water quality [30]. In more rural areas, there are also anecdotal reports of rapid social changes related to an increase in population numbers and density (especially of transient young men working in the oil and gas industry), an influx of new personal income from lease-signing bonuses and royalty income, a shortage of affordable housing, and increased crime [31, 32]. While anecdotal reports such as these may indicate that communities are experiencing increased psychological and social stress as a result of environmental and social changes, they do not provide systematic evidence that individuals and entire communities are experiencing the type of chronic stress that may lead to an increased susceptibility to disease or changes in overall health. To rigorously and systematically collect this type of information on chronic stress, we need a way to document both individual and collective experiences before, during, and after environmental and social changes take place. The practice of ethnography and its grounded data collection and iterative analysis methods offer a comprehensive way of doing just that.

ETHNOGRAPHIC METHODS

Ethnographic research methods seek to describe everyday lives and practices through cultural interpretation. An ethnographer's goal is to explain how these descriptions represent what can be called "webs of meaning" [12, pp. 5, 33] in which we all live. To do this, ethnographers have developed a variety of methods for studying the everyday lives of humans and the systems and patterns (language, artifacts, visual symbols, etc.) connecting humans to each other, as well as to natural and built environments, institutional structures, and other constructs of traditional and contemporary society [34]. In contrast to other social science methods and approaches, ethnography takes what is known as an inductive and grounded perspective, meaning that categories and meanings of analysis emerge from data collection rather than being imposed from existing models or hypotheses. Done correctly, this grounded perspective ensures that the data emerging from ethnographic fieldwork can be used to develop further research questions and hypotheses that have local salience. A closer look at the methods used in the Bradford County study illustrates these points.

The objective of the ethnographic study conducted in Bradford County was to describe the cultural world views and personal and social interactions of rural landowners, specifically related to their land, water resources, and the rapid industrial developments taking place as a result of the potential boom in Marcellus Shale gas production [35]. The study utilized mixed-methods data collection and analysis, including a community-integrated geographic information system (GIS) process [36, 37], focus group meetings [38, 39], questionnaires, photo-voice (described below) [40, 41], oral history interviews, ethnographic interviews, participant observations, and archival document analysis.

To develop a plan for recruiting landowners and other interviewees, conversations and informal interviews were held with individuals at the County

Conservation District and the Planning and Grants Office, County Commissioners, township supervisors, and several Bradford County residents who had lived 10 or more years along the Susquehanna River. Observations were also conducted at various meetings of landowners and concerned citizens in the county and north-central and northeastern Pennsylvania to understand the diverse types of landowners and other residents. Based on this early fieldwork, a decision was made to focus on landowners owning close to 100 acres, or more, and who were actively using their land for farming, timber, and other forest uses. Specific names of possible participants in the focus groups were drawn from word-of-mouth referrals from county staff and other farmers and forest landowners. The successful recruitment of focus group participants took four months longer than anticipated. Two things caused this delay: difficulties in gaining the trust of a diversity of rural landowners in the county and the inability to guarantee complete anonymity to potential focus group participants who had signed previous legal agreements (non-disclosure agreements) or were in legal proceedings with a shale gas company. These difficulties required the scaling back of the number and size of focus groups. It was a trade-off that favored the collection of deeper, richer data from a smaller group of participants instead of broader, more representative data from a larger group of participants. To capture some of the diversity of landowners that was lost in the smaller focus groups, individual interviews were conducted with the landowners who could not participate because of anonymity concerns (but who still wanted to participate), and with those landowners who were unable to make the meetings, felt uncomfortable in a group setting, or who no longer actively used their land for farming or forest uses. These individual landowner interviews, plus additional interviews with county residents who were recruited by word of mouth referrals and identified during participant observations, were used both on their own and as a supplement to the analysis of the focus group data.

Seven landowners participated in two focus groups, each of which met four times. The two separate groups were based on their primary land use, one group of four crop and livestock (primarily corn, hay, dairy, horse) farmers and the other group of three woodland (timber, hunting, wildlife watching) landowners. The focus group participants were involved in the community-integrated GIS process during which they selected geographic places of special importance to them in the county, mapped their land, and identified their neighbors, all the while discussing their relationship to place and community. Focus group participants were also involved in a photo-voice process that involved taking photographs of things and places that exemplified their relationship with their land, the county, and the changes they were experiencing, and then writing about those photographs and sharing them with others in the group. To supplement this group work, individual oral histories were conducted with each of these seven landowners.

Twenty-four landowners and 68 other local residents, including a county commissioner, agricultural extension specialist, town residents, small business owners, township supervisors, oil and gas contractors, and school teachers, participated in individual ethnographic interviews. Participant observations were conducted at community events such as local fairs and church dinners, at public meetings such as monthly township meetings and weekly county commissioner meetings, at public hearings related to Pennsylvania Department of Environmental Protection Marcellus Shale regulations, and at private meetings such as gas industry community advisory panels.

The ethnographic data from the Bradford County study includes audio and video of focus groups and interviews, photographs and writings from the photovoice process, spatial data and maps from the GIS process, informational brochures and handouts from meetings, field notes of participant observations and interviews, as well as historic photographs and documents from archival research. Even though all the data were collected in the same county, the data cannot be analyzed for generalizations about the entire county, a township, a specific type of landowner, the region, or the state. Instead, data was analyzed to differentiate and describe particular aspects of the relationships humans have to their local environments and to each other; in other words, the data were used to discern the various cultural worldviews and "webs of meaning" held by those who participated as interviewees or under observation as part of the study [42].

ETHNOGRAPHIC ANALYSIS: THEMES OF CHANGE AND STRESS

The interpretation of ethnographic data and its analysis is an iterative process. It involves coding of interviews and observational notes, re-entering the field and asking new questions where necessary to refine themes emerging from the coding, and finally developing a set of themes that can be used to convey a detailed cultural description of local places and local people who were the focus of the study. The iterative nature of the analysis process ensures that an ethnographic study remains grounded in the local cultural context over time. This refining of themes and descriptions over time is critical to documenting and describing real-time environmental and social changes and the impact of those changes on local individuals and communities.

In the Bradford County study, cultural analysis revealed three themes directly related to environmental and social changes and what were articulated by local participants as increased levels of psychological and social stress: anticipated or perceived changes to quality of life, economic inequalities, and acts of violence. These themes are being used in continued ethnographic fieldwork in the county to ask new questions and form hypotheses. But these themes can also serve in planning future ethnographic studies on community health in other rural, suburban, and urban locations where unconventional oil and gas developments are located or are being planned and to inform preventive public health policies. How each theme emerged from the ethnographic data, and each theme's significance to understanding the community health implications of unconventional oil and gas development, are described below.

Changes in Quality of Life

The seven rural landowners who participated in focus groups in Bradford County identified six components to what quality of life meant to them: clean water, fresh air, fertile soil, rural way of life, economic security, and family and personal histories with the land in the present time and for their grandchildren. This local meaning of quality of life was probed for relevance in ethnographic interviews with the 24 individual landowners and it was found to resonate with them as well. When focus group discussions, or individual interviews, turned to how these qualities of life were either currently being changed or anticipated to change as a result of the Marcellus Shale gas developments, landowners spoke of many changes, including these: destruction of their dirt and gravel roadways (which were described as "arteries of rural community life" and the boundaries of family lands); a noticeable increase in "dust" in the air that gets on laundry hung out to dry, porches, and even inside their houses; an increase in loud noises from trucks applying their brakes and from drilling rigs at all hours of the day and night; bright lights in the night sky from construction activities and drilling rigs; visual and odor changes in the appearance or odor of their drinking water (all landowners who participated have private water wells); the number of strange new faces and non–English-speakers at local stores and gas stations; chemical spills into landowners' ponds and crop fields; and expectations of greater economic security as a result of signing a lease to allow a gas well, compressor station, or pipeline on their property.

When matching emotions to these changes, one landowner in a focus group described a feeling of "dread in the pit of my stomach," and all the landowners interviewed said they felt that as a result of the development of the Marcellus Shale in the county they were losing certain aspects of their quality of life, especially the fresh air and rural feel. Most landowners also expressed great uncertainty about whether these changes in quality of life would be temporary or permanent. This uncertainty turned to fear, anxiety, and depression in some landowners, particularly regarding what the changes would mean for their future well-being and the well-being of their children and grandchildren.

Uncovering and naming what quality of life meant to them allowed landowners to name and describe some of the psychological, social, and environmental factors that they felt may be leading to improvements or declines in their quality of life and overall well-being as a result of both external and internal forces, including state or national farming policies, environmental regulations, the shale gas industry, local politics, family and social relationships, and many others. Landowners said this helped them name, sometimes for the first time, what their quality of life meant to them. They reported feeling more aware of what was important to them, and this gave them a greater will to fight to keep their quality of life and help their neighbors do the same; however, they also reported that this greater awareness left them at times with a greater sense of loss and sadness. Ethnographic methods, with the focus on asking questions that directly relate to accessing local culture through understanding the language and behaviors of locals, put interviewees' cultural viewpoints above the researchers' and thereby allow for this sort of awareness-raising in ways that other social science methods cannot.

The concept of quality of life is closely associated with what people report as a sense of well-being. Behavioral economists and political scientists have found that among individuals, families, and communities, this sense of well-being can lead to overall improvements in quality of life and society [43-46]. During a speech at the University of Kansas in 1968, Robert F. Kennedy famously said,

> ". . . the gross national product does not allow for the health of our children, the quality of their education, or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages; the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage; neither our wisdom nor our learning; neither our compassion nor our devotion to our country; it measures everything, in short, except that which makes life worthwhile" [47].

Today international development agencies and national governments are developing indicators that seek to measure the sense of well-being that Kennedy spoke of in his speech. Measurements such as the United Nation's Human Development Index [29, 48] look not just at income or financial indicators but also levels of health, education, political freedom, and inequality. These types of quality-of-life measures have also been used in epidemiologic studies to assess the impact of industrial development, specifically fossil fuel developments, on local communities [22]. Ethnography offers a set of methodological and analytical tools that allow for the rigorous documentation, description, and analysis of what quality of life means to local communities faced with periods of rapid change.

Economic Inequality

All participants interviewed or observed as part of the ethnographic study in Bradford County expressed the belief that crop/livestock landowners tend to have less money than landowners who own only woodlands. But would a crop/livestock landowner who needs annual or semi-annual supplemental income to meet expenses be more eager to sign a lease for locating a shale gas well pad, water impoundment pond, compressor station, or pipeline on his or her property than a woodland landowner or other type of landowner who does not rely on supplemental income to meet his or her financial obligations?

In focus group meetings of the crop/livestock landowners, all four landowners said that they would allow Marcellus Shale gas development on their properties if the "price was right." At the time of the focus groups (January 2010–August 2010) all four of the crop/livestock landowners had active gas leases on their properties. In individual interviews these same landowners expressed more specific concerns regarding how the property would be treated during the developments (e.g., spills of hazardous wastes, accidents, destruction of prime pasture, etc.), but as in guided conversations in the focus group meetings, they individually conceded that if enough money was offered they would consider agreeing to development.

In contrast, the three landowners in the woodland focus group said that what was most important to them was not the price they would be offered or paid by the gas company to develop their land, but instead how the land would be developed and if the gas company would allow them to negotiate protection of their water, timber, wildlife, and access. In individual interviews with these landowners, one of these landowners admitted that price was an important consideration although certainly not the only thing to be considered in signing an agreement to allow shale gas development on his land. The other two woodland owners had no interest in the money, but only in the preservation of their land and water resources. At the time of the focus groups (February 2010–August 2010), none of the three woodland owners had a gas lease on his/her property.

Responses to a socioeconomic questionnaire given to the focus group participants indicated that income, not land use, was the main factor separating the four crop/livestock landowners from the three woodland owners. All landowners in the crop/livestock group reported annual household incomes (minus the salaries of minors and dependents) of less than $40,000, with two reporting less than $20,000. All woodland landowners reported annual household incomes of greater than $40,000. These responses are within the same range of estimates for mean household income in the entire county as reported in federal census statistics from 2006-2010. The 2006-2010 mean household income for the county was $51,372, with 30.2 percent of all total households in the county reporting less than $24,999, 29.9 percent reporting between $25,000 and $49,999, and 40.3 percent reporting over $50,000 [49]. In addition, the crop/livestock group participants responded that an average of 67 percent of their annual household income is derived from agricultural activities, while in the woodland group the percentage from agriculture was reported as only 2 percent.

Differences in household income revealed in such a small sample cannot lead to conclusive evidence regarding the impact that economic differences or inequalities may have on the psychological, sociocultural, and environmental indicators of community health. However, data confirming these income disparities was also collected during open-ended ethnographic interviews with individual landowners and in participant observations at a 2011 meeting of the

Bradford-Sullivan Forest Landowners' Association. Specifically, the point was made in these open-ended interviews and observations that supplemental income from both harvest of timber resources and off-the-farm jobs may be more important for crop/livestock landowners than for woodland owners. In addition to this income disparity between different types of rural landowners in Bradford County, the differences in occupation and employment status between landowners raises questions about differential access to affordable and timely health services. For example, all of the crop/livestock landowners in the focus groups and the majority of crop/livestock landowners and active farmers who were interviewed individually reported having no health insurance coverage. Current evidence or lack of evidence for the health effects of employment status are reviewed in detail by Catalano et al. [50], with a recommendation that more research is needed to understand how job and income loss in families and individuals may impact well-being, anxiety, and overall health outcomes [50, p. 445]. Clearly, given what the data collected during this ethnographic research say about economic inequalities and rural landowner types in Bradford County, more research needs to be done to understand how rural landowners' economic status influences their well-being, anxiety, and overall health and what this may mean in light of new shale gas developments.

This ethnographic data on economic inequalities between different types of landowners raises important questions with regard to the geographic locations of shale gas facilities and what this may mean with regard to the uneven psychological, social, and environmental stressors faced by different landowners, or even an entire region and the nation. For example, could income differences between landowners have implications for where unconventional oil and gas facilities are located in the first place given different landowners' willingness to either accept "the right price" or preserve their land and water resources regardless of the price? If certain types of landowners, such as crop and livestock farmers, are more willing or eager to have development on their land, does this put them and their families and other farm workers at a greater risk of exposure to industrial accidents and hazardous materials related to shale gas development? If landowners who own cropland or livestock and are actively farming are more willing to have shale gas developments, does this mean the products that come from those farms also run a greater risk of being contaminated by hazardous materials? Do shale gas developments on farmland pose a threat to the nation's food supply? And, if there is a threat, what does this mean to the livelihoods, incomes, and overall sense of well-being of farmers in Bradford County? To answer some of these questions environmental health and toxicology studies must be done. However, in drawing conclusions, and more importantly in offering management and policy recommendations, these environmental health studies must also rely on the psychological and sociocultural information that is being collected from the on-going ethnographic research described here and elsewhere [34].

Acts of Violence

Violence is defined as “the intentional use of physical force or power, threatened or actual, against oneself, another person, or against a group or community that either results in or has a high likelihood of resulting in injury, death, psychological harm, mal-development or deprivation” [51]. Political scientists, psychologists, and social workers who research violence document how different types of violent acts (physical, sexual, psychological, deprivation or neglect, and environmental) can have long-term implications for individual, family, and community stress levels, leading to widespread abuses of power, racism, continuous cycles of abuse, and in the worst cases murder, civil war, and genocide [52-54].

During the first months of fieldwork among Bradford County landowners, local officials and residents of the county talked in open-ended ethnographic interviews about prior cases of beatings, rape, incest, murder, bullying, and intimidation that they had knowledge of or had been directly involved in. Analysis of these early interviews and field notes bears evidence that violence and violent behavior are a part of everyday life in the county. Sometimes particular stories of violence were brought up by interviewees when they wanted to illustrate their concerns about society or politics, such as a belief that lack of education and low-income conditions lead to social turpitudes. Other times, though, these violent stories told by Bradford County residents were very personal and conveyed individual feelings of fear, anxiety, disassociation, loss, and powerlessness, all found in other studies [55-58] to be feelings symptomatic of stress and psychological trauma.

In interviews with landowners and other residents of the county, and most notably in the focus group meetings with the seven rural landowners, these feelings surrounding personal experiences of violent behavior were spoken of as analogous to the way some participants felt they and their families were experiencing changes related to Marcellus Shale gas developments. For example, interviewees described being bullied or intimidated by gas industry employees and their agents, by their neighbors when there were disagreements about the pros and cons of gas development in the local community, and by local politicians when they denied or did not listen to residents’ experiences with the shale gas industry and the severity of pollution events at particular locations. An article published in the anthropology journal *Culture, Food, Agriculture, and Environment* provides a more comprehensive discussion of these findings [35]. Confirming this, participant observation and interview data also contain descriptions of bullying and intimidation of landowners by gas company employees, local politicians, and other landowners related to leasing, siting, construction, and operation of shale gas facilities throughout the county [35]. The recall of past violent acts and the creation of new anxieties and feelings of powerlessness around the Marcellus Shale developments could increase the development of chronic stress patterns [56].

With regards to acts of physical violence in the county since unconventional gas developments began, there is preliminary evidence of an increase in overall physical violence, or threats of violence, from filings of Protection from Abuse (PFA) orders and arrests [59, 60]. However, the current ethnographic data from Bradford County does not allow for an analysis of the relationship between different levels of physical violence and unconventional oil and gas developments or other factors.

Anthropologists, geographers, and political scientists working in Africa, the United States, and other fossil-fuel–rich nations have documented the different acts of violence—physical, psychological, economic, political, environmental, and social—that exist in the context of large-scale oil and gas developments [61-63]. However, none of this research makes the explicit connection between such acts of violence, increased chronic stress, and community health outcomes. In urban settings, the relationship between environmental health and violence has been investigated by social epidemiologists. Epidemiological research in Boston showed that in neighborhoods where childhood asthma rates are higher, children tend to also be exposed to greater violence [64, 65]. While this urban epidemiological research shows that the two issues—asthma and violence—are spatially and temporally correlated, it does not answer the question of whether they are causally linked and, if so, what factors may link them. Using ethnography to describe and monitor the levels of violence in communities where unconventional oil and gas developments are taking place gives community health researchers and epidemiologists a way to track the spatial and temporal interactions between psychosocial stress factors, such as violence and violent behavior, and community health outcomes.

CONCLUSION

Ethnography and ethnographic approaches for monitoring the community health implications of onshore unconventional oil and gas developments are not without their limitations. Several of the most important limitations are faced by all ethnographic researchers regardless of the topic. These involve lack of funding for qualitative, grounded, exploratory, or descriptive social science research, the enormous volumes of data produced from interviews and fieldwork and the amount of time and organizational skill required for analysis of the data, and the difficulty in recruiting and maintaining trust with a diversity of informants and interviewees for the duration of a project. An additional limitation is a lack of understanding of what ethnography is (and is not) and how it can be employed to understand environmental justice concerns, inform further research agendas, and make concrete policy recommendations. For example, ethnography uses qualitative and sometimes anecdotal information as part of a systematic approach to documenting and describing culture based on prescribed methodological and analytical practices. However, the results of this research methodology are not anecdotal stories and information, but are defensible descriptions and analyses of the cultural worldviews and context within which specific people or places exist, which are documented and verified through intense immersion in those people's ways of life or a place. In spite of these limitations, ethnographic approaches to community health have much to offer other researchers, community health practitioners, policy makers, and communities.

To enhance understanding and communication about the potentially important role ethnography can play in gathering environmental health data in communities where unconventional oil and gas developments are taking place, ethnographic researchers must build a solid case for the usefulness and importance of both fieldwork methods and analytical tools by detailing what exactly ethnographic approaches look like on the ground, providing more information about the history of the method in addressing environmental health concerns where necessary, and justifying what sets ethnography apart from other social science approaches. The examples from Pennsylvania's Marcellus Shale described in this article are just one attempt to begin communication and build the case for more ethnographic and other community health research in shale gas areas. Clearly much more needs to be done in this regard.

In many of the rural and urban communities across North America where onshore unconventional oil and gas developments are being considered or already taking place there is a lack of scientific and clinical information on the local psychological and sociocultural factors that may directly influence community health outcomes [9]. Without such baseline information on the determinants of community health with particular emphasis on psychosocial stress factors, practitioners and policy makers have a difficult time determining the potential for harm to public health associated with these relatively new development projects and then enacting appropriate preventive measures. Thus, serious problems are raised regarding application of the precautionary principle and social, geographic, and procedural equity [18, pp. 30-31].

Ethnographic approaches can serve as one way to evaluate community health outcomes related to unconventional oil and gas developments, a growing need identified by health care practitioners, researchers, and government agencies [2, 3, 5, 7, 17]. As illustrated by the examples from ongoing ethnographic fieldwork in communities living near Marcellus Shale gas wells, compressor stations, and pipeline routes in northeastern Pennsylvania, these approaches show potential usefulness in systematically documenting the psychological, sociocultural, and environmental determinants of health.

While the exact causal mechanisms that link stress to disease may vary from case to case, there are some physiological mechanisms that do seem to be consistent in similar cases and offer models of how psychological, social, and environmental factors influence individual and community health outcomes. One of these mechanisms is known as allostatic load, or "the cumulative physiological burden that results as the body adapts to environmental and psychosocial stressors" [66, p. 30]. Allostatic load has been implicated in poor health outcomes when social and environmental factors create chronic stress that elevates cortisol levels, which then work to biologically impact the body [67, 68]. There are physiologic indicators of this chronic stress that can be monitored, including high blood pressure, elevated blood sugar, and hormonal changes [69-72]. However, the psychological and behavioral indicators of chronic stress—such as higher rates of smoking, alcohol consumption, sleeping problems, accidents, and eating disorders—may be more difficult to track [10]. Ethnographic approaches, such as the ones described here, could be used to monitor some of these more difficult-to-track indicators and compare them over time in communities where unconventional oil and gas developments are occurring.

Ethnography also offers a way to collect data on the cumulative impacts of industrialization and chemical pollution on local communities. The assessment of cumulative risks and impacts to already overburdened local communities in the United States is the subject of scientific study and debate, and is also one of the top research priorities of environmental justice advocates [8, 73]. The close bonds and sometimes long-term engagements that ethnographic researchers have with the communities where they conduct fieldwork makes this approach to documenting localized changes in psychological, sociocultural, and environmental stress levels through time a valuable contribution to cumulative impact assessments.

The emergent themes described in this paper offer a possible starting point for further community health research by social epidemiologists and others into the impacts of onshore unconventional oil and gas developments. Studies can be designed to identify and describe some of the contributing factors to chronic stress by eliciting culturally and locally relevant meanings of quality of life and well-being and the factors that contribute to or detract from it. More research in rural communities can be conducted that provides data on the relationship between economic inequality and psychological, sociocultural, and environmental stress factors, including the impact on local livelihoods and incomes from public perceptions of food safety on farms near shale gas developments. And, psychological and anthropological studies could be undertaken that document and describe the ways that societal and individual forms of violence interact with psychological, social, and environmental factors that may contribute to chronic stress near unconventional oil and gas projects.

National and state decision-makers need to examine the solid scientific evidence on the psychological, social, and environmental determinants of community health. In collaboration with medical practitioners, researchers, and the communities they serve, strategies need to be developed that can address the large gaps still existing in our knowledge about the linkages between human health, ecosystem health, large-scale industrialization, and chemical pollution. The ethnographic approach introduced here, alongside an environmental justice framework that includes the public health model of prevention and the precautionary principle, offers an opening to such collaboration, and the outline of a strategy to fill in some of those gaps. As others have suggested [3, 73], public-policy–makers and decision-makers in the United States must step beyond the political rhetoric over the community and environmental health impacts of energy policies and decisions to develop informed policies that prevent harm, embolden the precautionary principle, and ensure that environmental protection is a right, not a privilege.

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AUTHOR'S BIOGRAPHY

SIMONA PERRY is a social and environmental scientist actively working to document, analyze, and develop alternative dispute mechanisms addressing social and environmental conflicts emerging from economic development projects across North America. She uses multiple data collection methods to conduct case study research on these conflicts. Her theoretical and practical focus is on understanding the everyday lives of individuals and communities in a rapidly changing world, sense of place phenomena in the face of globalized markets and identities, and conducting interpretive policy analyses. She is a member of c.a.s.e. "Community Awareness and Solutions for Empowerment," a cooperative roots-based consultancy. Send her email at communitypower.slp@gmail.com

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Direct reprint requests to:

Simona L. Perry
c.a.s.e. Consulting Services
9810 Dairyton Court
Montgomery Village, MD 20886
e-mail: communitypower.slp@gmail.com

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Scientific Solutions

INVESTIGATING LINKS BETWEEN SHALE GAS DEVELOPMENT AND HEALTH IMPACTS THROUGH A COMMUNITY SURVEY PROJECT IN PENNSYLVANIA

NADIA STEINZOR
WILMA SUBRA
LISA SUMI

ABSTRACT

Across the United States, the race for new energy sources is picking up speed and reaching more places, with natural gas in the lead. While the toxic and polluting qualities of substances used and produced in shale gas development and the general health effects of exposure are well established, scientific evidence of causal links has been limited, creating an urgent need to understand health impacts. Self-reported survey research documenting the symptoms experienced by people living in proximity to gas facilities, coupled with environmental testing, can elucidate plausible links that warrant both response and further investigation. This method, recently applied to the gas development areas of Pennsylvania, indicates the need for a range of policy and research efforts to safeguard public health.

Keywords: health surveys, shale gas, toxic exposure, hydraulic fracturing, fracking

> Public health was not brought into discussions about shale gas extraction at earlier stages; in consequence, the health system finds itself lacking critical information about environmental and public health impacts of the technologies and unable to address concerns by regulators at the federal and state levels, communities, and workers. . . .
>
> —Institute of Medicine at the National Academies of Science [1]

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http://baywood.com

For many years, extracting natural gas from deep shale formations across the United States (such as the Marcellus Shale in the East or the Barnett Shale in Texas) was considered economically and technologically infeasible. More recently, changes in hydraulic fracturing technology and its combination with horizontal drilling have made it possible to drill much deeper and further. Bolstered by declining global oil resources and a strong political push to expand domestic energy production, this has resulted in a boom in shale gas production nationwide and projections of tens or even hundreds of thousands of wells being drilled in the coming decades.

By mid-2012, there were nearly 490,000 producing natural gas wells in the United States, 60,000 more than in 2005 [2]. In Pennsylvania alone, more than 5,900 unconventional oil and gas wells had been drilled, and more than 11,700 had been permitted, between 2005 and September 2012; the pace of expansion has been rapid, with 75 percent of all unconventional wells drilled just in the last two years [3]. The rapid pace of industry expansion is increasingly divergent from the slower pace of scientific understanding of its impacts, as well as policy and regulatory measures to prevent them—in turn raising many questions that have yet to be answered [4]. Further, the limited availability of information has both contributed to public perception and supported industry assertions that health impacts related to oil and gas development are isolated and rare.

Modern-day industrial gas and oil development has many stages, uses a complex of chemicals, and produces large volumes of both wastewater and solid waste, which create the potential for numerous pathways of exposure to substances harmful to health, in particular to air and water pollution [5]. Many reports of negative health impacts by people living in proximity to wells and oil and gas facilities have been documented in the media and through research by organizations [6-8]. In addition, several self-reporting health survey and environmental testing projects have been conducted in response to complaints following pollution events or the establishment of facilities [9-12].

Such short-term projects have been initiated in a research context in which longer-term investigations—particularly ones that seek to establish causal links between health problems and oil and gas development—have historically been narrow and inconsistent [13]. Reflecting growing concern over the need to deepen knowledge among scientists, public agency representatives, and environmental and health professionals, four conferences on the links between shale gas development and human health were convened in just a one-year period (November 2011–November 2012), including those convened by the Graduate School of Public Health at the University of Pittsburgh; by Physicians, Scientists, and Engineers for Healthy Energy; and by the Institute of Medicine of the National Academy of Sciences.

In-depth research on the health impacts of oil and gas development has also begun to appear in the literature. In 2011, a review of more than 600 known chemicals used in natural gas operations concluded that many could cause cancer and mutations and have long-term health impacts (including on the skin, eyes, and kidneys and on the respiratory, gastrointestinal, brain/nervous, immune, endocrine, and cardiovascular systems) [14]. In early 2012, a study by researchers at the University of Colorado concluded that the toxicity of air emissions near natural gas sites puts residents living close by at greater risk of health-related impacts than those living further away [15]. Also in 2012, a paper (published in this journal) documented numerous cases in which livestock and pets exposed to toxic substances from natural gas operations suffered negative health impacts and even death [16].

Public health has not been a priority for decision-makers confronting the expansion of natural gas development and consumption. Commissions to study the impacts of shale gas development have been established by Maryland and Pennsylvania and by the U.S. Secretary of Energy, but of the more than 50 members on these official bodies, none had health expertise [17]. In addition, state and federal agencies in charge of reviewing energy proposals and issuing permits do not require companies to provide information on potential health impacts, while only a few comprehensive health impact assessments (HIAs) on oil and gas development have ever been conducted in the United States [18]. Data on air and water quality near oil and gas facilities are also lacking because federal environmental testing and monitoring has long focused on a limited number of air contaminants and areas of high population density [19], while testing at oil and gas facilities in states like Pennsylvania began only recently [20]. Finally, only a few states (including Pennsylvania, Ohio, and Colorado) have any requirements for baseline air and water quality testing before drilling begins, making it difficult for researchers and regulators—as well as individuals who are directly impacted—to establish a clear connection afterwards.

SUMMARY OF THE RELEVANCE OF SELF-REPORTING HEALTH SURVEYS

For many individuals and communities living amidst oil and gas development and experiencing rapid change in their environments, too much can be at stake to rely solely on the results of long-term studies, especially those that are just now being developed. Recent examples include a new study by Guthrie Health and the Geisinger Health System in Pennsylvania, set to take from 5 to 15 years [21], and research proposals solicited in April 2012 by the National Institute of Environmental Health Sciences [22].

In contrast, self-reporting health survey research facilitates the collection and analysis of data on current exposures and medical symptoms—thereby helping to bridge the prevailing knowledge gap and pointing the way toward possible policy changes needed to protect public health. Another premise throughout the various phases of this project (location selection, survey distribution and completion, environmental testing, report development and distribution, and outreach to decision-makers) was the value of public participation in science and the engagement of a variety of actors and networks to both conduct the research and ensure its beneficial application [23].

With this in mind, this health and testing project reflects some of the core principles of community-based participatory research (CBPR), including an emphasis on community engagement, use of strengths and resources within communities, application of findings to help bring about change, and belief in the research relevance and validity of community knowledge [24]. For example, the current project selected areas for investigation based in part on the observations of change in environmental conditions by long-time residents, and upon completion, participants received resources on testing and reporting of drilling problems for use in their communities.

In addition, CBPR is often used by public agencies and academic researchers to gather information on health conditions that may be related to social or environmental factors manifested on the community as well as individual level [25]. Relevant examples include identification of linkages between environmental health and socioeconomic status [26], adverse health impacts associated with coal mining [27], and the perception of health problems from industrial wind turbines [28].

Community survey and environmental testing projects such as the current one are also valuable in identifying linkages and considerations that can be used to develop protocols for additional research and policy measures. For example, community survey projects similar to the current one have revealed the presence of toxic chemicals in water and air that were known to be associated with health symptoms reported by residents, resulting in the strengthening of state standards for the control of drilling-related odors in Texas [9], expansion of a groundwater contamination investigation by the U.S. Environmental Protection Agency in Wyoming [10], and relocation of residential communities away from nearby oil refineries and contaminated waste storage areas in Louisiana) [29].

METHODS

Between August 2011 and July 2012, a self-reporting health survey and environmental testing project was undertaken in order to:

- investigate the extent and types of health symptoms experienced by people living in the “gas patches” (that is, gas development areas) of Pennsylvania;
- provide air and water quality testing to some of the participating households in need of such information;
- identify possible connections between health symptoms and proximity to gas extraction and production facilities;
- provide information to researchers, officials, regulators, and residents concerned about the impact of gas development on health and air and water quality; and

- make recommendations for both further research and the development of policy measures to prevent negative health and environmental impacts.

This project did not involve certain research elements, such as structured control groups in non-impacted areas and in-depth comparative health history research, that aim to show a direct cause-and-effect relationship or to rule out additional exposures and risks. Such work, while important, was beyond the scope of the project.

The primary routes of exposure to chemicals and other harmful substances used and generated by oil and gas facilities are inhalation, ingestion, and dermal absorption—of substances in air, drinking water, or surface water—which can lead to a range of symptoms. The health survey instrument explored such variations in exposure through checklists of health symptoms grouped into categories (skin, sinus/respiratory, digestive/stomach, vision/eyes, ear/nose/mouth, neurological, urinary/urological, muscles/joints, cardiac/circulatory, reproductive, behavioral/mood/energy, lymphatic/thyroid, and immunological). A similar structure was followed for different categories of problems in participants' disease history (kidney/urological, liver, bones/joints, ulcers, thyroid/lymphatic, heart/lungs, blood disorders, brain/neurological, skin/eyes/mouth, diabetes, and cancer). Questions were also asked about occupational background and related toxic exposure history. In addition, the survey included questions on proximity to three types of facilities (compressor and pipeline stations, gas-producing wells, and impoundment or waste pits) to explore possible sources of exposure. It also asked participants to describe the type and frequency of odors they observe, since odors can both indicate the presence of a pollutant and serve as warning signs of associated health risks [30].

As indicated in Table 1, the survey was completed by 108 individuals (in 55 households) in 14 counties across Pennsylvania, with the majority (85 percent) collected in Washington, Fayette, Bedford, Bradford, and Butler counties. Taken together, the counties represent a geographical range across the state and have active wells and other facilities that have increased in number in the past few years, allowing reports of health impacts and air and water quality concerns by residents to surface [31, 32]. The survey and testing locations were all in rural and suburban residential communities.

All survey participants were assured that their names, addresses, and other identifying information on both the surveys and environmental testing results would be kept confidential and used only for purposes related to this project, such as following up with clarifying questions, responding to requests for assistance, or providing resources. Due to expressed concerns about confidentiality, participants had the option of completing the surveys anonymously, which some chose to do. Most participants answered questions on their own. In some cases, spouses, parents, or neighbors completed surveys for participants, and a few provided answers to the project coordinator in person or over the phone.

Table 1. Survey Locations

County surveyed	Number of surveys collected and percent of all surveys
Washington	24 (22%)
Fayette	20 (18%)
Bedford	20 (18%)
Bradford	17 (16%)
Butler	12 (11%)
Jefferson	3 (3%)
Sullivan	2 (2%)
Greene	2 (2%)
Warren	2 (2%)
Elk	2 (2%)
Clearfield	1 (1%)
Erie	1 (1%)
Susquehanna	1 (1%)
Westmoreland	1 (1%)
Total	108

While less formal and structured, the approach taken to identifying project participants has similarities to established non-random research methods that are respondent-driven and rely on word-of-mouth and a chain of referrals to reach more participants, such as "snowball" and "network" sampling [33]. As in studies in which these methods are used, the current project had a specific purpose in mind, focused on a group of people that can be hard to identify or reach, and had limited resources available for recruitment [34].

The survey was distributed in print form either by hand or through the mail and was initiated through existing contacts in the target counties. These individuals then chose to participate in the project themselves and/or recommended prospective participants, who in turn provided additional contacts. The survey was also distributed to individuals who expressed interest in participating directly to the project coordinator at public events or through neighbors, family members, and friends who had already completed surveys.

A second phase of the project involved environmental testing conducted at the homes (i.e., in the yards, on porches, or at other locations close to houses) of a subset of the survey participants (70 in total) in order to identify the presence of pollutants that may be coming from gas development facilities. In all, 34 air tests and nine water tests were conducted at 35 households. Test locations were selected based on household interest, the severity of symptoms reported, and proximity to gas facilities; results were made available to the households where the testing took place. The air tests were conducted with Summa Canisters put out for 24 hours by trained individuals and the results analyzed with TO-14 and TO-15 methods, which are used and approved by the U.S. Environmental Protection Agency to test for volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene, and xylene (known as BTEX chemicals). The water tests were based on samples drawn directly from household sinks or water wells by technicians employed by certified laboratories and covered the standard Tier 1, Tier 2, and Tier 3 (including VOCs/BTEX) and in one case, gross alpha/beta radiation, radon, and radium.

FINDINGS

Health Surveys

Among participants, 45 percent were male, ranging from 18 months to 79 years of age, and 55 percent were female, ranging from 7 to 77 years of age. The closest a participant lived to gas facilities was 350 feet and the farthest away was 5 miles.

Participants had a wide range of occupational backgrounds, including animal breeding and training, beautician, child care, construction, domestic work, farming, management, mechanic, medical professional, office work, painter, retail, teaching, and welding. About 20 percent of participants reported an occupation-related chemical exposure (for example, to cleaning products, fertilizers, pesticides, or solvents). At the time of survey completion, 80 percent of participants did not smoke and 20 percent did. More than 60 percent of the current nonsmokers had never smoked, although 20 percent of nonsmokers lived with smokers.

Almost half of the survey participants answered the question on whether they had any health problems prior to shale gas development. A little less than half of those responses indicated no health conditions before the development began and a little more than half reported having had one or just a few—in particular allergies, asthma, arthritis, cancer, high blood pressure, and heart, kidney, pulmonary, and thyroid conditions were named by respondents.

While not asked specifically in the survey, some participants volunteered (verbally or in writing) additional information that points to health-related concerns warranting further investigation. For example, five reported that their existing health symptoms became worse after shale gas development started and 15 that their symptoms lessened or disappeared when they were away from home. Participants in 22 households reported that pets and/or livestock had unexplained symptoms (such as seizures or losing hair) or suddenly fell ill and died after gas development began nearby.

Some variation was noted with regard to the specific symptoms reported for each category surveyed, and some symptoms were reported to a notable degree in only one or a few locations. However, as seen in Table 2, the same overall categories of problems reported by survey participants garnered high response rates among survey participants regardless of region or county. For example, sinus/respiratory problems garnered the highest percentage of responses by participants overall, as well as in four of the five focus counties; the second top complaint category, behavioral/mood/energy, was the first in one county, second in three, and fourth in one. The total number of symptoms reported by individual participants ranged from 2 to 111; more than half reported having more than 20 symptoms and nearly one-quarter reported more than 50 symptoms. The highest numbers were reported by a 26-year-old female in Fayette County (90), a 51-year-old female in Bradford County (94), and a 59-year-old female in Warren County (111).

The 25 most prevalent individual symptoms among all participants were increased fatigue (62%), nasal irritation (61%), throat irritation (60%), sinus problems (58%), eyes burning (53%), shortness of breath (52%), joint pain (52%), feeling weak and tired (52%), severe headaches (51%), sleep disturbance (51%), lumbar pain (49%), forgetfulness (48%), muscle aches and pains (44%), difficulty breathing (41%), sleep disorders (41%), frequent irritation (39%), weakness (39%), frequent nausea (39%), skin irritation (38%), skin rashes (37%), depression (37%), memory problems (36%), severe anxiety (35%), tension (35%), and dizziness (34%).

Many symptoms were commonly reported regardless of the distance from the facility (in particular sinus problems, nasal irritation, increased fatigue, feeling weak and tired, joint pain, and shortness of breath). In addition, there was some variability in the percentage of respondents experiencing certain symptoms in relation to distance from facility, including higher rates at longer distances in a few instances. Possible influencing factors could include topography, weather conditions, participant reporting, the use of emission control technologies at facilities, or type of production (e.g., wet gas contains higher levels of liquid hydrocarbons than dry gas).

However, many symptoms showed a clearly identifiable pattern: as the distance from facilities increases, the percentage of respondents reporting the symptoms generally decreases [35]. For example, when a gas well, compressor station, and/or impoundment pit were 1500-4000 feet away, 27 percent of participants reported throat irritation; this increased to 63 percent at 501-1500 feet and to 74 percent at less than 500 feet. At the farther distance, 37 percent reported sinus problems; this increased to 53 percent at the middle distance and 70 percent at the shortest distance. Severe headaches were reported by 30 percent of respondents at the farther distance, but by about 60 percent at the middle and short distances.

Table 2. Percent of Participants Reporting Symptoms in the Most Prevalent Categories of Symptoms, by County

		Percent of individuals reporting symptoms in category					
Symptom category	All counties	Bedford	Bradford	Butler	Fayette	Washington	Others[a]
Sinus/respiratory	88	80	82	75	85	95	87
Behavioral/mood/energy	80	60	88	67	85	74	67
Neurological	74	45	71	50	70	79	60
Muscles/joints	70	55	82	67	70	74	47
Digestive/stomach	64	55	65	58	75	63	33
Ear/nose/mouth	66	40	59	50	75	68	47
Skin reactions	64	45	70	67	75	63	27
Vision/eyes	63	40	65	50	70	79	53

[a]Includes Clearfield, Elk, Erie, Jefferson, Greene, Sullivan, Susquehanna, Warren, and Westmoreland counties. The surveys from these counties (15) were analyzed together to create a group comparable in number to each of the counties where more surveys were collected.

Figure 1 shows, for the top 20 symptoms, the percentage of residents living within 1500 feet of a natural gas facility (well, compressor, or impoundment) who reported the symptom, compared to the percentage among residents living more than 1500 feet from the facility. For 18 of the 20 symptoms, a higher percentage of those living within 1500 feet of a facility experienced the symptom than of those living farther away.

The difference in percentages reporting the symptom in the two groups (i.e., 1500 feet or closer vs. more than 1500 feet from a facility) was statistically significant for 10 of the 20 symptoms. Notably, this finding reinforces the value of data attained through self-reporting health surveys. It shows that, regardless of how symptom data were acquired, they suggest that increased proximity to gas facilities has a strong association with higher rates of symptoms reported.

When the most prevalent symptoms are broken out by age and distance from facility, some patterns stand out [35]. Within each age group, the subset living within 1500 feet of any oil and gas facility had a higher percentage of most symptoms than the age group as a whole.

Among the youngest respondents (1.5-16 years of age), for example, those within 1,500 feet experienced higher rates of throat irritation (57% vs. 69%) and severe headaches (52% vs. 69%). It is also notable that youngest group had the highest occurrence of frequent nosebleeds (perhaps reflective of the more sensitive mucosal membranes in the young), as well as experiencing conditions not typically associated with children, such as severe headaches, joint and lumbar pain, and forgetfulness.

Among 20- to 40-year-olds, those living within 1500 feet of a facility reported higher rates of nearly all symptoms; for example, 44 percent complained of frequent nosebleeds, compared to 29 percent of the entire age group. The same pattern existed among 41- to 55-year-olds with regard to several symptoms (e.g., throat and nasal irritation and increased fatigue), although with smaller differences and greater variability than in the other age groups.

The subset of participants in the oldest group (56- to 79-year-olds) living within 1,500 feet of facilities had much higher rates of several symptoms, including throat irritation (67% vs. 47 %), sinus problems (72% vs. 56%), eye burning (83% vs. 56%), shortness of breath (78% vs. 64%), and skin rashes (50% vs. 33%).

In sum, while these data do not prove that living closer to oil and gas facilities causes health problems, they do suggest a strong association since symptoms are more prevalent in those living closer to facilities than those living further away. Symptoms such as headaches, nausea, and pounding of the heart are known to be the first indications of excessive exposure to air pollutants such as VOCs [36], while the higher level of nosebleeds in the youngest age group is also consistent with patterns identified in health survey projects in other states [9, 10].

The survey also asked respondents to indicate whether they were smokers. While the average number of symptoms for smokers was higher for smokers than nonsmokers (30 vs. 22), the most frequently reported symptoms were very

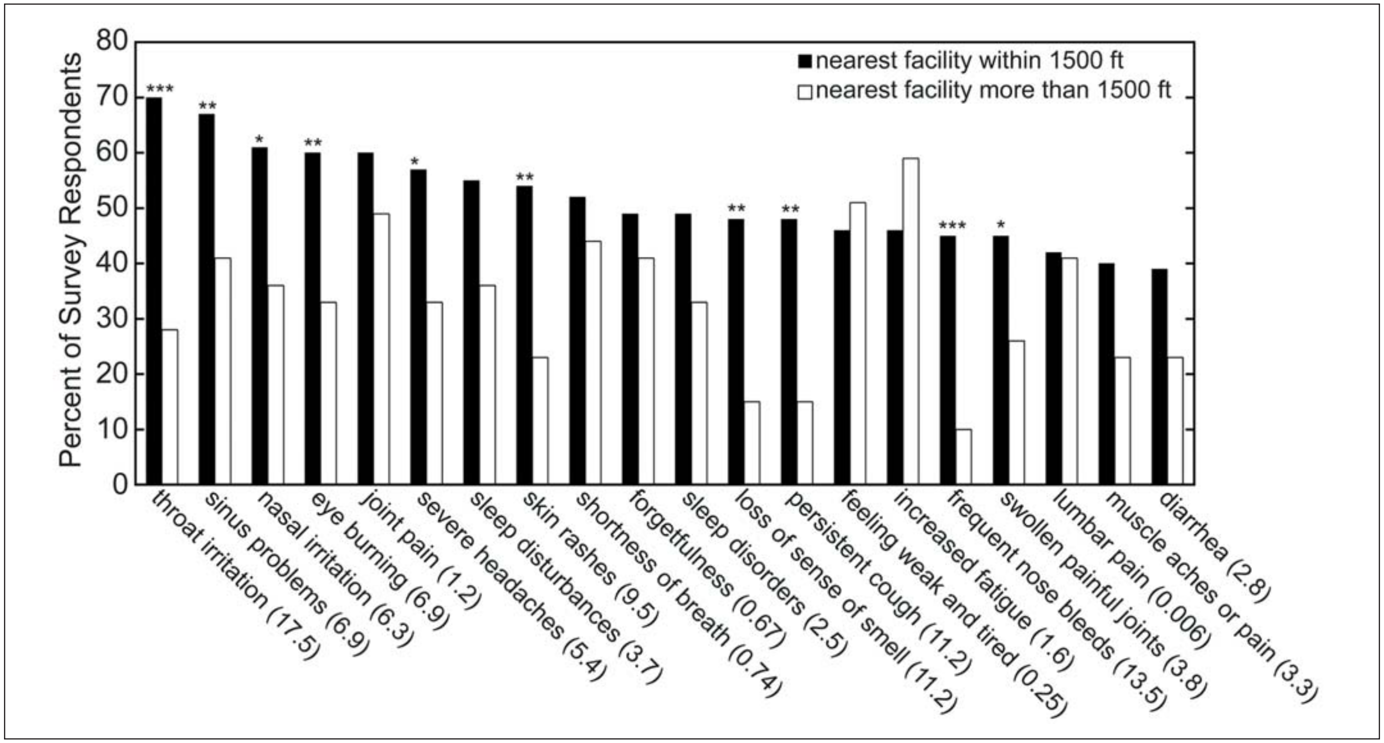

Figure 1. Association of symptoms and distance from facilities

Note: The significance of the effect was tested using a two-way contingency table analysis, and the chi-square value is given in parenthesis after each symptom. Effects significant at $p < 0.001$ are indicated by ***, those significant at $p < 0.01$ by **, and those significant at $p < 0.05$ by *.

similar (including forgetfulness, increased fatigue, lumbar pain, joint pain, eye burning, nasal irritation, sinus problems, sleep disturbances, severe headaches, throat irritation, shortness of breath, frequent nausea, muscle aches or pains, and weakness). The fact that the nonsmokers experienced symptoms that are commonly considered to be side effects of smoking (e.g., persistent hoarseness, throat irritation, sinus problems, nasal irritation, shortness of breath, and sleep disturbances) suggests that factors other than smoking were at play.

In addition, while the smoking subpopulation generally reported a larger number of symptoms, the symptoms most frequently reported by smokers and nonsmokers were remarkably similar within each age group [35]. For example, for 20- to 40-year-olds, increased fatigue, sinus problems, throat irritation, frequent nausea, and sleep problems were among the top symptoms for both smokers and nonsmokers. In the 41- to 55-year-old group, increased fatigue, throat irritation, eye burning, severe headaches, and nasal irritation were among the top symptoms for both smokers and nonsmokers, and in the over-55 age group, eye burning, sinus problems, increased fatigue, joint pain, and forgetfulness were among the top symptoms of both smokers and nonsmokers.

Participants were asked if they had noticed any odors and were asked whether they knew the source of the odors. In all but a few cases, survey participants mentioned only gas-related sources. Responses focused on locations, facilities, and processes, including drilling, gas wells, well pads, fracturing, compressor stations, condensate tanks, flaring, impoundments and pits, retention ponds, diesel engines, truck traffic, pipelines and pipeline stations, spills and leaks, subsurface ground events or migrations from underground, seismic testing, blue-colored particles in the air (possibly catalytic compounds or particulate matter), and water and stock wells. Odors were among the most common of complaints, with 81 percent of participants experiencing them sometimes or constantly. The frequency ranged from one to seven days per week and from several times per day to all day long; 18 percent said they could smell odors every day.

Participants were also asked to describe odors and whether they noticed any health symptoms when odor events occurred. The most prevalent links between odors and symptoms reported were:

- *nausea:* ammonia, chlorine, gas, propane, ozone, rotten gas;
- *dizziness:* chemical burning, chlorine, diesel, ozone, petrochemical smell, rotten/sour gas, sulfur;
- *headache:* chemical smell, chlorine, diesel, gasoline, ozone, petrochemical smell, propane, rotten/sour gas, sweet smell;
- *eye/vision problems:* chemical burning, chlorine, exhaust;
- *respiratory problems*: ammonia, chemical burning, chlorine, diesel, perfume smell, rotten gas, sulfur;
- *nose/throat problems:* chemical smell, chlorine, exhaust, gas, ozone, petrochemical smell, rotten gas, sulfur, sweet smell;

- *nosebleeds:* kerosene, petrochemical smell, propane, sour gas;
- *skin irritation:* chemical smell, chlorine, ozone, sulfur;
- *decreased energy/alertness:* chemical gas, ozone, rotten/sour gas, sweet smell; and
- *metallic/bad taste in mouth:* chemical burning, chlorine, turpentine.

Environmental Testing

As detailed in Table 3, the air tests detected a total of 19 VOCs in ambient air sampled outside of homes.

The number of compounds detected in a single sample ranged from one to 25; there was some consistency with regard to the chemicals present in most of the samples, although the concentrations of VOCs detected varied across counties [35]. The highest numbers of VOCs were detected in air samples from Washington County (15), Butler County (15), Bradford County (12), and Fayette County (9). Washington County also had the highest measured concentration of five VOCs and the second highest concentration of 12 chemicals. Samples from Butler and Bradford Counties had the highest concentrations of five and three VOCs, respectively. Five chemicals were detected in all nine of the samples from Washington County and in the six samples from Butler County: 1,1,2-trichloro-1,2,2-trifluoroethane, carbon tetrachloride, chloromethane, toluene, and trichlorofluoromethane.

It is also possible that in some places, sampling did not occur at the precise times when facilities were emitting high concentrations of chemicals or when the wind was blowing contaminants toward canisters. Some of the additional variation in number of chemicals and concentrations could be due to differences in topography, the total number of active oil and gas wells, the types of wells (conventional versus unconventional), the use of emission control technologies, and the number of active drilling sites, compressor stations, and oil and gas waste impoundments located within a certain radius of the sampling locations.

In 2010, the Pennsylvania Department of Environmental Protection (DEP) conducted air testing around natural gas wells and facilities in three regions across the state, in part using the same canister sampling methods as in this project [37]. When compared to DEP's results, our results showed some striking similarities in both the chemicals detected and concentrations. In particular, BTEX chemicals that we measured in Butler and Washington counties were consistently higher than concentrations found at DEP control sites (ethylbenzene and *m*- and *p*-xylenes were not detected at any of the control sites). When compared to the sampling done by DEP around oil and gas facilities, the concentrations in Butler and Washington counties were in the same range for benzene, but were considerably higher for toluene, ethylbenzene and *m*- and *p*-xylenes. It is also striking that some of the concentrations of ethylbenzene and

Table 3. Volatile Organic Compounds (VOCs) in Ambient Air, Sorted by Percent Detection[a]

Compound	Total number of samples	Number of samples detecting VOCs	Percent of samples detecting VOCs	Minimum concentration	Maximum concentration	Chemical reporting limits for the three labs		
						Columbia	Con-Test	Pace[b]
2-Butanone	17	16	94	0.95	2.9	0.85-1.3	NA	NA
Acetone	17	15	88	8.0	19	6.5-10	NA	NA
Chloromethane	34	27	79	1.0	1.66	0.59-0.90	0.1	1.39-1.53
1,1,2-Trichloro-1,2,2-trifluoroethane	34	26	76	0.54	0.73	0.22-0.34	0.38	5.13-5.67
Carbon tetrachloride	34	26	76	0.4	0.76	0.091-0.14	0.31	4.21-4.65
Trichlorofluoromethane	34	26	76	0.6	1.8	0.81-1.2	0.28	3.32-3.66
Toluene	34	22	65	0.68	7.9	0.53-0.82	0.19	2.52-2.79
Dichlorodifluoromethane	17	9	63	1.9	2.8	NA	0.25	3.32-3.66
n-Hexane	8	3	38	3.03	7.04	NA	NA	2.37-2.61
Benzene	34	11	32	0.31	1.5	0.46-0.67	0.16	2.14-2.36

Methylene chloride	34	10	29	1.9	32.62	0.49-0.76	1.7	2.33-2.57
Total hydrocarbons (gas)[c]	8	2	25	49.8	146	NA	NA	46.9-52.2
Tetrachloroethylene	34	8	24	0.12	10.85	0.10-0.16	0.34	4.54-5.02
1,2,4-Trimethylbenzene	17	4	24	0.38	0.61	NA	0.25	3.30-3.64
Ethylbenzene	34	6	1	0.27	1.5	1.4-1.9	0.22	2.91-3.21
Trichloroethylene	34	6	18	0.17	5.37	0.08-0.12	0.27	3.60-3.98
Xylene (*m*- and *p*-)	34	5	15	0.92	5.2	2.5-3.8	0.43	2.82-3.12
Xylene (*o*)	34	5	15	0.39	1.9	1.2-1.9	0.22	2.91-3.21
1,2-Dichloroethane	34	1	3	0.64	0.64	0.59-0.90	0.2	2.71-2.99

[a]Concentrations are in micrograms per cubic meter, μg/m^3 (*n* = total number of canister samples that were analyzed for a particular chemical).

[b]Pace Lab's reporting limits were in parts per billion volume (ppbv). We converted to micrograms per cubic meters (μg/m^3) using equations in the Air Unit Conversion Table (Torrent Labs, www.torrentlab.com/torrent/Home/ResourceCenter.html).

[c]Total hydrocarbons reported as parts per billion volume (ppbv).

xylene measured at rural and suburban residential homes in Butler and Washington counties were higher than any concentration detected by the DEP at the Marcus Hook industrial site in 2010.

As stated above, several factors can influence air results. However, it is also highly possible that the poorer air quality in the areas where we tested—which were rural and residential, with little or no other industry nearby—can be attributed to gas facilities. While the DEP reports on the agency's air testing indicated that some of the VOCs we found in our study may not be due to oil and gas development since they persist in the atmosphere and have been widely used (for example, as refrigerants), the agency also indicates that acetone and the BTEX chemicals can be attributed to gas development [37].

With regard to the water tests conducted, Table 4 shows the 26 parameters that were detected in at least one sample. More than half of the project water samples contained methane; although some groundwater contains low concentrations of methane under normal conditions, this finding could also indicate natural gas migration from casing failure or other structural integrity problems [38]. Four of the substances detected in water well samples in Bradford and Butler Counties—manganese, iron, arsenic, and lead—were found at levels that exceed the Maximum Contaminant Levels (MCLs) set by Pennsylvania DEP's Division of Drinking Water Management [39]. Two of the water samples, both from Butler County, were more acidic than the recommended pH for drinking water.

Some metals, such as manganese and iron, are elevated in Pennsylvania surface waters and soils, either naturally or due to past industrial activities, and levels can vary regionally [40]. In 2012, Pennsylvania State University (PSU) researchers found that some drinking water wells in the state contained somewhat elevated concentrations of certain contaminants prior to any drilling in the area [41]. However, seven out of the nine water supplies sampled in our study (78%) had manganese levels above the state MCL—a much higher percentage than what was found in the pre-drilling samples in the PSU study (27%). Even where metals are naturally occurring or predate gas development, drilling and hydraulic fracturing can contribute to elevated concentrations of these contaminants [42] and have the potential to mobilize substances in formations such as Marcellus Shale, which is enriched with barium, uranium, chromium, zinc, and other metals [43].

LINKAGES BETWEEN SURVEYS AND ENVIRONMENTAL TESTING

More research would be required to identify cause-and-effect connections between the chemicals present in air and water in Pennsylvania's gas patches and symptoms reported by residents in specific locations. Nonetheless, such links are plausible since many of the chemicals detected in the testing are known to be related both to oil and gas operations and to the health symptoms reported by individuals living at the sites where air and water testing was conducted [13-15].

The air tests together detected 19 chemicals that are known to cause sinus, skin, ear/nose/mouth, and neurological symptoms, 17 that may affect vision/eyes, and 16 that may induce behavioral effects; as well as 11 that have been associated with liver damage, nine with kidney damage, and eight with digestive/stomach problems. In addition, the brain and nervous system may be affected by five of the VOCs detected, the cardiac system by five, muscle by two, and blood cells by two [44, 45].

Using these sources [44, 45], we compared lists of the established health effects of the chemicals detected at households where testing occurred with lists of the symptoms reported in surveys by participants at those testing locations in order to identify associations. We then calculated the rate of association, in which the denominator is the total number of health impacts reported by an individual and the numerator is the total number of health impacts reported by that individual that are consistent with the known health impacts of the chemicals detected through air or water testing where they live.

Benzene, toluene, ethylbenzene, xylene, chloromethane, carbon disulfide, trichloroethylene (TCE), and acetone were detected through testing at the same households where survey participants reported symptoms established in the literature [13-15, 44, 45] as associated with these chemicals, including symptoms in the categories of sinus/respiratory, skin, vision/eyes, ear/nose/mouth, and neurological. Some of these chemicals, as well as others (such as carbon tetrachloride and tetrachloroethylene) were found at sites where survey participants reported known associated symptoms in the categories of digestion, kidney and liver damage, and muscle problems. Specific examples of chemicals and symptoms that are linked in the research literature, and were found together at households where testing and surveys were conducted, are: benzene and dizziness and nasal, eye, and throat irritation; carbon tetrachloride and nausea, headaches, and liver and kidney disease; and tetrachloroethylene and skin rashes, persistent cough, and nerve damage.

As shown in Table 5, health symptoms reported by the individuals living in a home where testing occurred matched the known health effects of chemicals detected in that home at an overall rate of 68 percent. Fayette and Washington counties had the highest match, followed by Greene, Bedford, and Butler counties.

In addition, the percent of individuals reporting symptoms that have been associated with chemicals detected in air testing at households participating in this study showed some consistency across counties with regard to the most significant categories of problems reported, as shown in Table 6—indicating that patterns in both chemicals detected and symptoms exist despite different geographic locations.

Table 4. Water Quality Results from Nine Private Water Wells in Bradford and Butler Counties, Pennsylvania

Parameter[a]	Units	Number of sample	Number above detection limit	Minimum[b]	Maximum	Mean[c]	PA DEP MCL[d]	Number of samples above MCL[e]
Barium	mg/L	9	9	0.029	0.5	0.25	2	0
Calcium	mg/L	9	9	33	66.2	43.7	None	
Magnesium	mg/L	9	9	4.5	16.8	9.1	None	
Sodium	mg/L	9	9	9.2	64.1	20.9	None	
Strontium	mg/L	9	9	0.126	1.7	0.5	None	
Hardness (total as $CaCO_3$)	mg/L	9	9	120	234	147	None	
pH	Std Units	9	9	6	7.9	6.5	6.5-8.5	[f]
Alkalinity (total as $CaCO_3$)	mg/L	9	9	38	285	130	None	
Total dissolved solids	mg/L	9	9	138	392	218	500	0
Sulfate	mg/L	9	9	6.7	231	33	250	0
Manganese	mg/L	9	7	< 0.005	6.44	1.04	0.05	7
Chloride	mg/L	9	7	< 5.0	84.3	24.1	250	0
Iron	mg/L	9	6	< 0.04	153	19.5	0.3	5
Potassium	mg/L	6	6	1.14	1.57	1.1	None	

Specific conductance	μmhos/cm	6	6	287	552	326	None	
Methane	μg/L	9	5	1.06	57.4	10	0.3	
Arsenic	mg/L	9	4	< 0.001	0.0282	0.005	0.010	1
Lead	mg/L	9	4	< 0.001	0.113	0.113	0.01	3
Total coliform	per 100 mL	9	4	Absent	Present		None	
Total suspended solids	mg/L	6	4	< 5	448	118	None	
Temperature, water	Degree/Celsis	3	3	25	29	28	None	
Turbidity	NTU	3	3	0.22	5.7	2.3	None	
Nitrate	mg/L	3	3	0.076	0.71	0.46	10	0
E. coli	per 100 mL	9	2	Absent	Present		None	
Sulfur	μg/L	1	1	< 1,000	7,550	2,850	None	
Bromide	mg/L	1	1	0.26	0.26	0.26	None	

[a]Note: not all parameters were analyzed in every sample.

[b]Minimum values: If reports included non-detects of a particular chemical, the minimum value in the table was shown as being less than (<) the lowest laboratory detection limit.

[c]Mean values: Non-detected chemicals were assigned a concentration equal to half of the detection limit *only if* there were other samples that detected the chemical.

[d]MCL: Maximum Contaminant Levels published by the Pennsylvania Department of Environmental Protection Division of Drinking Water Management.

[e]No values are provided if MCLs for substances do not exist.

[f]Two samples had higher acidity (lower pH) than the value recommended by the PA DEP.

Table 5. Match between Health Symptoms Reported by Individuals at Air Testing Sites and Known Effects of Chemicals Detected

County	Number of individuals surveyed at homes where testing was conducted	Match between known health effects of chemicals detected and symptoms reported (percent)[a]	
		Average	Range
Overall	59	68	33-100
Fayette	16	73	33-100
Washington	15	73	33-100
Bradford	8	58	16-100
Butler	8	63	56-68
Bedford	6	69	63-100
Elk	2	64	53-74
Clearfield	1	none	none
Greene	1	70	70
Susquehanna	1	50	50

[a]When a health symptom was associated in the literature with more than one of the chemicals detected, only one match was counted for that symptom.

As mentioned above, levels of iron, manganese, arsenic, and lead were detected in our water well samples in Bradford and Butler Counties at levels that exceeded drinking water standards set by the Pennsylvania DEP. These substances are known to be associated with numerous symptoms reported by individuals living in the homes where these particular exceedances occurred, including symptoms in the categories of sinus/respiratory, skin reactions, digestive/stomach, vision/eyes, ear/nose/mouth, neurological, muscle/joint, behavioral/mood/energy, and liver and kidney damage. Survey participants in the homes where water samples contained methane reported health symptoms known to be associated with methane, including symptoms in the categories of sinus/respiratory, digestive/stomach, neurological, and behavioral/mood/energy. While the water samples taken for this project did not show detectable exceedances of safety standards for other substances, it is notable that no drinking water standards have been set for methane, bromide, sodium, strontium, or Total Suspended Solids (TSS)—and thus no exceedances would be indicated in laboratory reports.

Table 6. Percent of Individuals at Air Testing Sites Reporting Symptoms Associated in the Literature with Chemicals Detected at Those Sites, by Symptom Category and Primary Air

		Testing counties					
Symptom category	All	Bedford	Bradford	Butler	Fayette	Washington	Others[a]
Sinus/respiratory	83	100	88	100	81	73	80
Vision/eyes	73	—	100	63	69	67	60
Digestive/stomach	69	50	63	88	75	80	—
Skin reactions	63	50	63	88	69	53	40
Neurological	60	50	88	75	44	53	60
Behavioral/mood/energy	54	67	50	63	63	47	40
Ear/nose/mouth	33	50	—	38	44	33	20
Muscle problems	—	—	—	—	—	40	—

[a]This includes air samples from Clearfield, Elk, Greene, and Susquehanna counties.

DISCUSSION

> Complete evidence regarding health impacts of gas drilling cannot be obtained due to incomplete testing and disclosure of chemicals, and non-disclosure agreements. Without rigorous scientific studies, the gas drilling boom sweeping the world will remain an uncontrolled health experiment on an enormous scale.
>
> —Michelle Bamberger and Robert Oswald [16]

While the survey and testing results, and their related findings, do not constitute definitive proof of cause and effect, we believe they do indicate the strong likelihood that the health of people living in proximity to gas facilities is being affected by exposure to pollutants from those facilities. Most participants report a high number of health symptoms; similar patterns of symptoms were identified across project locations and distances from facilities; and consistency in symptoms reported exists regardless of age group or smoking history. In addition, contaminants that result from oil and gas development were detected in air and water samples in areas where residents are experiencing health symptoms that are established in the literature as consistent with such exposures.

Because of the short-term nature of the air-canister testing (24 hours) and the single water tests conducted at households, our results were contingent on conditions at particular "moments in time." Thus additional chemicals, or the same chemicals at different concentrations, might be captured through expanded testing; and residents could be experiencing exposures that were not detected but would be detectable through such testing. In addition, some of the variation in the air test results may have been due to the different reporting protocols used by the laboratories used in this project. Although all the labs test for the same core suite of chemicals, both their reporting limits and the additional chemicals for which they test vary; these will be key considerations for future testing work.

Another consideration that warrants further exploration involves the established standards on both the state and federal levels for "safe" concentrations, which are set only for exposure to single contaminants. This prevailing regulatory approach can not adequately address the potential risks posed by chronic, long-term exposure to lower levels of multiple contaminants simultaneously—in other words, the experience of people living in oil and gas areas day in and day out, and of workers at job sites where toxic substances are continuously used. In addition, for many substances in the environment (including those that come from gas operations and were detected in our air and water sampling), data on health risks or safe exposure levels simply do not exist.

More research is also needed that focuses on the sources of odors and odor events experienced by residents living near gas facilities. In some cases, participants reported different health impacts associated with specific sources and odor events than those they reported in the overall health survey. Since odors are a clear sign of the presence of airborne substances (such as fuel and chemicals), this aspect warrants tracking and analysis.

Although we did not investigate additional factors that can influence health conditions (e.g., through ordered control groups, in-depth health history research, or identification of other potential sources of contaminants), such factors may affect an individual's health independent of gas operations. The relationship between symptoms and distance from gas facilities also warrants more research.

At the same time, we strongly suggest that for individuals with a history of other health concerns (e.g., asthma or heart conditions) and who are already living with other exposures (e.g., traffic fumes or workplace chemicals), the presence of gas facilities and related pollution could have a strong "trigger effect" that can make existing problems worse and put individuals at higher risk of developing new ones.

RECOMMENDATIONS

As discussed earlier, scientific knowledge about the health and environmental impacts of shale gas development—and also the adoption of policy and regulatory measures to prevent them—are proceeding at a far slower pace than the development itself. This timing mismatch creates situations (already being experienced by residents of Pennsylvania and other states) in which problems are widely reported but left unaddressed. Several measures can be taken to ensure that public health impacts are fully understood and given greater priority in decision-making about shale gas development.

1) *Elevate the role of public health considerations in gas development decisions.* A key measure would be to conduct health impact assessments before permitting begins. HIAs aim to minimize negative impacts and to improve health outcomes associated with land use decisions by analyzing problems that could arise over time as well as existing health and environmental risks that could be exacerbated by new activities [46]. HIAs can also have a strong preventive effect by identifying mitigation measures related to aspects such as toxic exposures, air and water pollution, and emergency response [47]. In addition, regulatory agencies could comprehensively plan the scope and pace of permits for wells and other facilities in order to reduce impacts on air and water quality, rather than continuing the permit-by-permit process currently being followed in Pennsylvania and other states. Information on where wells and facilities would be built in relation to places where health could be at risk (e.g., homes, schools, and hospitals) could also be required in permit applications.

2) *Increase the involvement of state departments of health in assessing the impacts of gas development.* Efforts should be increased to track and respond to health concerns, and a database should be established to document these problems and the agency response. Health departments could provide training for health and medical professionals on exposure pathways and health symptoms

related to gas operations, so that residents receive more informed advice and appropriate testing and care referrals. Financial aid mechanisms should be established to enable low-income residents to have blood and urine tests for chemical exposure.

3) *Conduct baseline water testing and continuous long-term monitoring of air quality.* Such testing would apply to private wells and public drinking water supplies prior to drilling and to the air at or near facilities during all phases of operations. Testing and monitoring should cover a full suite of chemicals, and contaminants and results should be reported regularly and made available to the public. Air quality testing in particular should be conducted at a range of facilities (e.g., compressor stations, impoundment pits, dehydrators) that cause emissions. These efforts could be carried out by the state regulatory agencies that issue permits or through an agreement between those agencies and health departments. Inter-agency agreements could also be developed to track potential health impacts that could result following spills of chemicals and waste, the underground migration of fracturing fluids, leaks, and other problems.

4) *Strengthen regulations for facilities to minimize air and water pollution risks.* These could include significantly increased setback distances; the installation of advanced technologies on all equipment to reduce emissions, odors, and noise; the use of closed-loop storage systems for waste and drilling fluids (rather than open pits); and the practice of "green completions" to reduce or eliminate flaring and venting of methane gas and other pollutants.

5) *Advance changes in testing parameters that determine "safe" exposure in order to account for low-level, chronic exposure and multiple chemical exposure in testing and monitoring.* Such changes are necessary to reflect impacts on people living in oil and gas development areas day in and day out, as well as workers at facilities. Under current testing parameters (which are based largely on acute episodes involving single contaminants), results may show below-threshold levels even though residents are negatively affected. For example, a recent paper showed that endocrine-disrupting chemicals can have different but still harmful effects at lower doses than at higher ones and concluded that fundamental changes in chemical testing and safety protocols are needed to protect human health [48]. Additionally, current health guidelines should be updated to capture more of the chemicals currently in use and to assess complex or indirect sources of contamination, such as oil and gas operations that rely on a variety of substances, equipment, and facilities at numerous stages of development.

CONCLUSION

> While we realize that human activities may involve hazards, people must proceed more carefully than has been the case in recent history. Corporations, government entities, organizations, communities, scientists, and other individuals must adopt a precautionary approach to all human endeavors. . . . When an activity raises threats of harm to human health or the environment,

> precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.
>
> —Wingspread Consensus Statement on the Precautionary Principle [49]

Across the gas patches of the United States, people experiencing health problems voice the simple wish to be believed. Many say that their health has worsened since gas development began in their communities and that they feel better when they are away from home. Often these conversations turn to what it will take for regulators and policymakers to view their stories not just as "anecdotes," but as valid concerns worthy of an effective response.

There is no doubt that more research on the environmental and health impacts of shale gas development is needed and can play a critical role in making sound decisions about a complex and controversial issue. Yet an equally important consideration is how to respond to the presence of unanswered questions. For many proponents of unfettered gas development, the absence of definitive causal links between gas facilities and specific health impacts indicates the absence of a problem. But for impacted communities and others who believe health and the environment deserve protection and that water and air quality should be maintained, what we don't yet know makes the need for caution even greater.

We believe that the findings of this survey and testing project in Pennsylvania, coupled with similar projects elsewhere and an emerging body of research, provide sufficient evidence for decision-makers to take action to slow the rush to drill, at least until the wide gaps in scientific knowledge, policies, and regulations are bridged. Much is already known about the chemicals used and pollution caused by oil and gas activities, which alone create the real potential for negative health effects in any area where development occurs [50]. The precautionary principle should be applied to decisions about shale gas development (both in existing gas patches and in areas slated for new development), and this should include shifting the burden of proof that harm does or does not occur to those proposing the action.

The status quo—in which science and policy changes proceed slowly while gas development accelerates rapidly—is likely to worsen air and water quality, resulting in negative health impacts and possibly a public health crisis. Greater understanding of the experiences reported by individuals living near gas facilities can play an important role in pointing the way forward to preventing these problems, both in Pennsylvania and nationwide.

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AUTHORS' BIOGRAPHIES

NADIA STEINZOR is the Eastern Program Coordinator of Earthworks' Oil & Gas Accountability Project. She works with landowners, concerned citizens, and environmental organizations to educate and support impacted communities, advance state oil and gas regulations, and promote Earthworks' federal reform agenda. Nadia has worked for nearly two decades in research, communications, writing, and editing to promote action and policies on environmental protection and land conservation. She holds an M.S. in Environmental Policy from Bard College and an M.A. in Peace and Development Studies from the University of Gothenburg, Sweden, Send email to her at nsteinzor@earthworksaction.org

WILMA SUBRA is President of Subra Company, Inc., a chemistry lab and environmental consulting firm in New Iberia, Louisiana, which provides technical assistance to citizens and victims of environmental issues. She serves on local, state, and federal committees dealing with oilfield waste, oil refineries, and toxic release inventory. Wilma holds an M.S. in Microbiology and Chemistry from the University of Southwestern Louisiana. She is a recipient of the MacArthur Fellowship Genius Award for helping ordinary citizens understand, cope with, and combat environmental problems in their communities. Send email to her at subracom@aol.com

LISA SUMI is a consultant who works on the environmental, community, and health impacts of extractive industries such as coal and hard rock mining, tar sands, and oil and gas. She conducts work that integrates science, technology, policy, and corporate research and analysis with community education and outreach. She has served as Research Director for the Oil and Gas Accountability Project and the Environmental Mining Council of British Columbia, and has worked for clients such as As You Sow, Council of Canadians, Earthworks, ForestEthics, Initiative for Responsible Mining Assurance, Massachusetts Institute of Technology Center for Future Civic Media, MiningWatch Canada, and Natural Resources Defense Council. Lisa holds a M.S. in Physican Geography from the University of Toronto. Isumi@earthworksaction.org

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Direct reprint requests to:

Nadia Steinzor
Earthworks' Oil & Gas Accountability Project
P.O. Box 149
Willow, NY 12495
e-mail: nsteinzor@earthworksaction.org

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Features

THE ECONOMIC IMPACT OF SHALE GAS DEVELOPMENT ON STATE AND LOCAL ECONOMIES: BENEFITS, COSTS, AND UNCERTAINTIES

JANNETTE M. BARTH

ABSTRACT

It is often assumed that natural gas exploration and development in the Marcellus Shale will bring great economic prosperity to state and local economies. Policymakers need accurate economic information on which to base decisions regarding permitting and regulation of shale gas extraction. This paper provides a summary review of research findings on the economic impacts of extractive industries, with an emphasis on peer-reviewed studies. The conclusions from the studies are varied and imply that further research, on a case-by-case basis, is necessary before definitive conclusions can be made regarding both short- and long-term implications for state and local economies.

Keywords: economic impact; shale gas development; extractive industries; hydraulic fracturing, fracking

The combined technologies of horizontal drilling and hydraulic fracturing have made it possible to extract large amounts of natural gas from the Marcellus Shale, which underlies portions of five states in the Northeast. Many commentators have assumed that shale gas exploration and development in these states will be enormously beneficial to the state and local economies. While externalities, both positive and negative, are commonly experienced along with the direct

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activities of extractive industries, the negative externalities and the overall net benefits are often overlooked in economic impact studies. Examples of negative externalities in connection with shale gas development include water, air and land contamination; related public health impacts; wear and tear on roads and other infrastructure; and costs to communities due to increased demand for services such as police, fire, first responders, and hospitals.

An understanding of economic impacts in the Marcellus Shale region can be enhanced by a wider knowledge of boom-bust cycles, the resource curse, and extractive industries generally. In an effort to investigate both the potential net benefits to state and local economies and how policymakers may evaluate them, this article offers a summary review of research findings and makes suggestions for further research that would be necessary to adequately analyze the net economic impact of shale gas development. It also offers a preliminary look at some economic measurements in the Barnett Shale play in Texas that are not often mentioned in relation to shale gas development. The first section provides a brief critique of some of the industry-sponsored, non-peer-reviewed studies, and it is followed by a summary of peer-reviewed literature and non-industry-funded studies that are relevant to extractive industries such as shale gas development. The final section discusses some of the costs and uncertainties inherent in any economic assessment of shale gas development.

STUDIES FUNDED BY INDUSTRY

Numerous studies have been prepared by and/or funded by the gas industry [1-6]. They generally conclude that there will be large, positive economic impacts to both states and local communities. These studies primarily highlight benefits such as employment, income, and tax revenue growth. Kinnaman [7] has reviewed several of these industry-sponsored studies and observed that they are not peer-reviewed. He has raised a number of concerns about the industry-sponsored studies, and concluded that due to unrealistic assumptions regarding windfall gains to households, location of suppliers and property owners, and the methodology used, the estimates of economic benefits in the industry-sponsored studies are very likely overstated. Any economic activity, including shale gas development, will generate some level of state and local economic revenues and provide some number of state and local employment opportunities, but policymakers should recognize that the estimated gains in revenues and employment are probably exaggerated in the industry-funded studies and the long-term economic impact may be far different than expected. In addition to the points made by Kinnaman [7], the estimates in these studies may be further overstated if overly optimistic gas reserve and production assumptions were used. There have been widely differing estimates of Marcellus Shale gas reserves from various sources, including academicians and federal government agencies [8]. For all these reasons, it is possible that the net benefits cited by industry-sponsored studies are overstated even before any adjustments are made for negative externalities.

Input-output analysis is frequently used by industry in their efforts to show direct, indirect, and induced economic impacts of shale gas development [1-3]. Using this technique, the industry-funded studies have captured some of the likely benefits of shale gas development, including the growth of ancillary and other industries. Input-output analysis relies on tables of coefficients that link each industry in a region to all other industries. An input-output matrix shows how much output from each industry is used as input into other industries. In a region where shale gas drilling has not existed in the past, it is impossible to know with certainty what the inter-industry coefficients will be, and "borrowing" them from other regions or industries may result in inaccurate impact conclusions [9].

An important fact to bear in mind when viewing the shale gas experience in Texas and trying to extrapolate it to other states, such as New York, is that Texas is likely to experience greater economic benefits from shale gas development than is New York. Texas has had a well-established oil and gas industry for many years and a labor force with the requisite skill sets. Oil and gas headquarters and main offices are more often in Texas than in New York. Many of the industries that are ancillary to gas exploration and development are also located in Texas, not in New York. New York will have to import skilled labor as well as materials and equipment, much of which is manufactured, managed, contracted for, and maintained in Texas. Economists at the Federal Reserve Bank of Dallas (Dallas Fed) have pointed out that due to the extensive oilfield machinery and energy services located in Texas, the state greatly benefits from oil and gas production throughout the world [10]. In addition, the Barnett Shale is in the Dallas–Fort Worth metroplex, a region that is much more urban than the Marcellus Shale region. The literature indicates that the impact of extractive industries in nonmetropolitan areas may be much different than in metropolitan areas [11]. Economic multipliers tend to be larger in metropolitan areas, such as the Dallas-Fort Worth metroplex, where there are larger populations and greater industrial diversity than in nonmetropolitan areas, such as the Marcellus Shale region of upstate New York [12].

Kinnaman has pointed out that "economic resources necessary to fuel a growing industry would either relocate from other regions of the country or shift from local industries within the region. . . . The IMPLAN model used . . . largely ignores the possibilities of direct spending crowding out other users of the resource" [7]. An additional weakness is the fact that environmental impacts are ignored. Wassily Leontief, who received the Nobel Prize in Economic Science for his model of input-output economics, had himself stressed as early as the 1970s that environmental repercussions and externalities should be incorporated into input-output analysis [13-15]. Leontief recommended that a pollution abatement industry be entered into the input-output matrix, and that the abatement industry be in the business of eliminating pollutants generated by the productive sectors, consumers, and the abatement industry itself. And Wiedmann, Lenzen, Turner, and Barrett stated, "in the last few years models have emerged that use a more sophisticated multi-region, multi-sector input-output framework . . . in order to calculate environmental impacts. . . . Results demonstrate that it is important to explicitly consider the production recipe, land and energy use as well as emissions in a multi-region, multi-sector and multi-directional trade model with detailed sector disaggregation" [16]. The industry-sponsored studies have not addressed environmental repercussions, such as water and air contamination, or externalities such as damage to roads and costs to communities. Unless appropriate adjustments are made, input-output analysis tends to use unrealistic assumptions. Bess and Ambargis [17] and Lazarus, Platas, and Morse [18] discuss some of the limitations of input-output analysis. For example, Bess and Ambargis state, "Regional input-output models can be useful tools for estimating the total effects that an initial change in economic activity will have on a local economy. However, these models are not appropriate for all applications and care should be given to their use. . . . Key assumptions of these models typically include fixed production patterns and no supply constraints. Assumptions about the amount of inputs that are supplied from the local region are also important in these models. Ignoring these assumptions can lead to inaccurate estimates" [17]. There are several additional problems of particular relevance to the application of input-output analysis to the study of shale gas development. For example, while spending patterns in communities with an established drilling industry would probably be different than spending patterns in communities without an established drilling industry, this difference is not reflected. Input-output analysis implicitly assumes that all populations have identical spending patterns. This assumption exaggerates the estimated economic impact if new workers are transient. The gas industry frequently brings in transient workers and houses them in man-camps or rental housing on a short-term basis [19]. Such workers often send their wages to their families living elsewhere, improving the economies in those distant locations, not in the shale region, and thereby exaggerating the estimated economic impact. In addition, input-output analysis assumes "constant returns to scale." This means that the gas industry would get no volume discounts on supplies. This is an unrealistic assumption, and it inflates estimates of industry spending and thus estimates of economic impacts from the industry's activity in the community. Input-output models used in the industry-sponsored studies tend to be static in time, implying that there are no changes in coefficients over time and no allowance for price changes in factors of production such as supplies and labor. The production function is also assumed to be constant. This does not allow for input substitution or changes in the proportions of inputs as technology and/or prices change over time. Input-output models tend to be aspatial, implying that transportation costs are not fully reflected. Transportation costs in gas drilling areas may differ due to differences in availability of and proximity to fresh water supplies and wastewater disposal wells.

In order to produce even somewhat accurate results using an input-output approach, inter-industry relationships must be known. There are several frequently used sources of input-output coefficients that indicate how the input and output of each industry in a given region are related [20, 21]. One cannot know what the true coefficient values are in a case where the industry being studied does not already exist in a region, as is the case for horizontal drilling and hydraulic fracturing in New York State. Even if the input-output coefficients could be known, the technique is of limited use. Input-output methodology estimates the positive impacts on variables such as employment, value added, and tax revenue, but as shown in the above discussion of assumptions, the estimates are often exaggerated; and the methodology does not capture the impacts of environmental degradation or the full costs to communities and society.

STUDIES NOT FUNDED BY INDUSTRY

While studies not funded by the gas industry on the economic impact of shale gas drilling are in short supply, there is substantial peer-reviewed literature on the economic impact of extractive industries generally. There are also some studies that are not peer-reviewed but are not funded by the gas industry. Conclusions from peer-reviewed literature and from studies not funded by the gas industry should be considered in the analysis of shale gas development. The research summary below is categorized into three areas: the resource curse, boom and bust cycles, and socio economics.

The Resource Curse

Research by Sachs and Warner [22, 23] concluded that there is a "natural resource curse," meaning that countries with great natural resource wealth tend to grow more slowly than resource-poor countries The so-called "resource curse" has been the subject of several literature surveys and the peer-reviewed research indicates that the resource curse holds within the United States, particularly in regions where there was once a strong extractive industry. After reviewing much of the literature, Stevens [24] pointed out that while there has been some disagreement, the evidence appears to support a negative relationship between abundance of natural resources and economic growth. He concluded that there is no simple single explanation of what creates a "blessing" rather than a "curse," and he argued for a case-by-case approach to analysis. His findings indicate that to decrease the likelihood of a "curse," the resource should be developed at a slow pace, thereby improving the chances that the economy and society can adjust and the crowding-out effect may be reduced. Increased diversification is suggested as another way to decrease the "curse" effect. Key dimensions of the resource curse that have been studied include negative impacts on economic growth, prevalence of poverty, and creation of greater conflicts in society. Regional and national impacts may be quite different. Stevens stated, "A final dimension of 'resource curse' is the regional impact of the projects. Thus while the effect at a national level might be debated, because of the heavy local impact of the projects, clear damage is done especially in terms of both the environment and human rights. Meanwhile, the benefits appear to flow to central rather than regional authority. However, this aspect of the 'curse' tends to be neglected in the economics literature" [24].

This dichotomy between benefits to a nation and damage to localities should be studied further in the case of shale gas development in the United States. Industry-funded studies [25, 26] have concluded that there will be large positive impacts on tax revenues and national employment levels, but they have ignored many negative impacts that would be incurred at the local and state levels. In the case of shale gas development, it is likely that policymakers at the state and local levels will have different interests than policymakers at the national level. One question that policymakers at all levels should consider is whether shale gas development, including its exploration, production, and exportation, is worth the costs to the states, communities, and individuals that are directly impacted.

Initial research on the natural resource curse was focused on how it impacts developing nations [22-24]. Such research includes extensive empirical analysis and speculation on what causes the resource curse. While there has been less research on the natural resource curse specific to the United States, Papyrakis and Gerlagh [27] focused on the United States. They concluded that even in the United States, natural resource abundance is a significant negative determinant of economic growth. James and Aadland [28] extended the research to a disaggregated level within the United States, by focusing on counties. Their results show "clear evidence that resource-dependent counties exhibit more anemic growth, even after controlling for state specific effects, socio-demographic differences, initial income, and spatial correlation" [28].

Headwaters Economics studied county-level impacts and concluded, "counties that were not focused on fossil fuel extraction as an economic development strategy experienced higher growth rates, more diverse economies, better educated populations, a smaller gap between high and low income households and more retirement and investment income" [29]. Peach and Starbuck [30] studied oil and gas extraction in New Mexico and found a small but positive effect on income, employment, and population.

It may be difficult to determine if extraction of a natural resource caused poorer economic performance in an affected region or if the region was already relatively poor or on the path to poverty prior to exploitation of the resource. In two cases that are specific to counties in the United States, and were cited above, James and Aadland [28] and Headwaters [30], attempts were made to control for initial income and other differing characteristics of the areas under study.

Boom and Bust

Extractive industries are known for their boom-and-bust cycles [31], and the bust must be analyzed as well as the boom. Weber [32] focused on the short-term impact of a natural gas boom in Colorado, Texas, and Wyoming and found modest increases in employment, wage and salary income, and median household income. The negative economic consequences during the bust may exceed the positive direct economic impact during the boom. Black, McKinnish, and Sanders [33] studied the coal boom in the 1970s and the bust in the 1980s on local economies in the four-state region of Kentucky, Ohio, Pennsylvania, and West Virginia. They concluded, "for each 10 jobs produced in the coal sector during the boom, we estimate that fewer than 2 jobs were produced in the local-good sectors of construction, retail and services. The spillovers from the coal bust were larger. During the coal bust, we estimate that for each 10 jobs lost in the coal sector, 3.5 were lost in the construction, retail and services sector" [33]. Seydlitz and Laska studied boom-and-bust cycles of the petroleum industry in Louisiana and concluded that improved community economic health is transitory in areas with petroleum extraction, and "improvements can be lost as early as the second or third year after an increase in petroleum activity and will be lost during the bust if not sooner" [34]. They suggest that a diversified economy may help to prevent some of the loss in benefits. Christopherson and Rightor [35] have written about the boom and bust phenomenon as it impacts shale gas extraction, and they suggest that the boom and bust cycle can be controlled by slowing the pace and scale of shale gas development.

Socioeconomics

Peer-reviewed sociology journals have published articles on the socioeconomic impact of extractive industries in the United States, and the results of this research should be considered by policymakers in their assessment of the economic impact of shale gas development. For example, Freudenburg and Wilson [11] analyzed 301 research findings regarding the impact of mining in the United States, and they concluded that adverse conditions are significantly more likely than positive outcomes. They also stated, "the areas of the United States having the highest levels of long-term poverty, outside of those having a history of racial inequalities, tend to be found in the very places that were once the site of thriving extractive industries" [11].

Wilson [36] studied the socioeconomic well-being of mining communities by comparing two communities in the Midwest and concluded that local well-being as a result of mining in a community is influenced by local circumstances such as "levels of economic dependence on mining, the geographic distribution of the workforce, and the options available to the companies to confront changes in minerals price." Wilson's research indicates that different mining communities within the same region of the Untied States can have different long-term employment impacts, and case-by-case research is required.

SOME COSTS AND UNCERTAINTIES SPECIFIC TO SHALE GAS

The relevant peer-reviewed research, as described above, indicates that each extractive industry and its impacts on specific states and locations must be studied on a case-by-case basis. There are many uncertainties regarding the long-term impacts on local and regional economies. Long-term impacts on the number of jobs created, unemployment rates, and income and poverty levels should each be considered. There are likely to be significant local costs, and these must also be considered. As horizontal, high-volume slick-water hydraulic fracturing for natural gas is still in its early stages, it is premature to analyze and attempt to make definitive conclusions regarding the long-term economic impacts of shale gas development in the United States. However, since the Barnett Shale play in Texas has been active for about a decade, some early indications of economic health are emerging. According to the Texas Railroad Commission [37], there are four core gas-drilling counties in the Barnett Shale: Denton, Johnson, Tarrant, and Wise counties. While there are many reasons why economic data and trends in certain counties differ from state-level data, it is interesting to examine unemployment rates, growth in median household income, and the number of people in poverty in these core gas-drilling counties as compared to statewide data. The data indicate that the residents of these counties are not experiencing great economic prosperity relative to the rest of Texas. Data were obtained from the U.S. Census Bureau, Small Area Estimates Branch, and the Bureau of Labor Statistics [38, 39]. For the period from 2003 to 2010, median household income increased by 21.2 percent in the state of Texas, but in the four core counties, median household income increased between 10 percent and 16 percent. And for the same period, the increase in the unemployment rates for the four counties ranged from 1.8 to 2.4 percentage points, a little higher than the increase in the state-level unemployment rate, which was 1.5 percentage points. Finally, the number of people in poverty in the four-county areas increased, in percentage terms, just as much as statewide.

Significant costs that are associated with shale gas development and other extractive industries should be considered in any study of the economic impact of shale gas development. Such costs are often omitted in both peer-reviewed literature and in the industry-funded studies. Kinnaman [7] briefly discusses the implications of social costs and implementation of a tax on negative externalities, which is intended as an incentive to reduce the negative externality and may be used as a source of funds to help mitigate negative impacts. A few of the costs that have not been adequately addressed in the literature are summarized here.

Shale gas development may transform a previously pristine and quiet natural region, bringing increased industrialization to the region in the form of industrial contaminants, heavy truck traffic, and excessive noise. Due to concerns regarding potential water, air, and land contamination, industries that have been vital to some of the communities in the shale region may decline. Industries that are incompatible with high levels of industrialization and potential environmental degradation include agriculture, tourism, organic farming, hunting, fishing, outdoor recreation, and wine and beer making. Each of these industries that rely on clean air, land, water, and/or a tranquil environment is currently important to the shale counties in upstate New York. Kauffman [40] has calculated that the net present value, using a discount rate of 3 percent over 100 years, of natural goods and services from ecosystems in the New York State portion of the Delaware River Basin is $113.6 billion.

Tourism is an industry that been encouraged in many of the communities on the Marcellus Shale, and Rumbach [41] reported that in 2008, visitors spent more than $239 million in three counties of New York State's Southern Tier, and the tourism and travel sector accounted for 3,335 direct jobs and nearly $66 million in labor income. The Outdoor Industry Association [42] reports that 6.1 million American jobs are directly supported by the outdoor industry and that Americans spend $646 billion each year on activities like camping, hunting, fishing, and snow sports, all of which are popular in the Marcellus Shale region.

Deller et al. [43] analyze economic growth due to tourism in areas with natural amenities that encourage outdoor recreation and conclude that rural areas that can take advantage of such amenities are in a position to expand their local economies. Public fears of water, air, and land contamination due to shale gas development, whether those fears are realistic or not, may forever negatively impact the public perception of the rural areas that currently enjoy tourism dollars. Another related sector of the economy in the shale region of New York centers around retirees and owners of second homes, both of whom may become less enamored of a region when it becomes industrialized. Such potential losses to communities should be reflected in an economic assessment.

Estimating the ignored costs is not a simple task, but there are ways to at least roughly estimate many of the costs that have been ignored to date. Rumbach [41] analyzed the potential impact of shale gas drilling on the New York tourism industry, and his work may assist in attempting to estimate impacts. He points out that tourism brings many non-monetary benefits to the region and its communities, and its amenities improve the quality of life for residents. He states, "Restaurants, shops, parks and outdoor recreation areas, campgrounds, wineries, festivals, museums and other related amenities are beneficial to local residents as well as visitors. These amenities also make a region more attractive for economic investment; they are some of the crucial resources that allow an area to attract economically mobile populations." He questions whether drilling will permanently damage the "brand" of the region as a pristine and picturesque destination. Brand image may also be affected for agricultural products from shale areas. In an open letter on the subject of shale gas development, the president of the Park Slope Food Coop, a very large food coop in Brooklyn, NY, stated, “I guarantee that our members will not want the fruits and veggies that come from farms in an industrial area” [44]. The use of surveys and focus groups may help to estimate the extent of the impact of “brand” image on customers and the overall impact on some of the impacted industries. Probability or risk models, based on the likelihood of contamination, may also be employed. In the case of the impact on hunting and fishing, volume decreases can be estimated using surveys of businesses and customers together with official state data on game animal harvests and creel surveys in areas already experiencing shale gas development. The impact on outdoor recreation and related facilities can be estimated through surveys, attendance records at major facilities, and the loss to businesses that cater to such customers.

Additional costs that should be estimated are the costs to communities associated with increased demand for community social services, such as police and fire departments, first responders, and local hospitals. Such cost increases resulting from gas drilling have taken place in the Rocky Mountains [45, 46], and research from Pennsylvania shows that many municipalities have experienced increased costs [47]. As the shale gas industry imports labor from other states, transient workers will exert additional demand on community services and further upward pressure on costs.

There will be costs associated with traffic congestion and road damage. The heavy truck traffic required for shale gas development is known to cause air quality issues and significant road damage. It was recently reported that the Texas Department of Transportation told industry representatives and elected officials that “repairing roads damaged by drilling activity to bring them up to standard would ‘conservatively’ cost $1 billion for farm-to-market roads and another $1 billion for local roads. And that doesn’t include the costs of maintaining interstate and state highways” [48]. The New York State Department of Transportation made a preliminary statement that “the impacts of Marcellus Shale gas development on State transportation financing needs is likely to be profound. . . . The incremental costs to mitigate Marcellus impacts for the State range from $90 million to $156 million per year. The estimate for costs for local roads and bridges range from $121 million to $222 million per year, some of which may well flow from the State Transportation Budget” [49].

The impact on property values is uncertain and has been inadequately addressed in the literature. On the one hand, increased property valuations of large tracts may be expected due to potential income from gas drilling, and an influx of transient workers will probably increase the demand for and value of rental properties. The net impact on property values, however, is uncertain. Shale gas drilling is taking place in homeowners’ backyards, and such industrial activity and the presence of hazardous materials are in many cases in violation of residential mortgage conditions [50]. Boxall, Chan, and McMillan [51] studied the impact of oil and gas drilling on residential property values in

Alberta, Canada, and found a negative relationship. The authors note that three industry-funded studies did not find a negative relationship between gas drilling and residential property values [52-54]. Again, while the impact on property values is difficult to estimate, there is relevant literature. For example, Taylor, Phaneuf, and Liu [55] used an empirical model to identify the direct impact of environmental contamination on residential housing prices separate from land use externalities. Muehlenbachs, Spiller, and Timmins [56] demonstrated that the risk of groundwater contamination from natural gas extraction leads to "a large and significant reduction in house prices." They further found that "these reductions offset any gains to the owners of groundwater-dependent properties from lease payments or improved local economic conditions, and may even lead to a net drop in prices. . . . To the extent that the net effect of drilling on groundwater-dependent houses might even be negative, we could see an increase in the likelihood of foreclosure in areas experiencing rapid growth of hydraulic fracturing."

Recent reports indicate that obtaining insurance is likely to become increasingly difficult, if not impossible, for properties that may be impacted by shale gas drilling [57]. This will negatively impact property values, as residential mortgages require the property owner to carry homeowner's insurance. A representative of Nationwide Insurance recently stated in email correspondence, "From an underwriting standpoint, we do not have a comfort level with the unique risks associated with the fracking process to provide coverage at a reasonable price" [58]. If available in the future, the cost of obtaining such insurance to protect against the substantial risks inherent in shale gas drilling using hydraulic fracturing techniques may become prohibitively high. This is another example of a cost that is omitted in the research to date. Data on trends in housing sales and prices in existing shale regions should be analyzed in detail to help identify the impact on property values.

Potential public health costs should be reflected in a thorough economic assessment. Multiple researchers have discussed potential negative health impacts that may result from water and air contamination. Various chemicals used in hydraulic fracturing include carcinogens and endocrine disruptors, which are related to serious diseases and birth defects, both involving significant costs. Bamberger and Oswald [59], Schmidt [60], Weinhold [61], and McKenzie, Witter, Newman, and Adgate [62] have investigated health impacts. In the case of humans, such costs can be estimated by measuring health services costs related to specific diseases and the loss of life and decreases in life expectancy. In the case of domestic and farm animals, values may be assigned based on market prices. All these health costs should be estimated using probabilities based on the likelihood of contamination by the various pathways.

An opportunity cost that should be factored into the analysis is the foregone economic development in areas where networks of gas pipelines are constructed.

As buildings cannot be placed on or adjacent to pipelines, shale gas development may cause future construction and economic development to be significantly curtailed [63]. This foregone regional development and the possibility of earthquake damage caused by disposing wastewater into deep injection wells [64] are uncertain costs that may be impossible to measure, but they may become enormous costs to communities in the long-run. Dutzik, Ridlington, and Rumpler [65] have outlined many of the economic costs, made a few suggestions regarding estimation of some of the costs, and shown that communities and states will bear many of the costs.

All potential benefits and costs of shale gas development should be considered during the decision-making process. Some questions that policymakers should ponder, in addition to the basic question of whether there will be net economic benefits to states and communities, are the following: (1) Are the potential benefits to the nation in the form of balance of payments gains from shale gas exports worth the risks to the environment, public health, and local economies? (2) Is the continued development of fossil fuels and their impact on climate change sensible in light of the uncertainty regarding the impacts on public health and state and local economies? One cannot answer such questions until a comprehensive analysis of net economic impacts has been completed. One way to view the net impacts and the many tradeoffs is to think of the benefits and costs to a region or a state as assets and liabilities in the form of a balance sheet for the region. As an example, Figure 1 presents such a balance sheet for New York State.

In conclusion, there are many uncertainties regarding the net benefits of shale gas development on state and local economies. There are sufficient independent research findings on extractive industry impacts to question the claims commonly propounded by the industry, and repeated by the press, that shale gas extraction will bring prosperity to local communities. The preponderance of independent research indicates that long-term prosperity for local communities is unlikely, but far more research is required in order to make a definitive conclusion. Policymakers should insist on unbiased, comprehensive economic assessments of shale gas development for each state and community that may be impacted.

AUTHOR'S BIOGRAPHY

JANNETTE M. BARTH, Ph.D., is founder and managing director of Pepacton Institute LLC, a research organization, and president of JM Barth & Associates, Inc., an economic consulting firm. She has been conducting economic analyses and developing economic models for more than 35 years. Much of her work has involved local and regional economic impacts. In recent years, her research has focused on economic impacts of shale gas development. Write her at this address: jm.barth@mac.com

A Balance Sheet for New York State: What is New York State's Net Equity from Shale Gas Development?

➤ Assets*

Tax Revenue:
- Direct from the gas industry based on future legislation
- Increased income tax based on
  - Royalty income to leaseholders
  - Lease income to landowners

Stimulation of industries based on byproducts of natural gas

Climate benefits from decreases in green house gases from burning shale gas

Indirect benefit to NYS from improved Balance of Payments assuming substantial shale gas exports

Short-term job gains in the gas industry and related industries

Increased spending by leaseholders in New York State

Lower cost of energy as long as it lasts

TOTAL ASSETS ???

*These are not necessarily comprehensive lists of assets and liabilities. They serve only as examples. Note that where an asset or liability is a future stream of income or expense, discounted present value should be used.

➤ Liabilities*

Tax Revenue Loss:
- Income tax losses by leaseholders who vacate properties and relocate out-of-state
- Income tax losses caused by decreases in tourism and other industries negatively affected by drilling
- Property tax losses caused by negative impact of drilling on property values and financing

Decreased spending by leaseholders if they move out of state, or buy second homes out of state

Human health costs associated with:
- Water contamination from frack fluids and wastewater
- Air pollution from compressors, leaks, gas released at well-sites

Costs due to impacts on animals (domestic, agricultural and game) of water, land and air contamination

Climate costs associated with increases in greenhouse gases from methane leaks and venting

Costs associated with declining quality of life due to the creation of an industrial landscape

Costs associated with declines in tourism industry

Costs associated with declines in organic farming and other agriculture and food manufacturing

Costs associated with declines in outdoor recreation

Costs associated with increased air pollution from increased truck traffic

Costs associated with declines in fisheries and trout fishing industry

Infrastructure costs due to use of and damage to roads and bridges from increased truck traffic

Costs due to declines in numbers of retirees and retirement housing market

Costs due to declines in numbers of second home owners and second home market

Costs due to crowding out (loss of jobs to existing businesses and governments)

Costs to communities due to increased demand for police, fire and first responder services

Social costs associated with the gas drilling industry

Costs to the mortgage industry and housing market, and related declines in property values and property tax revenue

Costs associated with increased homelessness

Costs associated with the postponement of investment in renewables

Opportunity costs due to the prevention of future building and economic development

Costs associated with a long-term bust, characteristic of extractive industries

TOTAL LIABILITIES ???

NET EQUITY ???

Is the **Discounted Present Value of Total Assets** minus the **Discounted Present Value of Total Liabilities** a positive value?

This question cannot be answered until a comprehensive risk assessment and economic analysis has been conducted.

Figure 1. A snapshot of one state's net impacts and tradeoffs, formatted as a balance sheet.

NOTES

QA: Please supply authors' initial

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Direct reprint requests to:

Jannette M. Barth, Ph.D.
Pepacton Institute LLC
P.O. Box 127
Croton on Hudson, NY 10520
e-mail: jm.barth@mac.com

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Features

HISTORICAL ANALYSIS OF OIL AND GAS WELL PLUGGING IN NEW YORK: IS THE REGLATORY SYSTEM WORKING?

RONALD E. BISHOP

ABSTRACT

The aim of this work was to evaluate New York State's regulatory program for plugging inactive oil and gas wells. Analysis of reports from the Division of Mineral Resources, Department of Environmental Conservation, reveals that three-fourths of the state's abandoned oil and gas wells were never plugged. Inadequate enforcement efforts have resulted in steady increases of unplugged oil and gas wells abandoned since 1992. Further, no program exists or is proposed to monitor abandoned wells which were plugged. These results strongly suggest that comprehensive reform and increased agency resources would be required to effectively regulate conventional oil and gas development in New York. Industrial expansion into shale oil and gas development should be postponed to avoid adding stress to an already compromised regulatory system.

Keywords: oil, gas, plugging, regulatory, New York, fracking

New York's oil and gas industry is just nine years from its bicentennial, since the pilot project, a natural gas well near Fredonia, was drilled in 1821. Now, there is a dedicated and sophisticated Bureau of Oil and Gas Permitting and Management (BOGPM), established as a unit of the Division of Mineral

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Resources (DMN) within the state Department of Environmental Conservation (DEC) in 1970. State guidance documents and regulations have undergone multiple updates, including those newly proposed in 2011 to accommodate concerns peculiar to the extraction of oil and gas from unconventional reservoirs such as shale. But before state regulators adopt new rules to permit expansion of the industry into shale oil and gas development, we should evaluate how the regulatory system has managed petroleum development so far. Few aspects of the regulatory system are as cogently diagnostic as New York's record on plugging abandoned oil and gas wells.

BACKGROUND

Abandoned Wells Issue

With great attention paid these days to proper oil and gas well construction, appropriate control of chemicals and wastes, and other production issues, post-production plugging and cleanup has received relatively little notice. But as production from the first oil and gas wells declined, this was recognized as an important issue. New York became the first state to require the plugging of abandoned wells in 1879 [1]. No particular state entity existed to monitor compliance or enforce the plugging law, but an 1882 amendment to it offered half of any fines collected to informants who reported violations [1]. From that time forward, regulating this aspect of the petroleum industry has posed a unique challenge.

Scope of the Problem

The number of abandoned oil and gas wells in New York State is not definitely known. The Historic Well Survey of 1988, included in that year's DMN annual report, established a baseline of 42,322 oil and gas wells of unknown status [2], while the Plugged Wells Estimate of 1993, included in that year's annual report, identified 13,070 wells which were known to have been plugged [3]. For their external review in 1994 by the Interstate Oil and Gas Compact Commission, BOGPM staff estimated that 61,000 wells had been developed historically, but the agency had no records on 30,000 of them [4]. Of the wells on record, 12,857 were active and about 18,000 were known to not be plugged. Therefore, of 48,000 abandoned oil and gas wells total, 13,000 were plugged and approximately 35,000 were not plugged as of 1994 [4]. It should be noted that this report represented an improvement in the BOGPM's accounting for oil and gas wells since the Historic Wells Survey of 1988, reducing the approximate number of "unknown status" wells from 42,000 to 35,000 over that six-year period.

Well Accounting Issues

Accounting for abandoned oil and gas wells is complicated by the fact that New York's BOGPM maintains more than one system for recording them. For example, the 2005 DMN annual report reported on (a) inactive oil and gas wells, (b) known, unreported wells and (c) "other, known orphan wells" [5], which summed to fewer than 9,000 wells, far short of the 35,000 unplugged, abandoned wells noted above. Annual reports from 2002 onward suggest that the locations of fully half of the state's orphan abandoned oil and gas wells are unknown, and from the 2009 annual report, "Most of the [abandoned] wells date from before New York established a regulatory program" [6]. Thus it appears that state regulators have given up on old wells for which location or operational data are missing; for clarity, I will call them "forgotten." Abandoned oil and gas wells in known locations, but for which the BOGPM lacks current ownership data, dominate the Priority Plugging List [7]. Although some of these wells have been plugged with the use of agency or external funds, most have not. Therefore, I refer to this group as "generally ignored." The primary focus of the BOGPM, then, is on those inactive wells for which all information is actionable; I call them "standing inventory." The boundaries that delimit these groups are not always clear, but the fresh discovery of a "forgotten" well typically results in its transfer to the "generally ignored" category, and the loss of ownership information may move a well from "standing inventory" to "generally ignored." Plugging oil or gas wells results in their removal from the state's accounting, although they are still abandoned structures; one might call them "forsaken."

Practical Significance

Why would abandoned wells matter to anyone? As if to answer this question, DMN annual reports from 2002 and 2003 presented case studies with photographs of individual abandoned oil and gas wells [8, 9]. One case involved an old gas well that discharged brine at a rate of five gallons per minute into a wetland near Rome, killing over an acre of vegetation [8]. Another involved the entire village of Rush, on the border between Ontario and Schuyler Counties, where two dozen unplugged abandoned wells were responsible for widespread emanation of gas from the soil, so that methane accumulated to explosive levels in some structures [8]. Plugging or excavation of abandoned wells on school properties in Allegany and Wyoming Counties cost those school districts thousands of dollars [8]. Further, abandoned wells have been found leaking oil into creeks and wetlands in Steuben and Allegany Counties, and into residential ponds and lawns in Allegany and Cattaraugus Counties [9]. These case studies provide evidence that many abandoned petroleum wells across New York leak fluids to the ground surface.

This issue is by no means limited to New York. In a 1987 report, the U.S. Environmental Protection Agency (EPA) estimated that, of about 1.2 million abandoned oil and gas wells nationwide, approximately 200,000 (17%) were portals for pollution to reach the surface [10], and in 1989 the U.S. General Accounting Office reported that the number of improperly abandoned wells was increasing [11].

Long-Term Instability

Abandoned wells leak because well casings deteriorate over time, and once-depleted rock formations repressurize with oil, gas, and brines [12–14]. Dusseault and coworkers showed that because temperature, pressure, and salt concentrations all tend to increase with depth, steel pipe and concrete degradation occurs most rapidly in the deepest segments of abandoned wells, where the damage is most difficult to detect. They estimated that essentially all unmaintained well bores lose integrity over a 50-year time frame, and further, that deep rock structures frequently repressurize [12]. One industry study of offshore oil and gas wells determined that half of the well casings studied began to leak in just 15 years [13]. A more recent industry study of oil and gas projects in Alberta, Canada, found leaks in just over 4 percent of the wellbores, including some which were plugged before abandonment [14]. A possible explanation for the lower percentage of leaks found in the onshore wells might be that they were more actively maintained. That is, the Canadian projects were more consistently monitored for sustained casing vent flow and external gas migration, and were more aggressively re-grouted when these problems were discovered [14]. Ongoing maintenance, then, is required to keep old wellbores stable. Therefore, to be effective, the state's oil and gas regulatory program must not only ensure that abandoned wells are properly plugged, but must also periodically inspect and, when necessary, repair the plugged wells.

Economic Impact

The cost of plugging abandoned oil and gas wells varies for different situations, but two contract awards cited in DMN's 2008 annual report provide some context [15]. One contract was for $190,000 to plug 45 wells in Allegany County, an average cost of $4,222 per well, and the other was for $150,000 to plug 25 wells in Cattaraugus County, or $6,000 per well. At about $5,000 per abandoned well, plugging the 4,722 wells on the BOGPM's current priority plugging list [7] would cost $23.6 million. And on this basis, finding and plugging the 35,000 unplugged, abandoned wells which were estimated in 1994 would cost at least $175 million.

In the agency's defense, the DMN began to amass an "Oil and Gas Fund" in 1981 to pay for the plugging of priority oil and gas wells, but in 1993 the Legislature appropriated $1 million of that fund for general expenditures, and changed state law to prevent the use of collected fines for plugging activities [4]. The DMN never accumulated that much money again; the plugging fund balance at the end of 2009 was $209,000 [6].

Difficulty of Enforcement

What is involved in enforcing compliance with the state's oil and gas plugging laws? This question is nuanced, according to Louis W. Allstadt, a former senior oil and gas company executive [16]:

> Very little attention is paid to the end of the life of an oil or gas well. I think you will find that it is rare for the larger companies to plug and abandon their older wells. Rather, at some point, a smaller company with lower overheads and less expensive operating costs will offer to buy the old wells at a price that gives the original company a better return than continued operations. The original company uses the cash to finance new investments. The buying company operates with lower costs because they spend less on maintenance and safety items and they have fewer well-qualified people to pay. The chain may end there or continue through smaller and ever lower cost operators who do no preventive maintenance at all, do the bare minimum of repairs to keep the well going and eventually walk away, maybe after plugging the hole as cheaply as possible and maybe not plugging at all.
>
> In conventional fields these selling/buying cycles might start when the field is 20-30 years old and run for another 20–30 years. By the time these wells are abandoned, the casings have been subjected to corrosive fluids for many years. When it costs too much to repair versus what might be produced, the well is abandoned. Whether it is plugged before it is abandoned depends on the final operator. In tight shale this could all take place over a much shorter time period and the abandoned wells could increase quickly [16].

Hence, inspecting low-production oil and gas projects and tracking well ownership through multiple transfers pose particular challenges to state regulators, and may help to explain how many owners have avoided plugging their abandoned wells. This problem would be exacerbated by shorter-lived projects, and indeed, industry analysts have presented evidence that tight shale gas wells decline much more quickly than oil and gas wells in conventional deposits, with shale gas projects exhibiting half-lives of about eight years [17, 18].

Therefore, with state regulators proposing to permit dramatic expansion of the oil and gas industry into extraction from shale, the principal aim of this study is to answer the question: "How successful has New York's oil and gas regulatory program been, especially since the 1994 review, with respect to post-production plugging?"

METHODS

Data Sources

Most data for this investigation came from annual reports by the DEC's Division of Mineral Resources. Reports that were accessible from the DEC's web site included those from 1994 through 2009 [19]. Reports from 1985 through 1993 were obtained by Freedom of Information Law (FOIL) request from the DEC. Other data came from the 1994 New York State Review (STRONGER review) [4] and the New York State priority plugging list [7]. These documents constitute the entire body of publicly available records on this topic in the State of New York.

Categories of Inactive Wells

As stated in the introduction, the primary focus of the BOGPM appears to be the "standing inventory" of oil and gas wells declining to zero commercial production, for which complete location and owner information is currently available. That subset of inactive wells represents all that are detailed in the DMN annual reports, and forms the main substance of the Results section, below.

Influence of Shut-in Wells

The results below are expressed in terms of oil and gas wells that had been reported as "inactive," defined as having zero commercial production. An oil or gas well may be considered inactive either because it is depleted or because it is shut in. From 1966 to 1990, no distinction was made in DMN annual reports between depleted and shut-in wells. Since 1991, shut-in wells have been consistently identified as those that may be capable of producing oil or gas, but are not connected to pipelines or for some other reason are temporarily sealed to prevent product loss. Shut-in wells are not required to be plugged, even though they are inactive. Therefore, a summary of shut-in application approvals by year was requested from the BOGPM. The agency claimed to have no responsive records, but informed me that "269 shut-in applications are currently approved" [20]. Hence, the number of inactive oil and gas wells in each year's standing inventory may include some which were not required to be plugged at the time, but no data are available to resolve that question for individual years.

Influence of "Other" Plugged Wells

In DMN annual reports, data for well plugging included oil, gas, and "other regulated wells." The other regulated wells included salt solution and strati-graphic geothermal wells, and their numbers were expressly stated in only seven of the reports, from 2003 through 2009. These "other" plugged wells ranged from 15 to 55 per year, with mean and median averages of 28.3 and 24, respectively. To maintain consistency of data handling across the entire 39 years reported, the more conservative median average of 24 wells was subtracted from the raw "plugged" data for each year from 1971 through 1992, and the actual number of "other" plugged wells was subtracted from the raw "plugged" data prior to plotting and analysis. This modest correction is supported by data from the salt solution mining section of the DMN 1995 annual report, which indicated that 167 wells were plugged in the seven-year period from 1988 through 1994 (average of 24 wells per year) for a single salt solution project (Tully Valley) [21].

RESULTS

The yearly data for inactive and plugged wells are summarized in Table 1, and a plot of inactive oil and gas wells and corrected plugged wells by year shows the results of Table 1 graphically (Figure 1).

Trend Analysis

The results shown in Figure 1 indicate that New York has maintained a significant standing inventory of inactive oil and gas wells, a fraction of which have been plugged each year. Over time, this standing inventory tended to increase, except for the period 1990-1992. That period, when the inventory decreased, coincided with Pennzoil's closing out of its Chipmunk Field operations in Cattaraugus County; it unilaterally plugged 629 wells in 1990, contributing to a record 937 wells plugged that year [22]. The inventory then increased steadily from 1992 through 2009, approximately doubling over that 17-year period. Hence, for most of their recorded history, New York regulators' efforts to enforce plugging laws have not kept pace with the number of oil and gas wells that needed to be plugged.

To evaluate what would be required for the BOGPM to prevent an increase in unplugged wells, we need to know how many oil and gas wells become newly inactive each year. When I requested this information, the agency responded that its records are not structured to provide it: one would have to simultaneously monitor every well in the database and observe when each one was first reported to have zero production [20]. Nevertheless, the annual decline of oil and gas wells to zero production can be deduced from the trends shown in Figure 1.

A stable standing inventory would indicate that plugging rates matched the entry of inactive wells into the DMN database. Plugging rates would have to be lower than the entry of inactive wells into the database for the inventory to increase, and conversely, plugging rates would have to exceed the entry of inactive wells into the database for the inventory of unplugged wells to decrease. Average annual values derived from these trend parameters are shown in Table 2.

Table 1. Annual Plugging Data for Abandoned Oil and Gas Wells in New York

Year	Inactive[a]	Number plugged (raw)	Correction	Number plugged (corrected)
1996[b]	4500	N.A.	N.A.	N.A.
1967	4600	N.A.	N.A.	N.A.
1968	4450	N.A.	N.A.	N.A.
1969	1009	N.A.	N.A.	N.A.
1970	1350	N.A.	N.A.	N.A.
1971[c]	1567	418	–24	394
1972	1619	573	–24	549
1973	1484	544	–24	520
1974	1862	622	–24	598
1975	1883	553	–24	529
1976[d]	1825	442	–24	418
1977	1820	455	–24	431
1978	1864	352	–24	328
1979	2020	117	–24	93
1980	1900	119	–24	95
1981	2128	184	–24	160
1982	2304	262	–24	238
1983	2431	90	–24	66
1984	2296	182	–24	158
1985	2519	269	–24	245
1986	2468	471	–24	447
1987	2543	417	–24	393
1988[e]	2348	322	–24	298
1989	2620	260	–24	236
1990[f]	2707	961	–24	937
1991[g]	2069	376	–24	352
1992	1502	244	–24	220
1993[h]	1642	263	–24	239
1994[i]	1887	248	–24	224

Table 1. (Cont'd.)

Year	Inactive[a]	Number plugged (raw)	Correction	Number plugged (corrected)
1995	1784	219	–24	195
1996[j]	2215	233	–24	209
1997[k]	1974	187	–24	163
1998	2169	169	–24	145
1999[l]	1748	138	–24	114
2000[m]	2190	131	–24	107
2001[n]	2259	79	–24	55
2002[o]	2272	146	–24	122
2003[p]	2379	142	–15	127
2004	2526	145	–39	106
2005[q]	2658	150	–55	95
2006[r]	2871	213	–22	191
2007[s]	2460	192	–31	161
2008	3071	221	–12	209
2009[t]	3043	240	–24	216

[a]Oil and gas wells reported to have zero commercial production.
[b]Earliest official records.
[c]Earliest plugging records.
[d]Earliest reporting of "shut-in" gas wells.
[e]Estimated 42,32 wells of unknown status.
[f]Record high number of wells plugged.
[g]"Shut-in" wells first referred to as "inactive."
[h]Total plugged wells reported as 13,070.
[i]Total unplugged wells estimated at 35,000 [4].
[j]96 newly discovered abandoned wells.
[k]200 newly discovered abandoned wells.
[l]270 newly discovered abandoned wells.
[m]220 newly discovered abandoned wells.
[n]150 newly discovered abandoned wells.
[o]First mention of priority plugging list.
[p]First explicit reporting of "other" plugged wells.
[q]2117 Known wells unreported.
[r]1103 Known wells unreported.
[s]822 Known wells unreported.
[t]Last available annual report.

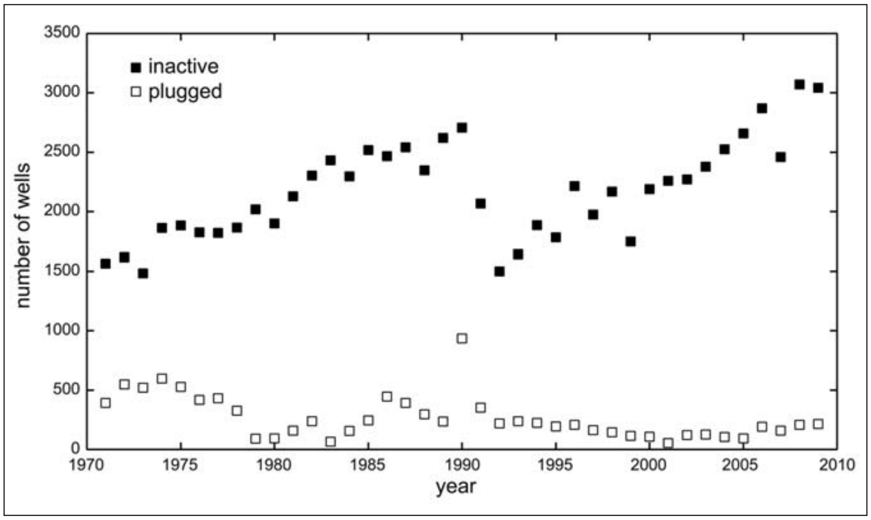

Figure 1. Annual reports of standing inventory of inactive wells (filled squares) and plugged inactive wells (open squares) by year reported, 1971-2009. Data taken from Table 1.

Table 2. Annual Newly Inactive Oil and Gas Wells

Period	Plug rate[a]	Inventory trend	Change[b]	Newly inactive[c]
1973-1978	499/yr	Stable	0	499/yr
1979-1987	151/yr	Increasing	+92/yr	243/yr
1987-1992	444/yr	Decreasing	–208/yr	236/yr
1992-2009	161/yr	Increasing	+91/yr	252/yr

[a]Total oil and gas wells plugged/number of years in period.
[b]Increase or decrease in inventory/number of years in period.
[c]Plug rate column value ± Add/subtract column value.

The results of Table 2 indicate that since 1980, approximately 250 oil and gas wells have become newly inactive annually. Therefore, for plugging to keep pace with ongoing demand, the BOGPM would have to enforce the plugging of at least 250 wells each year. The data in Table 1 show that such an enforcement level has not been achieved since 1991.

Current Status of Abandoned Oil and Gas Wells

Summary statistics from the DMN annual reports from 2008 and 2009 indicate that 75,000 total oil and gas projects are believed to have been developed in New York, of which about 11,000 remain active [6, 15]. Using these values in conjunction with the results shown in Table 1, it is possible to estimate how many oil and gas wells have been abandoned in the state, both plugged and unplugged. The data for 1994 and 2009 are presented for comparison in Table 3.

The results shown in Table 3 indicate that, while the number of plugged oil and gas wells has grown considerably since 1994, the number of unplugged abandoned oil and gas wells has increased even more. The percentage of plugged wells, out of all the abandoned wells, has slipped from 27 percent in 1994 to 25 percent currently, leaving the state with an estimated 48,000 wells that need to be plugged. At an estimated cost of $5,000 per well, about a quarter of a billion dollars would be needed to plug all these wells, if they could be found.

CONCLUSIONS AND RECOMMENDATIONS

Since 1970, New York's Bureau of Oil and Gas Permitting and Management has failed to adequately enforce state laws that require industry operators to plug inactive oil and gas wells. As a result, three-fourths of inactive oil and gas wells remain unplugged, and the number of unplugged abandoned wells in New York continues to increase. In the last year reported, only 216 of an estimated 250 newly inactive oil and gas wells (86%) were plugged. Further, no program to monitor and maintain plugged abandoned wells exists or is proposed, in spite of evidence that plugged wells can disintegrate and leak.

Table 3. Summary of Plugged and Unplugged Abandoned Oil and Gas Wells

Year	1994[a]	2009[b]
Total projects	61,000	75,000
Active wells	12,857	10,982
Abandoned wells, plugged	13,070	15,748
Abandoned wells, unplugged	35,000	48,000
Total abandoned wells	48,000	64,000
Percentage plugged	27	25

[a]Data from STRONGER review [4] and Plugged Wells Survey [3].
[b]Data from 2009 DMN annual report [6], Plugged Wells Survey [3], and Table 1.

Therefore, the following actions are recommended:

1. Approval of permits for conventional oil and gas development projects in New York should be reduced by 15 percent immediately until industry compliance with inactive well-plugging requirements can be demonstrated for a minimum of three consecutive years.
2. Oil and gas well transfer requests should be suspended immediately, until the DMN can re-evaluate financial security and bonding levels which will ensure that all declining oil and gas wells are plugged when they reach zero commercial production.
3. The state legislature should appropriate funding for the specific purpose of inspecting and plugging every well in the BOGPM standing inventory and priority plugging list.
4. New York should establish a program to register, inspect, and maintain abandoned oil and gas wells that have been plugged.
5. The New York State Bureau of Oil and Gas Regulation, Division of Mineral Resources, Department of Environmental Conservation should invite the Interstate Oil and Gas Compact Commission to conduct an updated state review.
6. Expansion of the state's petroleum industry into extraction of oil and gas from shale should be postponed until the above actions have been carried out.

Overall, the goal should be to establish a comprehensive plan for regulatory improvement, including progress on the issue of oil and gas well plugging and abandonment in New York.

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AUTHOR'S BIOGRAPHY

RONALD E. BISHOP has a B.A. in Chemistry from Youngstown State University and a Ph.D. in Biochemistry from The West Virginia University School of Medicine. Currently a lecturer in the Department of Chemistry and Biochemistry at the State University of New York at Oneonta, he is a Chemical Hygiene Officer listed with the National Registry of Certified Chemists. A member of the New York Academy of Sciences, the Union of Concerned Scientists, and Physicians, Scientists and Engineers for Healthy Energy, he actively maintains interests in chronic diseases, environmental challenges and national security. Ron can be reached at Ron.Bishop@oneonta.edu

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Direct reprint requests to:

Ronald E. Bishop
Department of Chemistry and Biochemistry
State University of New York, College at Oneonta
108 Ravine Parkway
Oneonta, NY 13820
e-mail: ron.bishop@oneonta.edu

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Features

ANALYSIS OF RESERVE PIT SLUDGE FROM UNCONVENTIONAL NATURAL GAS HYDRAULIC FRACTURING AND DRILLING OPERATIONS FOR THE PRESENCE OF TECHNOLOGICALLY ENCHANCED NATURALLY OCCURRING RADIOACTIVE MATERIAL (TENORM)

ALISA L. RICH
ERNEST C. CROSBY

ABSTRACT

Soil and water (sludge) obtained from reserve pits used in unconventional natural gas mining was analyzed for the presence of technologically enhanced naturally occurring radioactive material (TENORM). Samples were analyzed for total gamma, alpha, and beta radiation, and specific radionuclides: beryllium, potassium, scandium, cobalt, cesium, thallium, lead-210 and -214, bismuth-212 and -214, radium-226 and -228, thorium, uranium, and strontium-89 and -90. Laboratory analysis confirmed elevated beta readings recorded at 1329 ± 311 pCi/g. Specific radionuclides present in an active reserve pit and the soil of a leveled, vacated reserve pit included ^{232}Thorium decay series (^{228}Ra, ^{228}Th, ^{208}Tl), and ^{226}Radium decay series (^{214}Pb, ^{214}Bi, ^{210}Pb) radionuclides. The potential for impact of TENORM to the environment, occupational workers, and the general public is presented with potential health effects of individual radionuclides. Current oversight, exemption of TENORM in federal and state regulations, and complexity in reporting are discussed.

Keywords: reserve pit, radiation, Technologically-Enhanced Naturally Occurring Radioactive Materials (TENORM), Naturally Occurring Radioactive Materials (NORM), Barnett Shale, natural gas mining, fracking

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Reserve pits are commonly seen throughout areas of unconventional natural gas extraction. The purpose of the reserve pits (commonly referred to as pits, ponds, cellars, tanks, impoundments, etc.) is to hold the large quantities of water and drilling mud required for hydraulic fracturing ("fracking") operations. These pits also provide a depository for brine water that occurs naturally in natural gas deposits, drilling mud, drilling cuttings and hydraulic fracturing fluids. Hydraulic fracturing fluids can contain chemical additives (acids, bactericides, breakers, corrosion inhibitors, cross-linkers, emulsifiers, flocculants, foaming agents, proppants, scale inhibitors, surfactants) and cuttings (rock, soil and metal shavings excavated by the drill bit) which can contain technologically enhanced naturally occurring radioactive material (TENORM) [1, 2]. Previous research has identified ^{226}radium (^{226}Ra), ^{228}radium (^{228}Ra), and radon gas (^{222}Rn) as the predominant radionuclides in natural gas wastes from oil and gas drilling. The focus of existing regulation guidelines has been related to ^{226}Ra and ^{228}Ra, which have the potential to release radon gas into the atmosphere when these radioactive nuclides are brought to the surface through the oil and gas extraction processes [3]. The long half-lives of these two radium isotopes (^{226}Ra, 1,600 years; ^{228}Ra, 5.8 years) are particularly concerning given that they have been identified as abundant in saline and chloride-rich produced waters [4]. To date, few other radionuclides have been identified as associated with natural gas extraction, and fewer still have had regulatory guidelines developed for occupational or public health exposures.

Naturally occurring radioactive material (NORM) is terrestrial radiation distributed by nature throughout natural geologic formations. It is undisturbed radioactive material that exists in nature as background material, or at its in-situ location, whether at the earth's surface or subsurface. TENORMs are when naturally occurring radionuclides are transported by anthropogenic activity to where humans are present, thereby increasing exposure potential, which may result in concentrations enhanced above natural background levels [5]. As such, NORM transported or concentrated during exploration and mining of oil and gas is thereby reclassified, according to regulatory definition, as TENORM.

Both NORM and TENORM are clearly defined and distinct from radionuclides that are produced through nuclear reactions, nuclear explosions or nuclear accelerators (commonly referred to as "man-made, artificial, or anthropogenic"). The term NORM is often misused when applied to radioactive material introduced into the human environment by oil and gas exploration and mining processes.

Estimates of water needed for unconventional natural gas extraction are reported to range from one to five million gallons per well for initial well completion [6]. The use of up to 12 million gallons per well completion (one million gallons per stage) has been documented for the 12-stage open-hole completion systems [7]. Disposal of large quantities of chemical- and radionuclide-laden materials in wastewater is a known problem [8]. Reserve pits are commonly found in agricultural areas where the potential for crop and animal contamination is high. Animals drinking pit water, dust particles blowing onto soil and crops, and berms breaching (thus contaminating adjacent croplands) are all potential exposure pathways. If reserve pits are built with an aerator, aerosolized radioactive material can be further dispersed onto soil, crops, livestock, and humans. Deposition of reserve pit contents in county landfills and municipal water treatment facilities has elicited a public outcry of concern for environmental contamination and potential human exposure to harmful radioisotopes often present in the drilling mud and cuttings, since these facilities do not have the capability to test for or remove radioactive material from the waste stream [9-11]. Incorporation of reserve pit material into the earth's surface either by draining and leveling the reserve pit where it exists, and/or land farming the material into the ground in place or at other locations, may increase the potential for surface and drinking water contamination from percolation or migration of radionuclides into water bodies. A better understanding is needed to assess the potential effects that radionuclides may have on the health of cattle, on cattle productivity, and on agricultural products. The potential exposure to humans is from reserve pit contents via wind, and by consumption of crops and animal products that have taken up radioactivity, has not been established [12-17].

The purpose of this article is to present laboratory analysis of water and soil (sludge) analyzed for the presence of TENORM, obtained from two unrelated reserve pits located on agricultural land in the Barnett Shale (located in Texas) and used as holding ponds for unconventional natural gas mining and extraction processes. This study originated as part of a field study conducted as a preliminary exploratory investigation (Phase II) during a property transaction to ascertain if, in fact, any regulatory impact existed (such as the presence of radioactive materials in the reserve pits). Comparison of study findings to state and federal guidelines for TENORM material identifies the complexity in regulatory reporting and guidelines, and current voids in regulatory oversight.

EXPERIMENTAL METHODS

Field Sampling

Soil and water matrices from reserve pits in the core area of the Barnett Shale East Newark Field were obtained and analyzed for the presence of radionuclides (TENORM). Soil and water was collected from two separate site locations: 1) farmland that was once a reserve pit, which had been drained and leveled to the surrounding elevation; and 2) a reserve pit that, at the time of sampling, held drilling mud, water for hydraulic fracturing, processed water and/or cuttings. For the purpose of this report the drained reserve pit has been identified as Reserve Pit #1 (RP1) and the pit with fluid has been identified as Reserve Pit #2 (RP2). In total, four separate samples of water and soil were obtained, two from each sampling location, and identified by the laboratory as sludge due to high water content. Water was collected in clear plastic 500-ml containers with no preservative. Two sample points were selected for each pit based on each pit's use and the most likely impact resulting from surrounding exploration and extraction activities.

Samples in RP1 were obtained at a soil depth of 6 inches from the soil surface, since the RP1 pit had been drained and appeared to have the greatest potential to be relatively homogeneous from initial field investigation. This reserve pit was originally constructed with above-ground berms without any surface discharge outlet. Water could be pumped into the pit from an adjacent water well and could flow out of the pit only via its natural down-gradient seepage. Two samples were obtained along a line following the direction of the pit's down-gradient groundwater flow, which ultimately intersected with a flowing creek located near to and down-gradient from the pit.

RP2 is a typical triangular ranch pond with the triangle base side perpendicular to the downgradient flow line of the pond. A surface flow outlet is located at the center of the downgradient side. The samples were taken inside of the pond. Since cuttings and drilling mud settle to the bottom of ponds, efforts were made to obtain sludge/sediment samples from the pit bottom of RP2 along with water. Impact to or from the pit appeared to occur at either end of this down-gradient side (i.e., at the corners). Flow gradients dictated exploration and production impact would occur at the corners and then would flow from these corners down-gradient to the outfall. A sample was taken at one corner and a second sample was taken at the upstream pond side of the outfall. RP2 samples were collected from the pond's floor on the down-gradient side of the pit.

Initial observations indicated that impact from well mining extraction and injection materials appeared to be located on the upgradient side of each pond's downhill side. This observed material in the pit was considered likely to be from the geologic formations mined and materials injected. All samples were shipped to a certified radiological laboratory (American Radiation Services, Inc., Port Allen, LA) for analysis of radioactive isotopes by EPA method 901.1M (ARS-007/EPA901.1M). Radioisotope concentrations were reported in picocuries/gram (pCi/g). Reserve pit contents were analyzed for the radionuclides beryllium (^{7}Be), potassium (^{40}K), scandium (^{46}Sc), cobalt (^{60}Co), cesium (^{137}Cs), thallium (^{208}Tl), lead (^{210}Pb and ^{214}Pb), bismuth (^{212}Bi and ^{214}Bi), radium (^{226}Ra and ^{228}Ra), thorium (^{228}Th), uranium (^{235}U), strontium (^{89}Sr and ^{90}Sr), and total gamma, total alpha, and total beta radiation.

This study was designed to be an initial investigative field study performed for an industrial land transaction decision. Samples were not randomized, but selected to represent the most likely worst-case down-gradient impact point. Analysis of a control sample was not performed or authorized. Soil sample results were compared to findings of previous studies and to regulatory limits. However, inconsistencies in collection and analysis of specific radioisotopes in previous studies made comparison difficult and it was not easy to ascertain in many cases whether the samples exceeded expected baseline concentrations.

Reserve Pit #1 (RP1)

The location identified as Reserve Pit #1 (RP1) had originally been part of a reserve pond, but at the time of sampling had been drained and leveled to the original ground surface grade. The original reserve pit was a manmade pond of approximately 2.9 acres, whose depth was increased with berms to a height of six to seven feet above ground level. Soil in the drained and leveled area sampled (RP1 location) appeared to have been undisturbed and the pond material allowed to drain and settle naturally, incorporating back into the existing soil rather than being removed and disposed of offsite. The RP1 sampling sites chosen were at one time the reserve pit bottom material. The remaining reserve pit was still present at the time of sampling and was still in use as a water reservoir for mining operations. Soil and water samples taken at this location were identified as RP1.1-West and RP1.2-East. The RP1.1-West sample was obtained approximately 15 feet from the edge of the existing pit berm, and the RP1.2-East sample was obtained approximately 75 feet from the edge of the existing pit berm. The purpose of obtaining soil from this location was to examine if any radioactivity in the soil existed after the reserve pit had been drained and the land left fallow. The adjacent land was used as agricultural land, which at the time of sampling was growing livestock feed. Field notes taken at RP1 locations identified the soil to be homogeneous black clay with very little organic matter and high water content, believed to be related to a precipitation event a few days prior to sampling. The U.S. Department of Agriculture Natural Resource Conservation Service defines black clay as having slow infiltration rates, high runoff potential when wet, and high shrink swell potential [18].

Reserve Pit #2 (RP2)

At the time of sampling, Reserve Pit #2 was being used as a water reservoir for natural gas extraction and mining operations and was believed to have been used to hold drilling mud, processed water, water for hydraulic fracturing operations, and drill cuttings. RP2 encompassed approximately 11.3 acres. This pit was originally a manmade pond at ground level. The water level was high due to recent precipitation events with an area overflowing the banks of the pit into a neighboring stream. The overflow area led to a creek and had been graded and cemented to provide a controlled exit for overflow water to minimize water breaching the pit berm at various locations. Two separate samples were obtained at RP2: one was obtained inside the pit along the east edge at the overflow location (identified as RP2.1-North), inside the pit along the northeast edge; the second sample was obtained on the south end of the pit closest to the well pad site inside the pit (identified as RP2.2-South). The samples taken in the reserve pit consisted of both water, obtained from approximately 6 inches below the surface, and soil, obtained approximately 3 feet from the berm edge at the bottom of the pit.

The soil matrix at RP2 location was varied, with the presence of dark grey sticky clay soil, commonly referred to as black clay soils on the exterior of the pit and a light yellowish brown clay soil mixed with high very fine sand (<1 mm diameter) interior to the pit [20].

Field notes taken at the RP2 location identified a noticeable lack of any insects, fish, turtles, snakes or birds present in the or around the pit. The pit contained water grasses and reeds which are optimum breeding and cover areas for fish, snake and bird activity but no activity or signs of any feeding, nesting, or breeding activity were apparent.

RESULTS

Results of laboratory analysis of the four samples are presented in Table 1. The level of radioactivity is presented as pCi/g, and the minimum detection concentration (MDC) is the lowest concentration reliably detected by the laboratory equipment. The Analysis of Error is a numerical factor that represents error in the laboratory detection technique. This error factor is specific to each radionuclide and specific to each test. A zero is entered in the table if the radioactivity detected is below the MDC.

In general, specific radioisotopes detected included ^{40}K, elements of the ^{228}Th decay series (^{228}Th, ^{228}Ra, and ^{208}Tl), elements of the ^{226}Ra decay series (^{226}Ra, ^{214}Bi, ^{214}Pb, ^{210}Pb), and ^{90}Sr. With the exception of total alpha radiation for RP2-North, varying levels of total alpha, beta, and gamma radiation were detected in all samples. Interestingly, different portions of the same pit showed some differences in the radioactivity present.

It is important to note that not all radioisotopes present in sample RP1.1-West were also present in sample RP1.2-East, despite their close proximity and presumed homogeneous material. At the time of sampling, both locations had a high water content in the soil due to a recent precipitation event that may have been a contributing factor to variability in radioisotope concentrations. Sample RP1.2-East had a greater variety of isotopes recorded above laboratory minimum detection. Some of the isotopes present in this study are known to have very short half-lives (^{214}Bi, 20 minutes; ^{214}Pb, 27 minutes), and their presence is not easily captured. Their presence is likely to be due to the fact that they are part of a decay series and are continuously being generated. Other isotopes have longer half-lives and are more easily identified. In comparing results of the two RP1 locations, similar concentrations were noted for ^{40}K, ^{208}Ti, ^{214}Pb, ^{228}Ra, ^{228}Th. Notably, ^{210}Pb and ^{90}Sr were found in the RP1.1-West sample but not in the RP1.2-East sample, while ^{226}Ra was detected in the RP1.2-East sample but not the RP1.1-West sample. The gross gamma radiation (22.8 and 21.4 pCi/g),

Table 1. TENORMs Found in Reserve Pits

Isotope	RP1.1-west	RP1.2-east	RP2.1-north	RP2.2-soth
Beryllium (^{7}Be)	0 (0.45)	0 (0.48)	0 (0.45)	0 (0.53)
Potassium (^{40}K)	5.3 ± 1.3 (0.82)	5.5 ± 1.0 (0.41)	4.9 ± 1.1 (0.68)	3.6 ± 1.0 (0.67)
Scandium (^{46}Sc)	0 (0.076)	0 (0.078)	0 (0.064)	0 (0.58)
Cobalt (^{60}Co)	0 (0.090)	0 (0.064)	0 (0.10)	0 (0.69)
Cesium (^{137}Cs)	0 (0.086)	0 (0.062)	0 (0.72)	0 (0.62)
Thallium (^{208}Tl)	0.20 ± 0.07 (0.060)	0.27 ± 0.06 (0.041)	0.18 ± 0.06 (0.076)	0.19 ± 0.05 (0.04)
Lead (^{210}Pb)	1.7 ± 1.2 (1.4)	0 (0.94)	0 (1.1)	0.99 ± 0.65 (0.94)
Bismuth (^{212}Bi)	0 (0.56)	0 (0.46)	0 (0.56)	0 (0.54)
Bismuth (^{214}Bi)	0.45 ± 0.15 (0.17)	0.35 ± 0.30 (0.15)	0.36 ± 0.12 (0.15)	0.25 ± 0.12 (0.18)
Lead (^{214}Pb)	0.68 ± 0.63 (0.14)	0.70 ± 0.15 (0.14)	0.44 ± 0.12 (0.15)	0.40 ± 0.11 (0.13)
Radium (^{226}Ra)	0 (1.3)	2.4 ± 1.0 (1.2)	0 (1.5)	0 (1.1)
Radium (^{228}Ra)	0.66 ± 0.21 (0.26)	0.71 ± 0.13 (0.19)	0.51 ± 0.15 (0.25)	0 (0.24)
Thorium (^{228}Th)	0.72 ± 0.11 (0.087)	0.67 ± 0.11 (0.093)	0.64 ± 0.13 (0.12)	0.36 ± 0.10 (0.10)
Uranium (^{89}Sr)	0 (0.34)	0 (0.27)	0 (0.42)	0 (0.32)
Strontium (^{89}Sr)	0 (0.24)	0 (0.24)	0 (0.36)	0 (0.26)
Strontium (^{90}Sr)	0.30 ± 0.17 (0.24)	0 (0.24)	0.59 ± 0.26 (0.36)	0.29 ± 0.18 (0.26)
Total gamma	22.8	21.4	10.8	8.22
Total alpha	10.8 ± 3.3 (2.6)	16.4 ± 4.6 (3.1)	0 (3.6)	9.1 ± 3.4 (3.9)
Total beta	9.1 ±2.5 (1.8)	5.7 ± 2.0 (2.3)	1329 ± 311 (5.0)	5.8 ± 1.8 (1.7)

[a]The level of radioactivity is given in pCi/g and is shown with the analysis error. The numbers in parentheses are the Minimum Detection Concentrations (MDCs). In cases where the radioactivity measured was less than the MDC, a value of 0 is entered.

gross alpha radiation (10.8 ± 3.3 and 16.4 ± 4.6), and gross beta radiation (9.1 ± 2.5 and 5.7 ± 2.0) were not significantly different in the two RP1 samples.

Similar results were seen in individual radioisotopes in the second reserve pit RP2.1-North and RP2.2-South samples. ^{228}Ra was detected in RP2.1-North but not RP2.2-South, whereas ^{210}Pb was observed in RP2.2-South but not RP2.1-North. Total gamma radiation was similar in the two samples, but gross alpha radiation was observed only in RP2.2-South.

The most unexpected result of this study was the difference identified in gross beta radiation within the same pond. Gross beta radiation in the RP2.1-North sample was considerably higher than in the South sample (1329 ± 310 vs. 5.8 ± 1.8 pCi/g). The highest beta radiation levels were recorded near the spillway in pond RP2. Radionuclides are unstable isotopes of elements that undergo radioactive decay continually. Accumulation of sediment near the spillway may have accounted for the variability in beta radiation levels. Despite the close proximity of the soil samples within the pond, it is difficult to determine if the variability in concentrations reflects initial concentration in the soil, amount of material deposited in the pond, or lack of uniformity of soil chemistry. The fact that such variability can exist provides a complexity to single sample testing and may indicate that numerous samples within a single reserve pond are needed for accurate identification and quantification of TENORM, and proper representation of potential exposure to radioactive material.

DISCUSSION

Routine field study analysis of reserve pit contents from unconventional natural gas mining confirmed the presence of alpha, beta, and gamma radiation in the soil and water in reserve pits located on agricultural land. The specific gamma-emitting radionuclides identified included ^{40}K, ^{208}Tl, ^{210}Pb and ^{214}Pb, ^{214}Bi, ^{226}Ra and ^{228}Ra, ^{228}Th, and ^{90}Sr. Total beta radiation of 1329 pCi/g found in this study exceeded regulatory guideline values by more than 800 percent. Data from this limited field study showed elevated levels of alpha, beta, and gamma radiation to be present in reserve pit water/sludge material and also in the soil of a vacated reserve pit after draining and grading to original topographic levels. Based on the use of the pit, the presence of radioactive materials was not anticipated. Agricultural land adjacent to the drained reserve pit may have an increased potential for radioactive material taken up in livestock feed crops growing on the land due to wind transport, runoff, and migration of soil onto adjacent land. Deposition of radioactive material on land has been shown to have the potential to raise the radiation levels in soils above natural background levels increasing the potential for contamination of groundwater, soil, animals (domestic and migratory), and humans (through occupational and residential exposures). Historically, background levels of naturally occurring radiation prior to land use have not been measured, and little information on true background radiation actually exists. Texas has a long history of oil and gas exploration, which has involved the practice of land farming and surface deposition of mining material. Further, for decades, unrefined oil has been deposited on roadways for dust control. Assessment of true background radiation levels may not be possible given this historical misuse of the land. Total radiation was found to be elevated above known background levels for radiation, but information is limited and exposure pathways poorly understood. Regulatory guidance documents currently do not address many of the radionuclides found in this study and provide few directives and little guidance in determining the potential synergistic or additive effects of exposure to several radionuclides simultaneously, or the potential for an increased incidence of disease in animals or humans due to simultaneous multiple exposures. Expansion of urban drilling and the practice of siting reserve pits within residential communities will increase the potential for radiation exposure to the general public. Health complaints related to low-level radiation sickness, common to occupational workers, may be overlooked by medical professionals who do not anticipate an industrial-type exposure to patients living within these communities. Stricter guidelines may be warranted in order to protect the general public from increased levels of radiation in soil, water, and air.

Radionuclide Decay

Radioactive decay releases three types of radiation: alpha (α), beta (β) and gamma (γ) emissions. All three types of radiation are known to present health hazards. The radionuclides in TENORM that present the most concern in the human environment due to potential health impacts are isotopes of radium, thorium, and uranium and their decay products. ^{238}U decays by alpha emission into ^{234}Th, and ^{234}Th decays by beta emission to protactinium and then ^{234}U. ^{226}Ra, ^{214} Bi, and ^{210}Pb are all daughter isotopes of ^{238}U. ^{234}U decays by alpha emission into ^{230}Th, which decays by alpha emission into ^{226}Ra, ultimately decaying by beta emission into products seen in this study: ^{214}Pb, ^{214}Bi, and ^{210}Pb.

Environmental and Health Impact of Exposure to TENORM

There are numerous potential pathways of exposure to radioactive material from wastes extracted by natural gas exploration and mining. This study attempts to investigate only one form of waste, reserve pit contents. However, there are several potential pathways of exposure from this one waste form alone. The potential exposures to humans directly, whether occupational or residential, include: ground-water contamination, soil contamination, windborne particulates and aerosolized material, and fugitive air emissions from industrial processes. Another secondary potential exposure pathway exists in the ingestion of agricultural products (vegetables, dairy, and meat products) that may contain these radionuclides. This is an area that has received little attention or investigation.

The complexity in examining potential exposure is in quantifying how much radiation one has been exposed to, and the dose absorbed due to the exposure, and in accurately assessing the potential health impacts from multiple pathways. In order to properly assess exposure, exposures to all forms of radiation (alpha, beta, gamma) as well as to specific radioisotopes must be quantified and a thorough human health risk assessment performed. This is rarely done unless concentrations of a single radionuclide, for which regulatory guidelines have been established, greatly exceed those guideline levels; and for many radionuclides, no regulatory guideline levels have been established. Since many radionuclides have not been identified to be present in reserve pit wastes until recently, regulatory guidelines have not been established for non-occupational exposure limits.

The radionuclides discussed below were found in the samples taken in this study. Evaluating the potential health impacts of each radionuclide individually is important, in addition to evaluating the total decay (alpha, beta, and gamma) radiation, as the target organs and sites of damage can differ.

Health Effects of Potassium (^{40}K)

Potassium can be taken into the body through ingestion (food or water) or inhalation. ^{40}K is a naturally occurring radioisotope of potassium and widely distributed in nature (although normally at very low levels—0.015% in soil). It has a very long half-life of 1.3 billion years and decays primarily to ^{40}Ca by beta emission. External exposure to ^{40}K is generally to gamma radiation as ^{40}K decays to ^{40}Ar. Internal exposure to ^{40}K can pose a health hazard from ionizing beta and gamma emissions as it decays, with the potential to cause cell damage [19].

Health Effects of Radium (^{226}Ra, ^{228}Ra)

According to a U.S. Geological Survey (USGS) study (2009), little data exists on natural background concentrations of radium in the environment. Levels have been documented to increase as a result of human activity [20]. Radium levels in drinking water can become elevated in areas of mining. Exposure to radium may result in a variety of health effects such as tooth fractures, anemia, and cataracts. Chronic exposure to radium is known to increase the incidence of cancer in humans [21, 22]. Gamma radiation from radium is able to travel long distances through air before expending its energy, thus increasing exposure to the general population [23]. Radium is the radionuclide on which most of the drinking water and air regulations are set. It is the primary radionuclide identified in the past as a potential source of exposure to radon, a decay product of radium and a known lung carcinogen.

Health Effects of Strontium (^{90}Sr)

^{90}Strontium is a manmade isotope of strontium. ^{90}Sr is used as a subsurface radioactive tracer in mining processes and has a half-life of 29.1 years [24]. It is also present at low levels in surface soil due to fallout from previous atmospheric nuclear tests. It is hydrophilic, easily moving into and through the environment, adding to its ability to contaminate aquifers and drinking water sources [25]. It is known to be dangerous to the health of animals and humans. Exposure to ^{90}Sr can occur by inhalation of dust, eating food, or drinking water contaminated with the radionuclide. Grains, leafy vegetables, and dairy products can contain significantly high levels of ^{90}Sr [26]. The primary target organ for ^{90}Sr is bone. Strontium competes with calcium taken up in bone and can damage bone marrow, causing anemia. It can also cause cancer as a result of damage to cellular genetic material [27].

Health Effects of Thallium (^{208}Ti)

Thallium is absorbed by the human body through inhalation of dust particles and through ingestion of food and water. The nervous system is the primary target organ for thallium, which is known to cause trembling, nerve pains, paralysis, and behavioral impacts. Tiredness, depression, lack of appetite, and hair loss are all symptoms of chronic low-level Ti exposure. Thallium exposure to the fetus has been known to cause congenital disorders [28].

Health Effects of Thorium (^{228}Th)

Inhalation of thorium can adversely impact the respiratory system, causing damage that can eventually culminate as lung cancer. Exposure to thorium is known to cause pancreatic cancer, and thorium can be stored in bone, leading to bone cancer years after the initial exposure. People living in industrial areas near hazardous waste sites and near waste materials may be exposed to higher concentrations of thorium from wind-blown dust and consumption of food contaminated by the radionuclide [29].

Potential for Plant and Animal Exposure to TENORM

Contamination of soil and water from TENORM can expose workers and the general public to increased levels of radiation above normal background levels. Other important aspects of environmental contamination are through radiation taken up by the soil-plant system and exposure to animals through feedstock. Radionuclides in the soil can be directly intercepted by crops, which are then used as livestock feed, further increasing the potential for human exposure to increased levels of radiation through ingestion of milk and meat products.

In 2009, the U.S. Fish and Wildlife Service identified the importance of protecting migratory birds from exposure to reserve pit contents which can contain diesel, glycols, and heavy metals, but failed to recognize the potential for bird populations to be exposed to radioactive material deposited in reserve pits [30]. Some states with oil and gas regulations recommend netting or screening of pits or open tanks to prevent contamination of birds and wildlife. For example, Texas Administrative Code, Title 16, Part 1, Chapter 3, Rule §3.22(b) Protection of Birds requires that an operator "screen, net, cover or otherwise render harmless to birds" specific tanks and pits with "frequent surface film or accumulation of oil," but does not address the potential exposure of birds or cattle to radioactive materials. Proper reserve pit management techniques include fencing cattle out of areas to prevent livestock from drinking reserve pit contents. Consumption of reserve pit fluids by livestock has been documented to cause poisoning, abortions, birth defects, weight loss, contaminated milk, and death [31, 32].

Proper public health protection may involve stringent quality controls upon agricultural and farm practices, to prevent exposure to reserve pit waste materials, and controls on harvest and food movement to prevent exposures to workers and the public. The presence of radioactive materials in agricultural soils and food products can create financial hardship and a significant psychological impact for communities whose economic base consists of agricultural and food products. Many of the radionuclides have long half-lives, which can result in contamination of the soil for decades. This ultimately could affect the marketability of both the land and any products produced from the land for decades.

Federal Regulatory Oversight

Neither the U.S. Environmental Protection Agency (EPA) nor the U.S. Nuclear Regulatory Commission (NRC) has established federal regulations that directly govern NORM waste from the oil and gas industry. In fact, wastes containing NORM are generally not regulated by federal agencies with one exception, transportation. NORM-containing wastes with a specific activity greater than 2,000 pCi/g (70 Bq/g) are subject to U.S. Department of Transportation (DOT) regulations governing transport of radioactive materials [33]. The Occupational Safety and Health Administration (OSHA) has promulgated rules specific to occupational exposure to ionizing radiation [34] , which may be applicable to petroleum industry NORM management activities.

By definition, oil and gas industry NORM that does not exceed 0.05 percent uranium or thorium by weight or any combination, is not subject to regulatory control under the Atomic Energy Act of 1954 due to the fact it is not a source material, special nuclear material, or by-product material [35].

The Low-Level Radioactive Waste Policy Act as amended in 1986 provides guidance to states on disposal of low-level radioactivity material, like the waste material generated from oil and gas activities, but does not include oil and gas NORM waste. NORM wastes generated during the exploration, development, and production of crude oil, natural gas, and geothermal energy have been categorized by the EPA as "special wastes" and are currently exempt from federal hazardous waste regulations under Subtitle C of the Resource Conservation and Recovery Act (RCRA) by the Bevill Amendment and are not considered a listed or characteristic waste. The Superfund Amendments and Reauthorization Act listed none of the constituents of NORM as "extremely hazardous substances." The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) lists radionuclides as hazardous substances because the CAA (Clean Air Act) lists them as hazardous air pollutants. Oil and gas waste streams that may contain NORM are exempt under RCRA and therefore considered not hazardous substances under CERCLA, although individual radioisotopes might be. Reportable Quantities (RQs) are one pound of radionuclides (cumulative), or concentrations expressed in curies for individual radionuclide, whichever is less (40 CFR 302.4).

In 1989 EPA issued a final regulation covering RQs for radionuclides. EPA used 1, 10, 100, 1000, and 5000 pounds as RQs for non-radionuclides and 0.001, 0.01, 0.1, 1, 10, 100, and 1,000 Curies (Ci) as RQs for radionuclides. Release values for approximately 760 radionuclides were calculated for each of four human health intake pathways. The lowest pathway release value for each radionuclide was selected and then rounded down to the nearest decade to set the RQ for each radionuclide. Radionuclides not having published intake limits were assigned an RQ of 1 Ci, based on the observation that 91 percent of the radionuclides being studied were below the 1 Ci level [36]. These RQ are not applicable to oil and gas exploration as a result of the RCRA Bevill Amendment and its relationship to CERCLA.

The EPA under the CAA developed National Emission Standards for Hazardous Air Pollutants (NESHAPs) specific to radionuclide emissions for several sources, but not for industrial activities that include NORM generated by the oil and gas industry.

The EPA under the provisions of the Safe Drinking Water Act (SDWA) regulates the following radionuclides in drinking water: (adjusted) gross alpha emitters, beta particle and photon (gamma) radioactivity, ^{226}Ra and ^{228}Ra (combined), and uranium. The EPA established drinking water standards for several types of radioactive contaminants: $^{226/228}$Ra (5 pCi/L); beta emitters (4 mrems); gross alpha standard (15 pCi/L); and uranium (30 µg/L).

State Regulatory Oversight

NORM is subject primarily to individual state radiation control measures and varies across the nation. "Section 651(e) of the Energy Policy Act of 2005 gives NRC jurisdiction over discrete sources of NORM by redefining the definition of source material" [37]. For example, the State of Texas has three agencies are responsible for regulating different aspects of NORM. In Texas, NORM is regulated under the Texas Radiation Control Act (TRCA) as follows:

- The Texas Department of State Health Services (TDSHS), Radiation Control, has jurisdiction over the receipt, possession, use, treatment and storage of NORM (TDSHS NORM Licensing).
- "The Railroad Commission of Texas (RRC) has jurisdiction of handling and disposal of NORM wastes produced during the exploration and production of oil and gas (RRC rules for NORM)" [37], and disposal by the owner through on-site land farming and/or injection well. "The Texas Commission on Environmental Quality (TCEQ) has jurisdiction over the disposal of other NORM wastes" [37].

Under such a system, the Texas Administrative Code (TAC) defines exemptions for persons (parties/agencies) who receive, possess, use, process, transfer, transport, store, and commercially distribute NORM; that is, an exemption does not need to be licensed or is not regulated since NORMs are not hazardous waste streams. Often these exemptions are based on the NORM concentration of the waste stream being below a certain activity level (pCi/g) or radiation level (microRoentgens per hour μR/hr). Radium radionuclides are generally the measured standard for multiple radionuclide waste streams, while a higher exemption threshold is used for an individual radionuclide. This system requires the determination of nuclide concentration or emission only when a disposal permit is sought. Ponds used to store and receive waters from drilling, well rework, and hydraulic fracturing operations can be filled without determining radionuclide release or impact since they are not technically considered hazardous waste and no disposal permit is required.

The environmental management of lands contaminated with naturally occurring radioactive materials will require threshold guidance levels to be established to indicate when action is required. Successful management will need federal and state authority to enforce such threshold guidance levels. Unless regulatory loopholes are closed, testing, monitoring, and reporting of radionuclide release to the environment above existing background will continue, resulting in more human and environmental exposure. Guidelines for NORM/TENORM should correspond to levels of naturally occurring radionuclides in the environment at which it is practical to distinguish the radionuclides resulting from human activities from those in the undisturbed natural background. In 2008, the National Council on Radiation Protection and Measurements summarized the issue of radiation exposure and public health in the following statement: "There is a need to address public health concerns and to provide guidance on the cleanup and potential reuse of lands contaminated with NORM or technologically-enhanced NORM (TENORM). Although there are environmental cleanup standards in place for manmade radioactive contamination, there are no consistent federal or state regulatory controls or environmental management policies for NORM or TENORM contamination resulting from industrial practices associated with processing natural metal and mineral resources" [35].

Recommendations

Historically, ^{226}Ra and ^{228}Ra have been tested for in water and guidance levels set with the intention of protecting people from exposure to radon gas. The findings of this study raise the question of whether radium, a single radionuclide, is the proper indicator for assessing radiation exposure levels to the general public, given the potential for the vast amount of radioactive waste, and number of radionuclides, produced from oil and natural gas exploration and mining that may be present in reserve pits. Current regulations require that ^{226}Ra and ^{228}Ra combined exposure levels not exceed 5 pCi/g, averaged over 100 m^2, identifying radon as the primary emission of concern [39]. The Texas RRC Commission can issue a permit for the burial of oil and gas NORM waste "if, prior to burial, the oil and gas NORM waste has been treated or processed so that the radioactivity concentration does not exceed 30 pCi/g ^{226}Ra and ^{228}Ra or 150 pCi/g of any other NORM nuclide" [40]. These limits were not established with the support of public health/medical professionals nor based on potential human health impacts of cumulative exposures to multiple radionuclides. The total beta radiation found in one sample (RP2.1-North) of this study of 1329 pCi/g exceeds regulatory guideline values by more than 800 percent. However, individual radionuclides did not exceed existing regulatory guidelines. Data from this limited field study showed that elevated levels of alpha, beta, and gamma radiation were present in reserve pit water/sludge material and also in the soil of a decommissioned reserve pit. Evaluating the single radionuclide radium as regulatory exposure guidelines indicate, rather than considering all radionuclides, may indeed underestimate the potential for radiation exposure to workers, the general public, and the environment.

Limitations to this study include the small sample size and limited analysis of reserve pit contents. The study does not make the assumption that all reserve pits contain radioactive materials. The study does not imply that all reserve pit contents are disposed of by land farming (either onsite or offsite) or postulate the extent to which contaminated material is incorporated back into the earth. Comparison of radionuclide levels found in this study to existing regulatory levels was difficult since regulatory guidelines have been established for only a few radionuclides. Furthermore, TENORM waste has been excluded from many regulatory guidelines and from regulatory oversight. Future studies are needed to evaluate what percentage of reserve pits are actually used for deposition of radioactive materials. Further studies are needed to understand how radioactive materials transfer to vegetation and animal products and the uptake mechanisms of those materials through the food chain. The long half-lives that are intrinsic to many radionuclides are a major concern for future generations. Further research needs to be done to understand what exposure levels can be anticipated given the complex interactions within the physical and chemical components of soil and the lack of uniformity of soil chemistry.

As the United States goes forward with the expansion of drilling natural gas reservoirs (especially drilling in shale, which requires hydraulic fracturing with millions of gallons of water and producing nearly equal amounts of flowback), it is imperative that we obtain better knowledge of the quantity of radioactive material and the specific radioisotopes being brought to the earth's surface from these mining processes. Proper regulation of surface deposits and disposal of wastes can prevent elevation of natural levels of radiation and increased exposure of animals and humans to potentially harmful levels of radioactivity. It is essential that the public health community be consulted when establishing future regulatory guidelines. Materials classified as exempt under current regulations should be reviewed given the potential for adverse health effects from radiation exposure to the general public and with continued growth of urban drilling.

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ERNEST CROSBY was a Professor of Civil and Environmental Engineering with the University of Texas at Arlington for 28 years. He has 43 years consulting experience with the U.S. Army Corps of Engineering, Federal Highway Administration (FHWA), Department of Transportation (DOT), and Urban Mass Transportation Administration (UMTA). Send him email at eccrosby@transystems.com

ALISA RICH is an Adjunct Assistant Professor at the University of North Texas Health Science Center, School of Public Health, Department of Environmental and Occupational Health where she teaches graduate level Toxicology and Human Health Risk Assessment. Send her email at rich@wolfeagleenvironmental.com

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Direct reprint requests to:

Dr. Alisa Rich
Assistant Professor
Dept. of Environmental and Occupational Health
UNT Health Science Center School of Public Health
3500 Camp Bowie Blvd.
Fort Worth, TX 76107
e-mail: Alisa.Rich@unthsc.edu

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Features

COMMUNITY-BASED RISK ASSESSMENT OF WATER CONTAMINATION FROM HIGH-VOLUME HORIZONTAL HYDRAULIC FRACTURING

STEPHEN M. PENNINGROTH
MATTHEW M. YARROW
ABNER X. FIGUEROA
REBECCA J. BOWEN
SORAYA DELGADO

ABSTRACT

The risk of contaminating surface and groundwater as a result of shale gas extraction using high-volume horizontal hydraulic fracturing (fracking) has not been assessed using conventional risk assessment methodologies. Baseline (pre-fracking) data on relevant water quality indicators, needed for meaningful risk assessment, are largely lacking. To fill this gap, the nonprofit Community Science Institute (CSI) partners with community volunteers who perform regular sampling of more than 50 streams in the Marcellus and Utica Shale regions of upstate New York; samples are analyzed for parameters associated with HVHHF. Similar baseline data on regional groundwater comes from CSI's testing of private drinking water wells. Analytic results for groundwater (with permission) and surface water are made publicly available in an interactive, searchable database. Baseline concentrations of potential contaminants from shale gas operations are found to be low, suggesting that early community-based monitoring is an effective foundation for assessing later contamination due to fracking.

Keywords: high-volume horizontal hydraulic fracturing, groundwater contamination, certified baseline testing, volunteer stream monitoring partnerships, fracking

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The risk of contaminating surface water and groundwater as a result of shale gas extraction activities utilizing high-volume horizontal hydraulic fracturing (HVHHF) technology has not yet been assessed [1]. An abundance of evidence suggests that contamination can and does occur, including academic studies [2, 3], agency reports [4], accidents [5,6], regulatory violations [7, 8], interviews with sick homeowners near gas well pads [9, 10], and out-of-court settlements with confidentiality agreements between homeowners and gas companies [11]. There is also evidence to suggest that contamination may occur along natural subsurface pathways and not necessarily as a consequence of HVHHF [12]; however, probability bounds analysis points to disposal of HVHHF waste as the greatest risk to water [13]. Despite abundant indications of adverse effects on human health and the environment, conventional risk assessment methodologies have not yet been applied to the shale gas industry, and this has resulted in a void in public health protection on the part of the state and federal governments [14]. Here we explore one possible reason for this void: a lack of government data on water quality. We describe how rural homeowners and communities in New York's Southern Tier region are attempting to fill data gaps and create baselines for risk assessment purposes before HVHHF is approved in New York.

The nonprofit Community Science Institute (CSI) was founded in 2000 and has operated a state-certified water quality testing laboratory in Ithaca, New York, since 2003 (New York State Department of Health–Environmental Laboratory Approval Program (NYSDOH-ELAP) ID# 11790). With financial support from local governments in Tompkins County, CSI partners with seven groups of volunteers who perform synoptic sampling of Cayuga Lake tributary streams— that is, volunteers collect samples at specified locations within a few hours of one another, allowing comparison of water quality values throughout the area sampled. These volunteers collect approximately 350 samples a year and transport them to the CSI lab, where they are analyzed for bacteria, phosphorus and nitrogen nutrients, suspended sediment, minerals, and other parameters. Results are made publicly available in an interactive, searchable data archive at www.communityscience.org/database, which currently contains over 30,000 certified water quality data items. We have been recruiting, training, and providing technical support for community groups to conduct long-term baseline stream monitoring in New York's gas-rich Southern Tier region since 2010. Further, with the prospect of HVHHF in New York, CSI began offering pre-drilling baseline testing of private drinking water wells in 2009. The existence of pre-drilling data should make it possible to detect whether groundwater and surface water are impacted by HVHHF and to begin the essential task of conducting formal risk assessments using methodologies that are widely accepted in the public and private sectors [15-17].

METHODS

For the Cayuga Lake watershed, surface water samples (from Six Mile Creek and its tributaries) were analyzed for parameters including a set of gas well "signature chemicals." For the Upper Susquehanna River Basin, samples from Catatonk Creek and Cayuta Creek were analyzed for "red flag" indicators of water quality. Finally, samples of untreated groundwater, collected by CSI from private wells across the Utica and Marcellus Shale regions within New York, were analyzed for gas well "signature chemicals."

Streams in Cayuga Lake Watershed

Trained groups of volunteers perform synoptic sampling of Cayuga Lake tributary streams independently of each other up to five times per year under base-flow and stormwater conditions (Figure 1). Data collection began between 2002 and 2009, depending on when a monitoring group was established for a tributary of Cayuga Lake. Each group collects grab samples at four to 23 fixed locations, depending on the size of the watershed. Volunteer teams deliver samples to the CSI lab in Ithaca with chain-of-custody documentation. Certified analyses are performed within prescribed holding times and using methods approved by NYSDOH-ELAP. Certified results are posted in CSI's online searchable data archive at www.communityscience.org/database. While focused primarily on impacts from agriculture and residential development, such as nutrients and pathogenic bacteria, Cayuga Lake watershed monitoring also includes a number of parameters that overlap with gas well "signature chemicals": pH, alkalinity, total hardness, turbidity, total suspended solids, chloride, and specific conductance. Monitoring of Cayuga Lake tributaries is guided by a Quality Assurance Project Plan (approved by the New York State Department of Environmental Conservation (NYSDEC).

Expanded monitoring of gas well "signature chemicals" in the Cayuga Lake watershed began in 2012, with financial support from the Tompkins County Legislature. Volunteer teams collect additional samples once a year at a subset of their regular synoptic monitoring locations for certified laboratory analyses of barium, strontium, gross alpha and gross beta radioactivity, total dissolved solids, chemical oxygen demand, sulfate, and methylene blue active substances (MBAS) (anionic surfactants). The list of "signature chemicals" recommended by CSI to screen for gas well impacts on surface water quality is similar to that for groundwater quality (as listed in Table 7 below) and is based on general knowledge of HVHHF technology and on analyses reported in the NYSDEC's 2011 draft Supplemental Generic Environmental Impact Statement of the frequencies and concentrations of chemicals in flowback from gas wells in Pennsylvania and West Virginia [18]. A moderate degree of redundancy is included, such that screening for several of the major characteristics of flowback

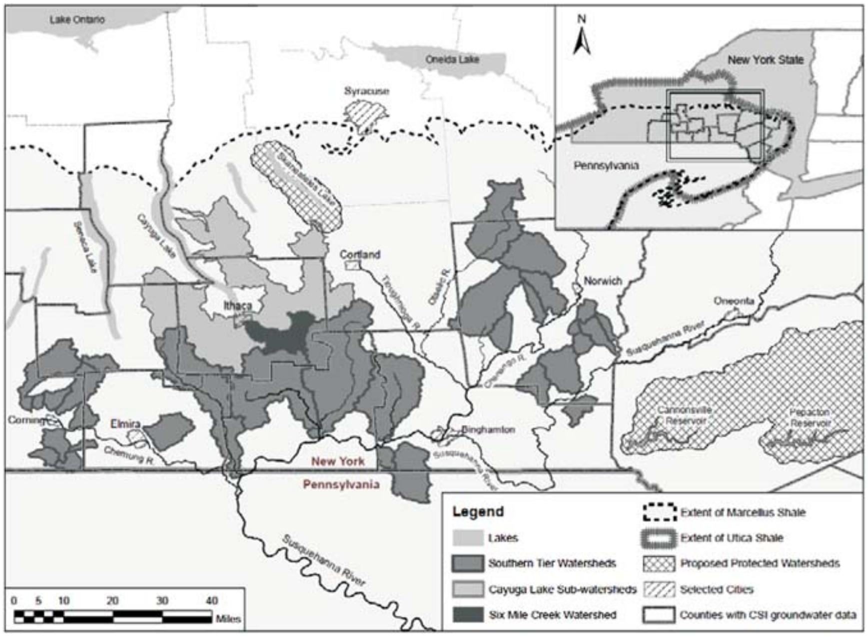

Figure 1. Map showing CSI-volunteer baseline water quality monitoring activities in the Marcellus and Utica Shale regions. Shaded areas are watersheds where volunteers monitor streams in the Finger Lakes and Upper Susquehanna River regions. The 13 counties where CSI has collected groundwater data from private drinking water wells and where clients have given permission to incorporate their results into CSI's regional groundwater baseline are shown in outline. The crosshatched areas—so-called Proposed Protected Watersheds—are areas feeding unfiltered drinking water systems in Syracuse and New York City where the New York State Department of Environmental Conservation proposes to exclude high-volume hydraulic fracturing per Section 6.1.5.4 in its 2011 draft Supplemental Generic Environmental Impact Statement, which states that "high volume hydraulic fracturing operations within the NYC and Syracuse watersheds pose the risk of causing significant adverse impacts to water resources" [18].

is based on two or more related tests. Streams are not tested for methane and volatile organic compounds (VOCs) as concentrations are expected to be low and difficult to detect due to volatilization.

Streams in Upper Susquehanna River Basin

CSI initiated a "red flag" volunteer stream monitoring program in 2010, training and partnering with groups of volunteers in several Southern Tier counties where HVHHF is most likely to take place if approved in New York

(Figure 1). Groups of 15 to 30 of these volunteers monitor local streams that together drain 250 to 400 square miles. Each group is organized in teams of two to six, and each team takes responsibility for monitoring a specific set of stream locations once a month for five red-flag indicators of water quality: temperature, pH, dissolved oxygen, specific conductance, and total hardness. Teams are required to calibrate their portable test kits and meters prior to each monitoring event, using standards provided by the CSI lab, and to perform at least one set of duplicate tests for each red-flag indicator. Teams submit original field data sheets to CSI in hard copy. Results that meet data quality criteria for accuracy and precision (Table 1) are entered in the open searchable data archive on the CSI website. For added quality control, red-flag groups are asked to split all samples with CSI's certified lab during the first two months of their monitoring program, and one sample per team per quarter thereafter. Groups are encouraged to seek funding from local sources and to contract with CSI or a local certified lab to conduct expanded baseline testing of gas well "signature chemicals" at as many stream locations as possible at least once a year, similar to the expanded baseline testing in the Cayuga Lake watershed made possible by the Tompkins County Legislature.

Stream water quality data presented for comparison with CSI data (see Tables 2, 3, and 4) were extracted from the U.S. Geological Survey's (USGS's) National Water Information System (NWIS) and the U.S. Environmental Protection Agency's (EPA's) STORET (STOrage and RETrieval) Data Warehouse. All data were filtered to extract only base flow sampling events. The NWIS data available for Six Mile Creek were from three sites on the main stem and two sites on tributaries. STORET data were for four sites in the Catatonk Creek watershed and five sites in the Cayuta Creek watershed.

Groundwater in the Marcellus and Utica Shale Regions

CSI's certified lab offers fee-for-service baseline testing of private residential wells for gas well "signature chemicals" in groundwater. Baseline testing provides a form of insurance for homeowners in the event their water supply is contaminated and the contamination can reasonably be traced to nearby shale gas extraction activities. Clients are advised that the recommended baseline is designed as a broad screen that attempts to balance cost against the probability of identifying a "chemical signature" of gas well contamination, and that more extensive testing for specific carcinogenic, neurotoxic, terratogenic, endocrine-disrupting, and radioactive chemicals is indicated if post-drilling changes in results for some, but not necessarily all, "signature chemicals" provide reasonable evidence that contamination has occurred. Residential groundwater well samples are collected by CSI staff onsite, at a point that precedes any treatment system, such as a filter or a water softener, with chain-of-custody documentation to the CSI lab and subcontract labs.

Table 1. CSI Acceptance Criteria[a] for "Red-Flag" Stream Monitoring Results Reported by Volunteer Teams on Hard-Copy Field Data Sheets

	Temperature (°C)	pH[b]	Dissolved oxygen[c] (mg/L)	Specific conductance[d] (μS/cm)	Total hardness[e] (mg $CaCO_3$/L)
Precision—acceptance of reported duplicates	± 1°C	± 0.5 pH Units	Greater of ± 20% or 0.4 mg/L[c]	± 10%	Greater of ± 20% or 8 mg/L[e]
Accuracy—acceptance of reported standards	Calibration[f]	± 0.5 pH Units	No calibration necessary[c]	± 1%	± 20%[e]
Splits—comparison with certified lab	N/A	N/A[b]	N/A[c]	± 20%[d]	± 20%[e]

[a]Red-flag teams of two to five volunteers typically monitor five or fewer stream locations once a month. For quality control, teams are required to perform one standard and/or one duplicate, depending on the analyte. Quality controls are performed once per monitoring event. Red-flag teams are required to split samples with CSI at the rate of one location per quarter, or four splits per year, for certified analyses of specific conductance and total hardness. In the first months of a new red-flag monitoring program, volunteer teams are required to split one sample from every location in order to establish baselines for specific conductance and total hardness and to facilitate trouble-shooting by CSI staff if the team is having difficulty performing the tests.

[b]pH is measured streamside using a wide range pH test kit accurate to 0.5 pH units over the pH range 3.0 to 10.5, LaMotte code 5858, or a hand-held meter, Hanna Instruments model HI98103. The CSI lab provides volunteer teams with an unlimited supply of pH 7.0 standard. Split samples are analyzed if requested by volunteers and if split is received by lab for analysis within 48 hours of sample collection as the frequency of spontaneous changes in pH is observed to increase after 48 hours.

[c]Dissolved oxygen is measured using test kit, LaMotte code 5860-01, based on the modified Winkler method approved by EPA. Test is accurate if performed correctly. Measurement range for titrator is 0.2-10.0 mg/L and is readily extended to higher concentrations by continuing to add titrant until the endpoint is reached. Limit of quantitation (sensitivity) is 0.4 mg/L or two times the smallest unit of measurement on the titrator. Results are considered reportable to the limit of quantitation, assuming quality control criteria are met, consistent with certified lab protocol. At low concentrations, precision is acceptable if duplicates agree within the limit of quantitation, 0.4 mg/L. Split samples are analyzed if requested by volunteers and if split is fixed streamside and received by lab within 8 hours of sample collection, as per EPA protocol.

[d]Specific conductance is measured using Hanna Instruments hand-held meter model HI 98303, range 1 to1,999 μS/cm. CSI lab provides volunteer teams with an unlimited supply of 353 NTU specific conductance standard. Volunteer teams may hold stream samples at 4°C and perform the specific conductance test up to 28 days after sample collection, as per certified lab holding time.

[e]Total Hardness is measured using LaMotte kit 4482-DR-LT-01. Measurement range for titrator is 4 to 200 mg/L as calcium carbonate equivalents (CCE) and is readily extended to higher concentrations by continuing to add titrant until the endpoint is reached. Limit of quantitation (sensitivity) is taken to be 8 mg/L CCE, or two times the smallest unit of measurement on the titrator. Results are reportable to the limit of quantitation, assuming quality control criteria are met, consistent with certified lab protocol. At low concentrations, precision is acceptable if duplicates agree within the limit of quantitation, or 8 mg/L CCE. The CSI lab provides teams with an unlimited supply of 100 mg/L CCE or 20 mg/L CCE total hardness standard, depending on sampling sites. Teams may hold samples at 4°C and perform the total hardness test up to 14 days after sample collection, as per certified lab holding time.

[f]Volunteers are instructed to calibrate their thermometers based on the temperature of boiling water equal to 100°C.

While onsite, CSI staff ask clients for voluntary written permission to incorporate their test results in CSI's data pool on groundwater quality in the Marcellus and Utica Shale regions in upstate New York. Approximately 85 percent of clients have granted permission to date. Groundwater data will be incorporated into CSI's online interactive data archive by 2013. Data will be pooled in one-mile grid squares to protect homeowners' privacy. Each grid square will link to 20 separate graphs, one for each "signature chemical" (Figure 2). The grid squares will allow chemical concentrations to be mapped, providing enough information to spot spatial trends in "signature chemicals" relative to nearby gas wells or other potential sources of contamination, while protecting homeowners' privacy. As the map in Figure 2 shows, sample wells tend to occur in loose clusters, probably because private clients often find out about CSI through word of mouth, and because CSI splits travel costs among clients whose wells we sample in the same area on the same day. Other than splitting travel costs, CSI does not offer financial incentives. Clients pay 100 percent of the cost of baseline tests themselves. Therefore, pooled groundwater results comprise a near-random sample of groundwater quality in the Marcellus and Utica Shale regions in rural Southern and Central New York.

Groundwater quality data for New York State were downloaded from NWIS from 1990 to September 2012. ArcGIS [19] was used to select groundwater sampling sites in the area of New York State underlain by the Utica and Marcellus shale gas formations. Within the shale gas formations, a subset of sites was selected that corresponds more closely with the 13 counties in upstate New York where CSI has performed baseline testing on private wells: Otsego, Tompkins, Chenango, Delaware, Steuben, Tioga, Schuyler, Broome, Chemung, Yates, Schoharie, Seneca, and Sullivan. Results were averaged if a well was sampled more than once. A geographic information system (GIS) layer representing urban centers, residential areas, and industrial zones was created as a way to evaluate the distribution of the USGS's groundwater monitoring sites.

The CSI Database: A Tool for Community-Based Risk Assessment

Placing water quality data in the public domain and facilitating its analysis and use by stakeholders is central to the Community Science Institute's nonprofit mission of empowering communities to understand local water resources and manage them sustainably. The CSI data archive at www.communityscience.org/database is an integral feature of community-based risk assessment because it makes it possible for any member of the public, free of charge, to view, search, download, and analyze surface water data developed in collaboration with our volunteer stream monitoring groups as well as groundwater data belonging to our private clients who voluntarily agree to include their test results in CSI's anonymous groundwater data pool. CSI's database structure has evolved from a

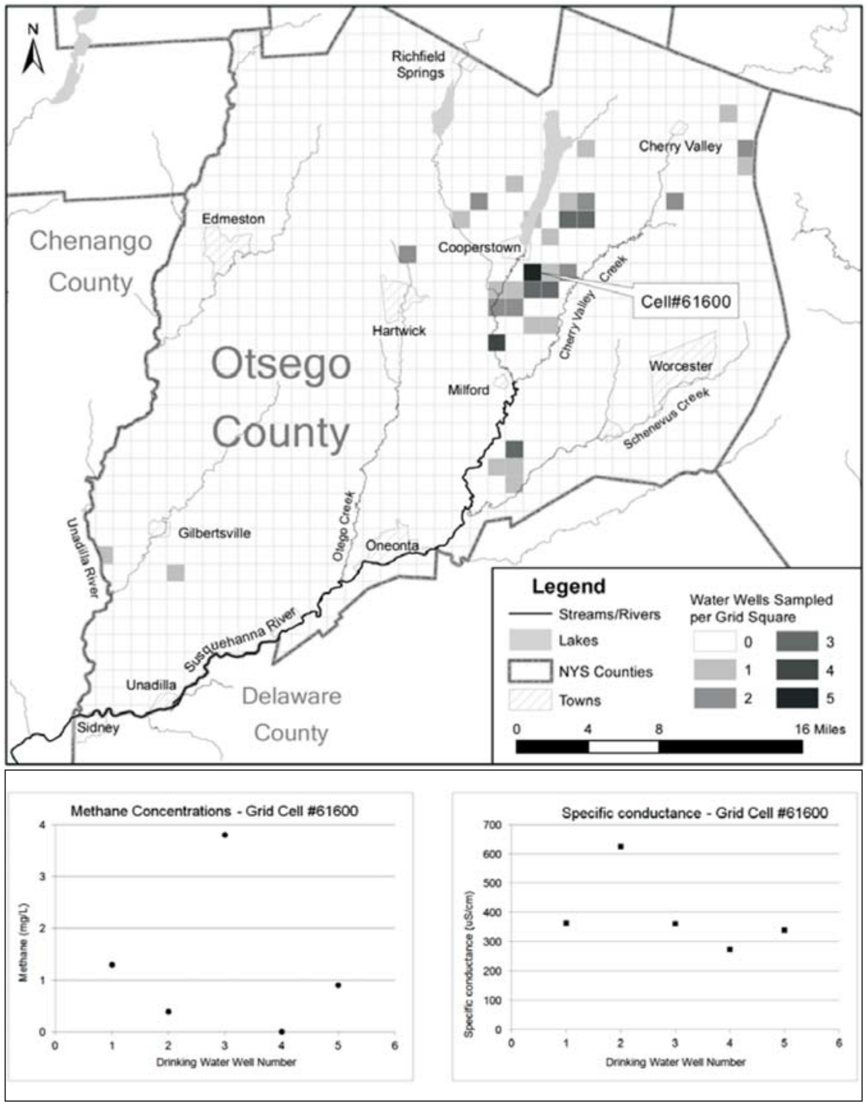

Figure 2. Example map and graphs illustrating presentation of regional groundwater baseline data planned for CSI website in 2013. The drinking water wells sampled by CSI in Otsego County are aggregated by one-mile grid square (total wells = 65). Methane and specific conductance data are grappled for one-mile grid square #61600.

Microsoft Excel-based approach, to a web-based architecture using the PHP scripting language and an SQL database back-end, and finally since 2011 to a Ruby on Rails® platform, chosen for its efficiency in building web applications. Visitors are provided with interactive tools to access over 30,000 data items linked to maps and graphs and to use a powerful querying mechanism to search the archive and export raw data. As a scalable archive, the CSI database is capable of organizing and presenting surface water and groundwater data from geographic areas of any size, including individual monitoring locations, watersheds, regions, countries, and continents. One hundred percent of the raw data produced by volunteer-CSI stream monitoring partnerships is made available to the public on the CSI website. Surface water data is searchable by region, stream, location, date, "signature chemical," and flow conditions. Pooled groundwater data shared by private clients will be incorporated into the database by 2013. Groundwater data will be searchable by region, county, one-mile grid square and "signature chemical" (see Figure 2).

RESULTS AND CONCLUSIONS

Surface Water Monitoring in Partnership with Groups of Trained Volunteers

Streams in Cayuga Lake Watershed

Baseline stream monitoring for an expanded list of gas well "signature chemicals" is in progress at this writing (October 2012). As noted above, although CSI's volunteer monitoring partnerships in this watershed since 2002 have focused on impacts from agriculture and residential development, there is some overlap between CSI's traditional sampling parameters and gas well "signature chemicals." Beginning in 2012, additional gas well "signature chemicals" are being tested once a year at a subset of Cayuga Lake watershed monitoring locations (see Methods). As a representative dataset for streams in the Cayuga Lake watershed, selected certified test results for Six Mile Creek and tributaries, downloaded through the data query interface for the CSI database at http://www.communityscience.org/database/entries, are summarized in Table 2 and compared to available data from the NWIS database. Median values are in good agreement considering CSI volunteers and agency staff sampled different locations on Six Mile Creek. As a preliminary estimate of variability in the CSI data set, the coefficient of variation was calculated for specific conductance under base-flow conditions for each of the 14 monitoring locations on Six Mile Creek, as follows. The data query interface in the CSI database was used to select the time period (2004-2012), monitoring region (Cayuga Lake watershed), monitoring set (Six Mile Creek), analyte (specific conductance), flow conditions (base flow), and test location (lab). The filtered data were

Table 2. Comparison of Selected "Signature Chemical" Indicators of Water Quality Under Base Flow Conditions[a] in Six Mile Creek and Tributary Streams as Measured by CSI's Certified Lab in Stream Samples Collected Synoptically by Volunteers[b] and by the U.S. Geological Survey (USGS)

	Data from certified CSI lab analyses of samples collected by Six Mile Creek volunteer group in 23 synoptic sampling events at 15 stream locations[c]			USGS data[d]
Parameters	Min	Max	Median (*n*)	Median (*n*)
Alkalinity (mg $CaCO_3$/L)	10.3	165	92.3 (299)	79 (14)
Barium (mg/L)[e]	0.017	0.056	0.0435 (8)	no data
Calcium hardness (mg $CaCO_3$/L)	19	89	71 (13)	no data
Chloride (mg/L)	3.54	57.8	18.6 (312)	19.7 (18)
Gross alpha radioactivity (pCi/L)[e]	0.22	1.55	0.595 (8)	no data
Gross beta radioactivity (pCi/L)[e]	0.97	3.83	1.69 (8)	no data
Total hardness (mg $CaCO_3$/L)	10.3	183	108 (312)	120.5 (18)
pH	6.75	8.85	7.5 (312)	8 (17)
Total nitrogen (mg/L)[f]	non-detect (< 0.11)	1.754	0.4 (291)	0.545 (15)
Total suspended solids (mg/L)	non-detect (< 0.625)	85	2.05 (311)	no data
Specific conductance (μS/cm)	58	450	254.5 (312)	297.5 (20)
Strontium (mg/L)[e]	0.045	0.108	0.085 (8)	no data
Sulfate (mg/L)	4.4	17.4	10.25 (139)	11.7 (18)
Total dissolved solids (mg/L)[e]	100	180	161.5 (8)	173 (17)
Turbidity (NTU)	0.38	81.2	4.48 (312)	no data

[a]Base flow is defined as a flow equal to or less than two times the historic median as recorded by the U.S.GS gauging station on Six Mile Creek at Bethel Grove for the day of a synoptic sampling event. The Six Mile Creek volunteer group performs on average three base flow and two stormwater sampling events per year.

[b]A "synoptic sampling event" or "synoptic monitoring event" is defined as one in which a group of volunteers collect samples at specific locations on the same day within a few hours of each other in order to facilitate comparison of water quality values throughout the sampled drainage area. In the CSI database (www.communityscience.org/database), "synoptic monitoring location" refers to a stream location that is always included in synoptic monitoring events for a particular monitoring set (e.g., the Six Mile Creek watershed) year after year. An "investigative monitoring location" is one which is sampled occasionally to track pollution that may be detected at synoptic locations.

[c]Certified lab data from 23 base flow sampling events at 14 synoptic sampling sites plus one investigative site on the Six Mile Creek mainstem and tributary streams from 2004-2012. Results may be viewed at www.communityscience.org/database/monitoringsets/5. Raw data may be selected and downloaded at http://www.communityscience.org/database/entries.

[d]U.S. Geologic Survey data from 16 sampling events at three sites on the Six Mile Creek main stem and six sites on Six Mile Creek tributaries from 2003-2005 (waterdata.usgs.gov/).

[e]Expanded gas well baseline parameters measured one time at seven synoptic sampling sites and one investigative site as part of a base flow synoptic sampling event in 2012.

[f]CSI Total Nitrogen equal to sum of total Kjeldahl nitrogen (TKN) and nitrate- + nitrite-nitrogen. According to Table 5.10 in the 2011 draft Supplemental Generic Environmental Impact Statement (dSGEIS) by the New York State Department of Environmental Conservation (NYSDEC), TKN is elevated approximately 300-fold in flowback compared to typical values in Six Mile Creek, making it a potential contributor to a "chemical signature" of gas well impacts.

downloaded to MS Excel, the mean and standard deviation were calculated, and the coefficient of variation (COV) was calculated as the ratio of the standard deviation to the mean multiplied by 100. The COV was calculated for each of the 14 synoptic sampling locations on Six Mile Creek. COVs for specific conductance at the 14 locations ranged from 13.6 percent to 31.5 percent, the mean COV was 21.4 percent, and the median COV was 20.7 percent. It is noted that the data query interface in the CSI database can be used to select and export other data sets for Six Mile Creek and analyze their variability. For example, COVs for total hardness were calculated for each of the 14 locations, and the mean COV for total hardness was found to be 22 percent. This low variability strengthens the baseline from which to assess possible impacts on specific streams and stream reaches if HVHHF activities take place in the Cayuga Lake watershed.

Streams in Upper Susquehanna River Basin

Unlike the Cayuga Lake watershed, where volunteer groups collect grab samples two to five times a year for certified analyses by the CSI lab, volunteers in the Upper Susquehanna River Basin perform monthly measurements of five red-flag parameters in the field and report their results to CSI. At this writing (October 2012), 77 red-flag volunteers are monitoring 125 locations draining 1,233 square miles in sub-watersheds of the Upper Susquehanna River basin (Figure 1). Volunteers are added continuously as word spreads and citizens contact CSI for training and technical support. Volunteer results that meet data acceptance criteria (provided in Table 1) are entered in the CSI database by CSI staff and may be searched and downloaded via the data query interface at http://www.communityscience.org/database/entries. Results obtained by CSI's first red-flag group, the Cayuta-Catatonk Water Watch, in the first year of their monthly monitoring program from February 2011 to February 2012, are summarized in Tables 3 and 4 and compared to data reported by state and federal agencies. Median values for pH, specific conductance and total hardness are lower than values reported by the NYSDEC and the Susquehanna River Basin Commission (SRBC). A possible explanation is that most of the agency data are collected from a single monitoring site located near the mouths of Catatonk Creek (Table 3) and Cayuta Creek (Table 4), while volunteers collected red-flag data throughout both watersheds including headwater streams. Coefficients of variation for specific conductance at 26 red-flag monitoring locations under base-flow conditions in Catatonk and Cayuta Creeks ranged from 9.8 percent to 74.6 percent with a mean COV for all locations of 33 percent and a median COV of 32.9 percent. The generally higher COVs at red-flag monitoring locations compared to Six Mile Creek locations may be due to the smaller data set, the lower accuracy of field measurements (Tables 3 and 4) compared to certified lab results (Table 2), greater temporal variation in specific conductance in Cayuta and Catatonk Creeks compared to Six Mile Creek, or a combination of these and other factors. Nevertheless, field measurements at fixed stream locations by volunteers (Tables 3 and 4) are sufficiently consistent over time to serve as effective baselines for detecting possible HVHHF impacts on streams. Baselines established by volunteers are important in view of the paucity of agency data on streams in recent years. A search of the federal STORET database indicated that stream data had been collected at 270 agency monitoring sites between 1990 and October of 2012 in the 13 counties in upstate New York where CSI is focusing its baseline monitoring programs (Figure 1). At least three of four red-flag parameters (pH, dissolved oxygen, specific conductance, total hardness) were measured at 85 percent of STORET sites. However, the median number of sampling events per site over the 22-year period from 1990-2012 was only four. Of the 270 STORET sites in the 13-county region, only 39 have been sampled since January 1, 2010.

Groundwater in the Marcellus and Utica Shale Regions

The NWIS database was searched for gas well "signature chemicals" that might be used in a regional baseline to assess HVHHF impacts on groundwater quality. Search results indicated that only a small fraction of wells in New

Table 3. Comparison of "Red-Flag" Indicators of Water Quality Measured by Cayuta-Catatonk Water Watch (CCWW) Volunteers with Agency Data under Base Flow Conditions in Catatonk Creek

	Catatonk Creek—CCWW data[a]			Catatonk Creek—NYSDES data[b]		
"Red-flag" indicators	Median (*n*)	Min	Max	Median (*n*)	Min	Max
pH	7.25 (48)	6.39	8.14	7.76 (46)	6.49	8.42
Dissolved oxygen (mg/L)	9.25 (58)	5.8	13.4	10.25 (22)	7.85	13.48
Specific conductance (μS/cm)	154.5 (56)	36	431	211 (46)	49	395
Total hardness (mg/L)	68 (44)	16	160	98.5 (10)	70.4	160

[a]Data collected by 4 volunteer teams at 11 sites throughout the Catatonk Creek watershed from Feb. 2011-Feb. 2012 (http://www.communityscience.org/database/monitoringsets/13).

[b]Data are primarily from the New York State Department of Environmental Conservation (NYSDEC), Rotating Integrated Basin Studies (RIBS), site #06032102, Apr.-Nov. 2004 (http://www.epa.gov/storet/dw_home.html), with additional data from two Susquehanna River Basin Commission sites and one NYDEC site.

Table 4. Comparison of "Red-Flag" Indicators of Water Quality Measured by Cayuta-Catatonk Water Watch (CCWW) Volunteers and Agency Data under Base Flow Conditions in Cayuta Creek

	Catatonk Creek—CCWW data[a]			Catatonk Creek—SRBC data[b]		
"Red-flag" indicators	Median (*n*)	Min	Max	Median (*n*)	Min	Max
pH	7 (118)	6	8.71	7.8 (186)	6.1	9
Dissolved oxygen (mg/L)	9.4 (135)	5.8	13.9	9.8 (164)	4.95	15.2
Specific conductance (μS/cm)	118 (134)	22	351	282 (190)	71	1165
Total hardness (mg/L)	53 (128)	12	152	120 (3)	106	148

[a]Data collected by 4 volunteer teams at 15 sites throughout the Cayuta Creek watershed from Feb. 2011-Feb. 2012 (http://www.communityscience.org/database/monitoringsets/12).

[b]Data are primarily from the Data are primarily from the Susquehanna River Basin Commission (SRBC), Interstate Stream Water Quality Network, Apr.-1990)-Oct. 2010 (http://www.epa.gov/storet/dw_home.html). The station providing the majority of data is CAYT001.7-4176 near the mouth of Cayuta Creek. Additional data are from three SRB stations and one NYSDEC station within the Cayuta Creek watershed.

York have been characterized with respect to potential HVHHF contamination. A total of 1,995 wells in New York have been analyzed for at least one chemical in at least one of eleven "signature chemical" categories since 1990 (Table 5). However, only 208 wells have been analyzed for at least one chemical in each of eight "signature chemical" categories, and of these, only 16 are located in rural areas of the Southern Tier (Table 5). Thus, the geographic distribution of agency data on groundwater quality is skewed away from the rural areas that are most at risk of impacts from HVHHF in New York.

Available agency data were filtered and tabulated in Table 6 to facilitate comparison with CSI groundwater data on "signature chemicals" in Table 7. Median values in CSI's regional groundwater database reported in Table 7 were generally similar to median values extracted from the USGS's NWIS database and tabulated in Table 6. Chloride, total dissolved solids, total hardness and specific conductance values were somewhat higher in the USGS data set. These differences could be explained by random variability. Groundwater quality is known to change over short horizontal and vertical distances as a result of differences in aquifer characteristics, geochemical conditions, and residence time [20]. Indeed, we observed substantial variability among private drinking water wells, including wells in the same 1-mile grid square (Figure 2). Another possible

Table 5. Certified Measurements of CSI "Signature Chemicals" in Groundwater Wells in Urban and Rural Areas of New York State Performed by the Community Science Institute and the U.S. Geological Survey

Geographic area	Number of groundwater wells where certified measurements of gas well "signature chemicals" (SC) have been performed in New York					
	CSI		USGS			
	8[a] of 11 SC categories[b]	11[a] of 11 SC categories[b]	1[a] of 11 SC categories[b]	5[a] of 11 SC categories[b]	7[a] of 11 SC categories[b]	8[a] of 11 SC categories[b]
New York total	121	110	1,995	1,260	580	208
New York shale region	121	110	709	458	109	80
Shale region—rural[c]	121	110	415	274	62	46
Shale region—urban/contaminated[c]	0	0	294	184	47	34
Outside of shale region	0	0	1,286	802	471	128
13-county area	121	110	245	162	48	27
13-county area[d]—rural[c]	121	110	178	110	28	16
13-county area[d]—urban/contaminated[c]	0	0	67	52	20	11

[a]Number of “signature chemical” categories for which certified measurements were performed on groundwater wells.

[b]CSI’s recommended list of 19 gas well “signature chemicals” and 52 volatile organic compounds (VOCs) were organized into eleven (11) categories of chemical characteristics with the goal of searching the NWIS database of the U.S. Geological Survey for existing groundwater quality data related to “hydrofracking.” Each of the eleven “signature chemical” (“SC”) categories contains one or more certified tests recommended by CSI as part of a pre-HVHHF baseline designed for use in screening groundwater for possible contamination due to gas well waste. The eleven (11) CSI “signature chemical” categories used to search the NWIS database are: (1) Methane; (2) Chemical oxygen demand; (3) Methylene blue active substances (anionic surfactants); (4) Total hardness, calcium; (5) Barium, strontium; (6) Iron, manganese, arsenic; (7) Turbidity, total suspended solids; (8) Gross alpha radioactivity, gross beta radioactivity; (9) Benzene, ethylbenzene, toluene, xylene; (10) pH, alkalinity; and (11) Chloride, specific conductance, total dissolved solids. While these eleven (11) categories are considered to be broadly representative of the chemical characteristics most likely to change as a result of contamination from shale gas wells, it is recognized that they are not completely inclusive, and that there are other groundwater characteristics in the NWIS database that might be impacted by “fracking.”

[c]Urban/contaminated areas are defined as the union of four GIS layers: (1) U.S. Census Bureau 2010 populated places, (2) U.S. Census Bureau 2010 urban areas, (3) One-mile corridors around EPA facilities and sites subject to environmental regulation and (4) One-mile corridors around the NYDEC remediation sites. This final GIS layer represents a rough measure of areas that have intensive residential, commercial, and industrial land use and can be distinguished from areas that are primarily rural in character.

[d]The 13-county area in upstate New York is defined as those counties where CSI has performed baseline testing on private groundwater wells: Otsego, Tompkins, Chenango, Delaware, Steuben, Tioga, Schuyler, Broome, Chemung, Yates, Schoharie, Seneca, and Sullivan.

Table 6. Levels of Gas Well "Signature Chemicals" in USGS Groundwater Monitoring Wells, 1990-2012

	USGS results for Marcellus and Utica Shale regions			USGS results for 13-county area in rural Southern Tier[a]		
Gas well signature chemical (units)	Wells tested (wells with detects)[b]	Min-max values for all wells[c]	Median values for all wells[d]	Wells tested (wells with detects)[b]	Min-max values for all wells[c]	Median values for all wells[d]
Calcium (mg Ca/L)	16 (16)	11.13-309.2	85	0 (0)	—	—
Alkalinity (mg $CaCO_3$/L	0 (0)	—	—	0 (0)	—	—
Total hardness (mg $CaCO_3$/L)	590 (590)	0.28-87,600	219	119 (119)	1.47-1,700	137
Total dissolved solids (mg/L)	459 (459)	33-193,000	294	119 (119)	33-7,130	205
Total suspended solids (mg/L)	0 (0)	—	—	0 (0)	—	—
Turbidity (NTU)	17 (17)	0.2-230.06	15.9	0 (0)	—	—
pH (pH units)	566 (566)	5.8-12.4	7.6	114 (114)	5.9-9.1	8
Chloride (mg/L)	574 (574)	0.4-126,000	32.4	119 (119)	0.4-3,380	13
Specific conductance (μS.cm)	555 (555)	45-129,333	535	119 (119)	47-11,300	356
Chemical oxygen demand (mg/L)	4 (0)	non-detect (< 10)	non-detect (<10)	4 (0)	non-detect (< 10)	non-detect (< 10)
Gross alpha radioactivity (pCi/L)[e]	98 (90)	–4-10.7	0.7	24 (16)	–0.4-10.7	1.05
Gross beta radioactivity (pCi/L)[e]	98 (87)	–0.9-19.1	1.6	24 (13)	–0.5-19.1	1.05
Methane (mg/L)	172 (153)	non-detect (< 0.001)-45.4	0.003	37 (18)	non-detect (< 0.001)-38.3	non-detect (< 0.001)

Methylene blue active substances (MBAS) (mg/L)	0 (0)	—	—	0 (0)	—	—
Barium, unfiltered (mg/L)	276 (276)	0.00109-10.4	0.1155	73 (73)	0.00488-10.4	0.110
Iron, unfiltered (mg/L)	275 (272)	non-detect (< 0.0046)-29.171	0.138	69 (66)	non-detect (< 0.0046)-3.47	0.138
Manganese, unfiltered (mg/L)	273 (271)	non-detect (< 0.00016)-1.6	0.0351	70 (68)	non-detect (< 0.00016)-0.594	0.03265
Arsenic, unfiltered (mg/L)	219 (209)	non-detect (< 0.00006-0.148)	0.00084	50 (40)	non-detect (< 0.00006)-0.027	0.00079
Strontium, unfiltered (mg/L)	276 (276)	0.0104-53.8	0.227	73 (73)	0.0104-31.1	0.247
Benzene (mg/L)	338 (5)	non-detect (<0.00002)-0.0561)	non-detect (< 0.00002)	85 (1)	non-detect (< 0.00002)-0.0003)	non-detect (< 0.00002)
Ethylbenzene (mg/L)	335 (4)	non-detect (< 0.00003)-0.0076)	non-detect (< 0.00003)	85 (1)	non-detect (< 0.00003)-0.0001	non-detect (< 0.00003)
Toluene (mg/L)	340 (30)	non-detect (< 0.00002)-0.023	non-detect (< 0.00002)	85 (8)	non-detect (< 0.00002)-0.001	non-detect (< 0.00002)
Xylene (mg/L)	27 (2)	non-detect (< 0.0002)-0.00475)	non-detect (< 0.0002)	0 (0)	—	—

[a]Counties included in this analysis: Otsego, Tompkins, Chenango, Broome, Steuben, Sullivan, Delaware, Schuyler, Tioga, Chemung, Schoharie, Seneca, Yates. Rural areas are defined as not urban/industrial areas. Urban/industrial areas are defined as U.S. Census Bureau 2010 populated places and urban areas; these GIS layers were merged with a layer comprised of 1-mile corridors around EPA facilities and sites subject to environmental regulation as well as NYSDEC remediation sites.

[b]Number of wells with concentrations above the laboratory's limit of quantitation (similar to detection).

[c]Minimum values that are below the laboratory's limit of quantitation (LOQ) are reported as "non-detect" with the LOQ in parenthesis.

[d]If the laboratory reported a non-detect, the value is less than the laboratory's limit of quantitation (similar to detection). If a well was sampled more than once, the value is taken to equal the average of all samples collected from that well. The quantitation limit is indicated by "<"; for example, a chloride value of < 2 means that the measurement was less than a limit of quantitation of 2 mg/L.

[e]USGS non-detects defined as "Radiochemistry non-detect, result below sample specific critical level."

Table 7. Levels of Shale Gas Well "Signature Chemicals" in Private Groundwater Wells Measured by the Community Science Institute, 2009-2012

	USGS results for rural Southern Tier[a]			Drinking water regulations/guidelines	
Gas well "signature chemical" (units)	Number of wells tested (number of wells with detects)[b]	Min-max values for all wells[c]	Median values for all wells[d]	Federal MCL value[e] (number of CSI wells over)	NY State MCL value[f] (number of CSI wells over)
Calcium (mg Ca/L)	121 (120)	< 1.2-156	32.6	none	none
Alkalinity (mg $CaCO_3$/L	122 (122)	8.13-450	140.5	none	none
Total hardness (mg $CaCO_3$/L)	121 (121)	8.8-635	107	none	none
Total dissolved solids (mg/L)	120 (114)	< 50-1090	180	none	500g (3)
Total suspended solids (mg/L)	121 (5)	< 4.0-91.6	< 4.0	none	none
Turbidity (NTU)	121 (120)	< 0.01-91.8	0.83	5 (14)	5 (14)
pH (pH units)	122 (122)	5.9-8.65	7.535	none	6.5-8.5[g]
Chloride (mg/L)	121 (82)	0.46-281.5	4.18	none	250[g] (2)
Specific conductance (μS.cm)	122 (122)	40.4-1682	298.5	none	none
Chemical oxygen demand (mg/L)	121 (31)	non-detect (< 10)-26.9	non-detect (< 10)	none	none
Gross alpha radioactivity (pCi/L)	121 (121)	–0.45-4.97	0.655	15 (0)	15 (0)
Gross beta radioactivity (pCi/L)	121 (121)	–0.59-40.83	1.08	15-50[j] (0)	15-50[j] (0)
Methane (mg/L)	122 (51)	non-detect[h]-14	non-detect[h]	none	10[i] (2)

Methylene blue active substances (MBAS) (mg/L)	122 (13)	non-detect (< 0.04)-0.054	non-detect (< 0.04)	none	0.5[g] (0)
Barium, unfiltered (mg/L)	122 (122)	0.0019-0.895	0.0657	2 (0)	2 (0)
Iron, unfiltered (mg/L)	122 (110)	non-detect (< 0.005)-11.3	0.0885	none	0.3[g] (26)
Manganese, unfiltered (mg/L)	122 (101)	non-detect (< 0.002)-1.52	0.045	none	0.3[g] (2)
Arsenic, unfiltered (mg/L)	122 (44)	non-detect (< 0.0005)-0.0248	non-detect (< 0.0005)	0.01 (2)	0.01 (2)
Strontium, unfiltered (mg/L)	108 (108)	0.0006-2.07	0.217	none	none
Benzene (mg/L)[k]	114 (0)	non-detect (< 0.0005)	non-detect (< 0.0005)	0.005 (0)	POC[l]
Ethylbenzene (mg/L)[k]	114 (0)	non-detect (< 0.0005)	non-detect (< 0.0005)	0.7 (0)	POC[l]
Toluene (mg/L)[k]	114 (3)	non-detect (< 0.0005)-1.3	non-detect (< 0.0005)	1 (1)	PCO[l]
Xylene (mg/L)[k]	114 (0)	non-detect (< 0.0005)	non-detect (< 0.0005)	10 (0)	POC[l]

[a]Counties (number of wells included in baseline): Otsego (59), Tompkins (13), Chenango (13), Broome (10), Steuben (7), Sullivan (5), Delaware (4), Schuyler (4), Tioga (3), Chemung (2), Schoharie (1), Seneca (1), Yates (1). Private clients must give written permission for their results to be included in the regional baseline.

[b]Number of wells with concentrations above the laboratory's limit of quantitation (similar to detection).

[c]Minimum values that are below the laboratory's limit of quantitation (LOQ) are reported as "non-detect" with the LOQ in parenthesis.

[d]If the laboratory reported a non-detect, the value is less than the laboratory's limit of quantitation (similar to detection). The quantitation limit is indicated by "<"; for example, a chloride value of < 2 means that the measurement was less than a limit of quantitation of 2 mg/L. If a well was sampled more than once, the value is taken to equal the average of all samples collected from that well with one exception: Exceedances of federal and state standards are noted regardless of the number of times a well is sampled.

Table 7. (Cont'd.)

[e]The MCL refers to the Maximum Contaminant Level, a health-based, enforceable standard under the federal Safe Drinking Water Act (SDWA). MCLs are based on human health risk assessments and are listed on the EPA website at: http://water.epa.gov/drink/contaminants/index.cfm#List. MCLs are distinct from National Secondary Drinking Water Standards (NSDWS), which are not health-based and not enforceable by EPA.

[f]State standards refer to levels of chemicals in drinking water that are enforced by New York State under the federal Safe Drinking Water Act (SDWA) and are listed at http://www.health.ny.gov/regulations/nycrr/title_10/part_5/subpart_5-1_tables.htm. An enforceable state standard must be equally or more stringent than a federal standard. A state is not required to base its enforceable standards on human health risk assessments; however, a state may refer to its standards as MCLs. In general, state MCLs are a mixture of federal health-based MCLs and federal non-health-based National Secondary Drinking Water Standards (NSDWS). For example, New York bases several enforceable standards on NSDWS, available at http://water.epa.gov/drink/contaminants/index.cfm#SecondaryList. NSDWS are not enforceable at the federal level because they are directed at cosmetic properties of drinking water such as taste and odor, not at risks to human health.

[g]Based on a National Secondary Drinking Water Standard (NSDWS) that is not health-based and is not enforceable by the federal government (see http://water.epa.gov/drink/contaminants/index.cfm#SecondaryList).

[h]The limit of quantitation (LOQ) for methane depends on the subcontract lab used. The lab used from 8/2009 to 6/2010 had an LOQ of 0.01 mg/L; the lab used since 6/2010 has an LOQ of 0.001 mg/L.

[i]A guidance value, not a standard. The U.S. Department of the Interior recommends that wells containing greater than 10 mg/L of dissolved methane be vented to minimize the explosion hazard that could result from methane volatilizing (escaping) from water and building up inside a home.

[j]Standard is based on an exposure limit of 4 mrem/year. This level of exposure corresponds to a concentration of 15 pCi/L to 50 pCi/L, depending on various factors. It is possible that the one well that exceeded 15 pCi/L may have resulted in an exposure greater than the federal MCL of 4 mrem/year.

[k]Results for so-called BTEX chemicals are reported here. Additional 48 volatile organic compounds (VOCs) analyzed by EPA Method 524.2 are omitted from this table but will be included in CSI's online groundwater database.

[l]*POCs* (principal organic contaminants) have an automatic New York State MCL of 0.005 mg/L: http://www.health.ny.gov/regulations/nycrr/title_10/part_5/subpart_5-1_tables.htm

explanation is that more USGS samples may have been collected in areas or regions with higher mineral content than CSI samples. Minimum values were similar in the CSI and USGS data sets, while maximum values were significantly higher in the USGS data set (compare Tables 6 and 7). The most likely explanation for the maximum values for chloride (126,000 mg/L), total dissolved solids (193,000 mg/L) and specific conductance (129,333 μS/cm) is groundwater brine resulting from salt deposits in the Syracuse area [21].

CSI's growing database indicates that groundwater quality in rural areas of New York's Southern Tier region is generally excellent with respect to gas well "signature chemicals." Results from 122 private wells with an aggregate total of 8,224 certified test results including 2,296 tests for 19 parameters related to brine, acid, metals, suspended solids, surfactants, bulk organic compounds, radioactivity, and methane, and 5,928 tests for 52 VOCs included in EPA Method 524.2, are summarized in Table 7. Twelve wells exceeded the federal standard for turbidity, one well exceeded the federal standard for arsenic and one exceeded the federal standards for both turbidity and arsenic. A fifteenth well exceeded the federal standards for turbidity and toluene; however, this was a newly drilled well, and no exceedances were observed in follow-up sampling. The remaining 107 wells showed no exceedances of federal standards for any of the 19 "signature chemicals" and 52 VOCs. Stated as a fraction of the total number of "signature chemical" results summarized in Table 7, exceedances of federal standards comprised 17 of 8,224 test results or 0.2 percent. Methane was detected in 51 of 122 wells (detection limit 0.001 or 0.01 mg/L, depending on subcontract lab); two wells had levels greater than 10 mg/L, the federal guideline for explosion hazard (Table 7). Methane concentrations may have been underestimated because containers were open during the approximately 20 seconds required to collect a sample, providing an opportunity for methane, a gas, to volatilize. Ethane, which was routinely analyzed along with methane, was not detected in any wells (detection limit 0.019 mg/L, data not shown).

It is important to note that state drinking water standards differ substantially from federal standards. In particular, New York enforces several federal National Secondary Drinking Water Standards (NSDWS), which address cosmetic, smell, and taste characteristics as MCLs, including state MCLs for iron, manganese, total dissolved solids, and methylene blue active substances (MBAS) (anionic surfactants). While the state has valid reasons for these regulations, they result in MCLs that are not based strictly on human health risk assessments. For example, the Institute of Medicine of the National Academy of Sciences has set an upper intake level (UL) for iron for adults of 45 mg/day [22], and thus an adult would have to ingest 150 liters or about 37 gallons of water per day to incur adverse health effects when the iron concentration is 0.3 mg/L, the MCL for New York State. A number of VOCs are regulated by New York as Principal Organic Contaminants (POCs) with obligatory MCLs of 0.005 mg/L even though health-based toxicity thresholds may be higher or unknown (Table 7). For these reasons, the number of MCL exceedances under New York State regulations exceeded the number of MCL exceedances under federal regulations (Table 7).

DISCUSSION

High-volume horizontal hydraulic fracturing or HVHHF, commonly known as fracking, is a new technology that is widely believed to present substantial risks to human health and the environment. Weak regulation of fracking by federal and state governments has resulted in a dearth of data on exposure to the hazardous chemicals employed by the shale gas industry and the effects of exposure on humans and other species.

The Value of Risk Assessment

Many if not most large-scale industrial activities entail the use of hazardous chemicals and the generation of hazardous chemical waste. The role of government is to encourage entrepreneurship, innovation, and productivity while ensuring that public health and environmental resources required for diverse economic activities are protected [23]. Risk assessment, properly conducted, provides an effective tool with which to evaluate industrial activities and decide the extent to which benefits to society justify inherent risks to human health and environmental resources. Even rudimentary risk assessments offer effective decision-making tools by helping to situate risks and benefits within the broader context of economic activity and quality-of-life goals for a place or a region.

The principles of risk assessment are well known to policymakers in government agencies and, one presumes, to lawmakers and their staffs in state legislatures and Congress. Nevertheless, the authors are not aware of a single systematic risk assessment anywhere in the United States that follows protocols developed by the National Academy of Sciences and the U.S. Environmental Protection Agency [15-17, 24] and widely accepted throughout the risk assessment community to marshal available evidence and examine the risks and benefits of HVHHF-based shale gas extraction. To the contrary, the industry has been exempted from key provisions of federal environmental laws [25], and its hazardous byproducts have been arbitrarily classified as non-toxic "industrial wastewater" in New York [26], effectively privileging the industry's growth and deflecting attention from the risks its growth entails. Risk assessment is the only available tool to evaluate the industry's impacts within the broader context of the diverse human and environmental communities in which it operates. In the absence of action by government, it is up to citizens to gather evidence on risk. The goal of CSI-volunteer monitoring partnerships is to target data gaps at the local level where government agency data is scarce or non-existent.

Surface Water Monitoring by Citizen Volunteers

Through its partnerships with groups of volunteers from rural communities in Upstate New York, the Community Science Institute collects scientifically credible water quality data in an effort to evaluate risks to local streams and lakes from land uses such as agriculture, residential development and, most recently, from the burgeoning HVHHF-based shale gas industry. Results are disseminated to the general public through CSI's unique online data archive, providing factual information that can be accessed by citizens and municipal and county governments to help understand and manage water resources in their jurisdictions.

There is a growing scientific literature that seeks to understand the degree to which data collected by volunteers are valid, the purposes for which these data can or should be used, how volunteer data might be disseminated, and how to create a nexus between volunteers, planners, and regulators so that the data are put to use [27-31]. We report here on monitoring partnerships between trained groups of volunteers and CSI's certified lab that represent a workable compromise between a formal structured program with integrated quality control and a more autonomous organizational structure that promotes volunteer empowerment. Key elements of CSI-volunteer monitoring partnerships are:

- Recruitment of volunteers in groups of 15-30 people loosely defined by region.
- A series of three free training workshops spaced at least two weeks apart to give group members an opportunity to reflect on what they are learning and to foster group identity and commitment.
- Stream-side demonstrations of test kits and meters by CSI staff and hands-on practice with test kits by volunteers.
- Organization of each group into teams of two to five volunteers.
- A clear quality assurance protocol that volunteer teams can implement on their own.
- Selection of sampling sites by teams with guidance and mapping support from CSI.
- Management of the online data repository by CSI, with CSI staff entering only data that satisfy acceptance criteria (Table 1).
- Capacity for dynamic mapping and graphing of data in CSI's public database, including capacity for visitors to the CSI website to select and export raw data free of charge.

The results presented here provide evidence that surface water monitoring partnerships between groups of public-spirited citizens and CSI's certified lab are capable of generating and publicizing data for use in understanding, protecting, and managing water resources in New York State's shale gas region. Median values obtained by CSI-volunteer monitoring partnerships agreed well with available agency data on surface water quality in the same general region, taking into account CSI's intentional focus on sampling sites located upstream and on small tributary streams as opposed to agencies' greater reliance on sampling sites located near stream mouths and agencies' inclusion of areas where contamination is suspected. Generally low coefficients of variation of data collected by volunteers at individual monitoring locations suggest that potential contamination events as well as long-term trends can be detected. The quality of volunteer data reported here is consistent with reports by other authors [29, 31].

Regional Groundwater Initiative

Groundwater monitoring is structured differently from surface water monitoring. While surface water monitoring is structured around active partnerships between CSI and volunteer groups, groundwater monitoring is based on private clients who contract with CSI's certified lab to collect and test drinking water samples from their home, then grant permission to aggregate their test results for anonymous dissemination on the CSI website. CSI's groundwater database continues to grow as more private clients request baseline tests and grant permission to pool their results. The groundwater data in CSI's archive of aggregated private client results were found to be representative of New York's shale gas region as indicated by the similarity of median values for gas well "signature chemicals" (Table 7) to groundwater data in the NWIS database (Table 6). Higher median and maximum values in the NWIS data set (Table 6) were probably due to the inclusion of groundwater data from areas with salt deposits and industrial and contaminated sites. The quality of groundwater in rural households with respect to gas well "signature chemicals" can only be described as excellent (Table 7). The most prevalent water quality issue by far was turbidity, which exceeded the federal standard of 5 NTU in 14 out of 122 private groundwater wells tested and which accounted for 14 out of 17 documented exceedances of federal health-based standards (Table 7). Methane was present in nearly half of private wells, in line with agency data [32, Table 6]. Methane concentrations ranged from barely detectable up to 14 mg/L, and the median value was 0.005 mg/L. The principal hazard associated with methane is explosion when concentrations reach 5.5 percent by volume in air, or about 55,000 ppm, and similar concentrations of methane can cause asphyxiation [33]. The U.S. Department of the Interior recommends venting wells containing methane concentrations greater than 10 ppm by weight or 0.001 percent in water in order to avoid gradual methane accumulation in air in enclosed living spaces. Methane is classified as toxicologically inert as long as oxygen is available, and animals are not affected by concentrations up to 10,000 ppm by volume in air [33, 34]; however, at concentrations greater than 50 percent or about 500,000 ppm by volume in air, nonspecific toxic effects secondary to oxygen deprivation have been noted [33]. The prevalence of methane in groundwater does not negate the value of methane as a "signature chemical," because concentrations would be expected to increase dramatically in the event of contamination resulting from leaks in well casings or from methane migration through subsurface fractures [12]. Ethane was not detected in any groundwater wells.

Aggregated private client groundwater results are being incorporated into CSI's electronic database (www.communityscience.org/database) and will be made available to the general public online by 2013. Online groundwater data will be organized by region, county and 1-mile grid square (Figure 2) in contrast to surface water results, which are organized by region, "monitoring set" (e.g., the watershed of a stream such as Six Mile Creek or Catatonk Creek), and monitoring location. One-mile grid squares should provide sufficient spatial information to investigate increases in post-drilling concentrations of "signature chemicals" in private drinking water wells.

Documenting HVHHF Impacts on Water

A post-fracking increase in the concentration of one or more "signature chemicals" can, in principle, be interpreted as evidence that water has been contaminated by nearby shale gas operations. The greater the number of "signature chemicals" and the higher their concentrations compared to pre-fracking baseline levels, the stronger the evidence of contamination. This application of "signature chemical" baselines should be valid both for an individual groundwater well and for a specific stream reach where pre-fracking baseline data is available. While it should be easier to detect contamination of a groundwater well that has been characterized on the basis of over 70 certified lab tests than a stream location that has been characterized on the basis of five red-flag tests performed by volunteers in the field, the guiding principle is the same: A significant change in the "chemical signature" of water quality that can be reasonably attributed to waste from the shale gas industry. Clearly the terms "significant" and "reasonable" are subject to interpretation. We anticipate that regulatory agencies and the courts will make decisions on a case-by-case basis, and that they will use a weight-of-evidence approach and take into account other factors in addition to changes in water quality, for example, proximity to a drill pad and visual evidence of a spill. Nevertheless, an increase over pre-fracking levels of "signature chemicals" is likely to constitute a strong, if not the strongest, piece of evidence that HVHHF-related contamination has occurred.

Detecting contamination by extrapolating "signature chemical" levels to groundwater wells and stream locations that lack pre-fracking data is decidedly less robust conceptually than comparing pre- and post-fracking data for the same drinking water well or the same stream location. Nevertheless, regional baselines should prove useful to agencies as part of a weight-of-evidence approach to identifying HVHHF impacts. Agencies will have to decide whether post-fracking levels of "signature chemicals" exceed regional values for groundwater, in the case of a private well, or regional values for surface water, in the case of a stream or a stream reach, sufficiently to support a determination that the well or the stream has been degraded as a result of shale gas extraction activities.

It seems possible that despite the heterogeneity of groundwater sources in the regional baseline, some "signature chemicals" might be distributed in statistically recognizable patterns, the simplest example being a normal distribution, or bell curve. The regional baseline for a normally distributed "signature chemical" in groundwater might be used to estimate the probability that its post-fracking concentration in a private well is due to chance (that is to say, it falls within the normal distribution of the pre-fracking data set); a low probability would strengthen the case for contamination. Similarly, statistical patterns of "signature chemicals" in regional stream baselines, if present, might be used to estimate the probability that post-fracking concentrations signify contamination of a stream for which no baseline data exists. Regional surface water baselines also include a temporal component, because red-flag data are collected monthly. Temporal patterns such as seasonal variation, which can be readily analyzed by filtering and downloading red-flag data from the CSI database (http://www.communityscience.org/database/entries), might strengthen the case for or against HVHHF impacts.

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AUTHORS' BIOGRAPHIES

REBECCA J. BOWEN is an Outreach Coordinator at the Community Science Institute (CSI) in Ithaca, NY. She works on the development and implementation of CSI's "red flag" monitoring partnerships with volunteer groups in New York's Southern Tier region. Her responsibilities also include the collection of groundwater samples from private drinking water wells for comprehensive baseline testing of gas well "signature chemicals." A member of the Ithaca Carshare staff before coming to work at CSI, she serves on the Board of Directors of the Finger Lakes Permaculture Institute. Rebecca is interested in designing practical solutions to complex ecological problems and finding mutually beneficial ways for humans to interact with the earth. Write to becky@communityscience.org

SORAYA DELGADO, the Latin American Director of Great Wilderness, is a Conservation Biologist and Environmental Educator and a native of coastal Ecuador. She studied Biology in Ecuador and has a bachelor's degree in environmental sciences from Florida International University. She has worked on conservation of biodiversity and research projects in diverse regions of Ecuador and Venezuela, including the Galapagos Islands, the Andean region, Pacific rainforests, and the Amazonian region. Since 2004, she has helped develop a long-term study of wild parrot communication in Venezuela established by scientists from U.C. Berkeley. In 2010 and 2011, she worked as Field Coordinator at CSI, coordinating the collection of groundwater samples from private drinking water wells for baseline testing of gas well "signature chemicals." Great Wilderness is a small NGO that supports protection and preservation of tropical biodiversity in South America. You can reach her at soraya@greatwilderness.org

ABNER X. FIGUEROA is a Senior Web Developer at the Community Science Institute, Ithaca, N.Y. and Web Applications Engineer III, UT Southwestern Medical Center in Dallas, Texas. He contributes extensive experience with relational database technologies to the development and design of CSI's website and its database web application. He is a skilled web applications engineer with a love of clean code and strong fundamentals in object-oriented programming. His passion is to make beautiful products and to bring critical thinking to real challenges.

STEPHEN M. PENNINGROTH holds a Ph.D. in Biochemical Sciences from Princeton University. He is founder of the non-profit Community Science Institute (CSI) in 2000 and serves as its Executive Director as well as Lead Technical Director of its state-certified environmental testing lab. Previously, Steve served on the faculty of the University of Medicine and Dentistry of New Jersey's School of Osteopathic Medicine as assistant and associate professor from 1978-1993, pursuing research on the molecular basis of cell motility and teaching pharmacology and toxicology to medical students. From 1993 to 2000, he taught environmental toxicology at Cornell University in Ithaca and worked as a consultant for community groups impacted by Superfund sites in New York and New Jersey, with funding through EPA's Technical Assistance Grant (TAG) program. He is interested in ways that scientists at non-profit organizations can support sustainable development at the local level by fostering the production of data to inform communities about the state of their local resources. Write to him at spenningroth@communityscience.org

MATTHEW M. YARROW has a Ph.D. in Ecology and Evolutionary Biology from the Universidad de Chile. He is a GIS analyst at the Community Science Institute in Ithaca, NewYork and a member of the Centro Transdisciplinario de Estudios FES-Sistemicos in Santiago, Chile. At CSI, he works as a cartographer, GIS analyst and data analyst. His doctoral thesis addressed the spatial aspects of nutrient cycles, and as a member of the Ecological Modeling Lab at the Universidad de Chile, he participated in an international multidisciplinary project that created integrated management tools for stakeholders in the Aysen Basin of southern Chile. Matt seeks to understand how water, nutrients, and contaminants move in the landscape and how these processes interact with human activities. He thinks that furthering this knowledge is key to managing our water resources sustainably. His email address is myarrow@communityscience.org

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Direct reprint requests to:

Dr. Stephen Penningroth
Community Science Institute
284-284 Langmuir Lab/Box 1044
95 Brown Road
Ithaca, NY 14850
e-mail: spenningroth@communityscience.org

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Features

DISCLOSURE OF HYDRAULIC FRACTURING FLUID CHEMICAL ADDITIVES: ANALYSIS OF REGULATIONS

ALEXIS L. MAULE
COLLEEN M. MAKEY
EUGENE B. BENSON
ISAAC J. BURROWS
MADELEINE K. SCAMMELL

ABSTRACT

Hydraulic fracturing is used to extract natural gas from shale formations. The process involves injecting into the ground fracturing fluids that contain thousands of gallons of chemical additives. Companies are not mandated by federal regulations to disclose the identities or quantities of chemicals used during hydraulic fracturing operations on private or public lands. States have begun to regulate hydraulic fracturing fluids by mandating chemical disclosure. These laws have shortcomings including nondisclosure of proprietary or "trade secret" mixtures, insufficient penalties for reporting inaccurate or incomplete information, and timelines that allow for after-the-fact reporting. These limitations leave lawmakers, regulators, public safety officers, and the public uninformed and ill-prepared to anticipate and respond to possible environmental and human health hazards associated with hydraulic fracturing fluids. We explore hydraulic fracturing exemptions from federal regulations, as well as current and future efforts to mandate chemical disclosure at the federal and state level.

Keywords: groundwater, Safe Drinking Water Act, contamination, legislation, fracking

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Hydraulic fracturing, also known as fracking, is an increasingly widespread practice used to extract natural gas and oil from shale formations deep below the surface of the earth. Optimization of recovery technologies and lucrative natural gas prices led to a 48 percent increase in U.S. shale gas production from 2006 to 2010 with an estimated 35,000 wells drilled annually [1, 2]. Hydraulic fracturing involves drilling a vertical well approximately 5,000 to 9,000 feet into a shale formation [3]. Horizontal drilling, when appropriate, stems perpendicularly from the base of the vertical well and may extend outwards up to 10,000 feet [4]. Wells are drilled and lined by a steel pipe and cemented into place. After placement, electric currents are sent to a perforating gun located near the base of the well, where a charge shoots small holes through the steel and cement into the shale [3]. This allows the highly pressurized fluid-and-proppant mixture injected into the well to escape the well and create cracks and fractures in the surrounding shale layers [5]. Proppants are size-graded, rounded and nearly spherical white sand, ceramic, or man-made particles which are suspended in pressurized fluid [6]. The resultant fractures allow gas trapped within the shale to escape, along with some fracturing fluid and naturally occurring mineral deposits, and flow back up the well to the surface for capture [3].

FRACTURING FLUIDS AND ENVIRONMENTAL HEALTH

Hydraulic fracturing is controversial. Proponents argue that fracking creates a novel source of cheap, domestic energy and may replace some “dirty” energy sources like coal-fired power plants [5]. They claim that using natural gas as a “clean” energy source will make it easier to meet federal air and water quality standards [7] while also reducing our dependence on foreign oil [4]. The website of Halliburton, one of the major corporate proponents of fracking, states: “fracture stimulation is a safe and environmentally sound practice based on the industry’s decades-long track record, as well as the conclusions of government and industry studies and surveys” [8]. In 2009, industry estimated undeveloped but recoverable shale gas reserves in the lower 48 states amounting to 24 billion barrels: enough to heat U.S. homes for 30 years [9, 10].

Use of Fracturing Fluids

Opponents of hydraulic fracturing primarily cite concerns related to the environment, human health, and questions about the reality of promised long-term economic benefits in areas that are heavily drilled. The primary threat and controversy surrounding hydraulic fracturing, as it pertains to human health and groundwater contamination, is the use of fracturing fluids. Current estimates place the volume of fracturing fluid pumped into each well between 2 million and 4 million gallons, with the major components being water (90%), sand or proppants (8-9.5%), and chemicals (0.5-2%) [11]. Chemicals are added to fracturing fluids to increase well productivity by creating fractures in the rock (mostly shale) formation and holding the fractures open for the release of natural gas. Fracturing fluid additives include proppants (particles that keep fractures open), acids, gelling agents (which thicken the fracturing fluid), gel breakers (which allow fracturing fluid and gas to flow easily back to surface), bactericides, biocides, clay stabilizers, corrosion inhibitors, crosslinkers (which help maintain viscosity of fracturing fluid), friction reducers, iron controls, scale inhibitors, and surfactants. The composition of the fluid is determined based on characteristics of the well (e.g., geology of area) and production objectives. Some of the identified chemicals have known human health effects. For example, the surfactant benzene is classified by the U.S.EPA as a known human carcinogen (Group A), and xylene is a central nervous system depressant [12, 13]. Since companies invest time and resources into perfecting their fluid technologies, industry views chemical recipes as proprietary information that should be protected as trade secrets; thus many of the chemicals used remain unknown [5, 14].

The use of chemicals in the natural gas extraction process is not limited to the injection of fracking fluids. During the initial process of drilling the vertical well, chemicals are added to "drilling muds" to reduce friction, ease the drilling process, and shorten drilling time [14]. In addition to concerns regarding contamination of water during the drilling and fracturing process, there are concerns about groundwater contamination from the salts, chemicals, and naturally occurring radioactive material present in flowback, which is usually temporarily pumped into wastewater ponds and then moved off-site, where it is re-injected back into the ground or transferred to wastewater treatment facilities for treatment and disposal. The practice of treating flowback and "produced water" at publicly owned treatment works (POTWs) has largely ended; particularly in Pennsylvania, where less than 1 percent of fracking wastewater is treated in this manner after the state's Department of Environmental Protection (PaDEP) asked POTWs to voluntarily stop accepting fracking wastewater [15]. Now, the majority of flowback or "produced water" that is not disposed of in injection wells is treated at centralized waste treatment (CWT) facilities that are designed to treat industrial wastewater, and which may then discharge into sewers or surface water bodies. However, a report by the Natural Resources Defense Council (NRDC) found that wastewater discharged from these CWT facilities into surface water bodies still contained high levels of salts, bromides, and other pollutants [15].

Between 2009 and 2011, the EPA investigated potential groundwater contamination due to fracking in Pavilion, WY, and released its draft report in December 2011 [16]. EPA detected high concentrations of benzene, xylenes, and other gasoline and diesel range organics (types of petroleum hydrocarbon compounds), indicating a source of shallow groundwater contamination [16].

This EPA report is one of the few investigations of possible environmental contamination by hydraulic fracturing fluid injection. A single EPA report from 2004 found minimal risk to underground sources of groundwater due to hydraulic fracturing; however, this study was conducted in an area where coalbeds were being fractured, and not shalebeds, where the vast majority of fracturing occurs today [17]. No EPA reports to date have been released regarding the risks to groundwater and air associated with hydraulic fracturing in shalebeds. However, in 2011, Osborn and colleagues at Duke University published a study that showed increased concentrations of methane, ethane, and propane in private drinking-water wells directly attributable to the gas-well drilling in the Marcellus shale formation of Pennsylvania and New York [18]. The same research group did not find evidence of increased salinity or contamination from fracking fluids in a sample of private drinking-water wells [19]. However, these two studies and others acknowledge that hydraulic fracturing increases the permeability of shalebeds, creating new flow paths and enhancing natural flow paths for gas leakage into aquifers; these same pathways create a possible, although unlikely, contamination pathway for fracturing fluids [18-20]. The creation of additional fractures in the shalebeds and the drilling of wastewater disposal injection wells also change the hydrostatic pressure of the shale formation, possibly speeding up the normally extremely slow vertical flow of native and injected fluids closer to aquifers and the surface [20].

Voluntary Chemical Disclosure

With the exception of state-specific laws, disclosure of the chemicals present in fracturing fluid is primarily based on self-regulation: that is, voluntary reporting by the natural gas companies. Starting in January 2011, the Groundwater Protection Council and the Interstate Oil and Gas Compact joined forces to create the website FracFocus.org. Natural gas companies can provide well-specific information including the chemical composition of the fracturing fluid used at that particular well [21]. The chemical information may include Chemical Abstract Service (CAS) numbers, the purpose of an additive (e.g., proppant, biocide, gelling agent), and the maximum volume of the additive in hydraulic fracturing fluid [21]. The reporting of hydraulic fracturing chemicals is completely voluntary, and thus the accuracy and completeness of the information reported is unknown. The website does provide guidance stating that any chemical that has a Material Safety Data Sheet (MSDS) and is deemed nonproprietary should be reported [21]. However, chemicals are often reported as classes of chemicals (e.g., carbohydrate polymer, aliphatic alcohol), so that the exact identity of the chemical is unknown. While voluntary reporting is a first step toward increasing disclosure and public knowledge—and industry and some state governments view it as sufficient—the website does not have any government oversight nor does it provide complete information for lawmakers, regulators, or communities regarding the specific chemicals that are being injected during hydraulic fracturing.

Recently, The Endocrine Disruption Exchange (TEDX)[1] conducted a study to determine chemical mixtures present in fracturing fluids [14]. TEDX created a list of 944 products currently used in natural gas operations as reported by a variety of sources including the U.S. Bureau of Land Management, the U.S. Forest Service, state government departments, and the natural gas industry. Among those products, 632 different chemicals were identified (e.g., methanol, ethylene glycol) [14]. More than 75 percent of the chemicals identified in the TEDX report are known to affect the skin, respiratory system, and/or the gastrointestinal system. Further, approximately 50 percent of the chemicals are known to have effects on the nervous system, immune system, and/or cardiovascular/circulatory system [14].

The chemical additives are undeniably a small fraction of the fluid composition. However, they consist of up to 2 percent of approximately 2 million gallons of fluid used in each operation; which results in nearly 40,000 gallons of undisclosed chemicals used at each well [11]. TEDX was able to identify many chemicals commonly used in fracturing fluid; however, it reports that for 43 percent of the products it investigated, only 1 percent of the total chemical composition of the product was identified [14]. This demonstrates that the precise chemical makeup of most fracturing fluids remains largely unknown. Lawmakers and the public lack information regarding the chemical mixtures used in fracturing fluid because companies are largely not required to release this information to regulators or the public. There is no federal regulation that mandates chemical disclosure, and state regulations exist but are varied. Lack of full chemical disclosure prevents us from understanding possible health and environmental effects associated with hydraulic fracturing and injection of fracturing fluids, as well as preventing proper monitoring of chemical contamination as a result of hydraulic fracturing operations.

HYDRAULIC FRACTURING EXEMPTIONS IN FEDERAL REGULATIONS

Currently there are no federal regulations requiring natural gas companies to disclose information about chemicals used in hydraulic fracturing fluids. As a technology used by the natural gas industry, hydraulic fracturing is often considered a protected practice in laws from which the oil and gas exploration industry as a whole is exempt from regulation, including the Emergency

[1] TEDX (www.endocrinedisruption.com) is a nonprofit organization whose mission is to prevent harmful exposures to endocrine-disrupting chemicals by seeking out, selecting, organizing, reviewing, and interpreting scientific research.

Planning and Community Right-to-Know Act of 1986 (EPCRA) [22]. Hydraulic fracturing as an injection process is specifically exempt from the Safe Drinking Water Act (SDWA) [23, 24].

Emergency Planning and Community Right-to-Know Act

Hydraulic fracturing and reporting of the chemicals used in fracturing fluid is exempt from EPCRA [24]. Section 313 of EPCRA created the Toxic Release Inventory (TRI), which requires companies that manufacture and/or use toxic chemicals to report information on chemicals, including identities and quantities that are stored, released, transferred, or "otherwise used" [25, 26]. The reporting requirements for toxic chemical releases include any intentional or unintentional discharge of toxic chemicals into the air, water, and/or soil [25]. Except for chemicals claimed as trade secrets, the information reported to TRI is deemed public knowledge, so that communities remain informed about possible chemical exposures [26]. However, the North American Industry Classification System (NAICS) code for Oil and Gas Extraction is not listed under Section 313 of EPCRA, exempting this industry from reporting information on the release of toxic chemicals [26]. Consequently, quantities of chemicals used in hydraulic fracturing fluid are not subject to TRI reporting guidelines.

Safe Drinking Water Act

Historically, the EPA did not regulate hydraulic fracturing under the Underground Injection Control (UIC) Program of the SDWA because the combined processes (well-drilling, injection of hydraulic fracturing fluids, and natural gas extraction) were considered primarily "extraction" processes rather than "injection" processes [17]. The UIC Program is responsible for regulating the construction, operation, permitting, and closure of injection wells that place fluids underground for storage or disposal [27].

However, a 1997 decision by the11th Circuit Court of Appeals in a lawsuit brought by the Legal Environmental Assistance Foundation (LEAF) against EPA required the agency to regulate hydraulic fracturing in Alabama as a Class II injection well (injection related to the production of oil and gas) under the UIC Program of the SDWA [28].

LEAF originally petitioned the EPA on behalf of the McMillian family, who claimed that nearby fracking had contaminated their well water [29]. The petition requested that the EPA withdraw Alabama's primary enforcement responsibility (known as primacy) for the state's UIC program until the state included regulations for the injection of hydraulic fracturing fluids as part of the program plan [29]. If included under this regulation, injection of fracturing fluid would be subject to a permitting, reporting, and monitoring process [26]. The EPA asserted that the UIC Program under the SDWA does not specifically require regulation of hydraulic fracturing and maintained that it had no legal requirement to regulate hydraulic fracturing as an injection process [30]. The 11th Circuit Court of Appeals disagreed with the EPA. Following the court's decision, the EPA was required to conduct a study to assess the risk posed to human health by the process of hydraulic fracturing.

While EPA's study was ongoing, in 2003, the agency entered into Memorandum of Agreement (MOA) with three companies which are together responsible for 95 percent of the hydraulic fracturing projects in the United States. As part of the MOA, these companies would not use diesel as part of the fracturing fluid mixture when they are removing natural gas from areas near underground drinking water sources. However, this MOA is not enforceable, and there is no penalty for a company should it wish to terminate the agreement [31].

EPA's court-mandated report, issued in 2004, determined that no further study into the health effects of hydraulic fracturing was necessary. Critics have questioned the legitimacy of this study because it did not involve any data collection, instead depending on existing literature and interviews with industry representatives and state and local government officials. In addition, the study considered effects on drinking water only from drilling in coal beds, but fracking takes place in additional types of substrates [32].

Regardless of the alleged flaws in the EPA report, in August 2005 Congress passed the Energy Policy Act exempting fracking from regulation under the 1974 Safe Drinking Water Act [17]. Specifically, the Energy Policy Act included in Section 322 an amendment to Section 1421(d)(1) of the SDWA exempting hydraulic fracturing as an underground injection process (42 USC 15801 § 322). The amendment states that underground injection "excludes – (i) the underground injection of natural gas for purposes of storage; and (ii) the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities" [23].

FAILED ATTEMPTS AT FEDERAL REGULATION

Two acts introduced in the last five years, and one proposed rule by the Obama Administration [33], attempted to amend federal exemptions of hydraulic fracturing and/or introduce provisions mandating the disclosure of the chemical composition of fracturing fluid. All three attempts to regulate chemicals in fracturing fluid at the federal level failed. A third act has proposed to specifically designate this as a responsibility of states.

The American Power Act

In 2010, Senators John Kerry (D-MA) and Joseph Lieberman (I-CT) introduced the American Power Act, which included a section amending Section 324 of the Emergency Planning and Community Right-to-Know Act of 1986 [34]. As mentioned previously, as a practice of the oil and gas extraction industry, hydraulic fracturing is not included in the list of activities/industries required to report toxic chemical releases under EPCRA. Section 4131, Notice of Hydraulic Fracturing Operations, of the proposed American Power Act stipulated that "a hydraulic fracturing service company shall disclose all chemical constituents used in a hydraulic fracturing operation to the public" [35]. The bill would have required information to be distributed to the public via the internet, for the benefit of both private citizens and state and local authorities who are often unaware of the fracturing chemicals being used in their regions [35]. The Act was reportedly opposed for reasons unrelated to the hydraulic fracturing amendment clause and never made it out of committee [34].

The Fracturing Responsibility and Awareness Act

The Fracturing Responsibility and Awareness (FRAC) Act entered House and Senate committees in both the 111th and 112th Congressional Sessions with the sole purpose of regulating hydraulic fracturing at a federal level [36]. The FRAC Act had two major purposes: (1) to amend Section 1421(d)(1) of the SDWA by removing the clause that exempts hydraulic fracturing from regulation under the UIC program; and (2) to mandate the disclosure of fracturing fluid chemical composition by adding regulations to Section 1421(b) of the SDWA, which outlines requirements for State UIC programs [37].

The chemical disclosure requirements in the FRAC Act had four specific objectives. First, operators of a well site must disclose to a designated federal or state regulator a list of chemicals intended for use before the fracturing fluid is injected [36]. When injection and extraction operations are complete, the operator must disclose the list of chemicals that were present in the fracturing fluid that was actually used [36]. Specifically, for every chemical being used (intended and actual), companies must disclose names (including CAS numbers), safety information (MSDS), and specific volumes of each chemical used. Second, the disclosure clause stipulated that information on nonproprietary chemicals be released to the public [36]. Third, if a spill occurs or an emergency situation arises, well operators must disclose the specific identity of all proprietary chemicals so that regulators and emergency personnel can properly address the situation [36]. Finally, the bill allows for proprietary information to be excluded from public disclosure in emergency and non-emergency situations [36]. Only information on nonproprietary chemicals will be released into public domain.

Supporters of the FRAC Act emphasized that the proposed amendment to the SDWA made certain that hydraulic fracturing would be regulated under "a consistent set of federally enforceable regulatory requirements" [38]. Senator Casey (D-PA) released a statement saying, "Disclosure will ensure that if drinking water supplies, surface waters, or human health are compromised, the public and first responders will know how to respond properly. I view disclosure as a simple matter of citizens having a right to know about all risks in their community" [38].

Opponents of the act included state lawmakers, industry representatives, and even some environmental groups. State lawmakers made arguments against the FRAC Act, asserting that states where hydraulic fracturing is common practice already effectively regulate operators [39]. Furthermore, they argued that each state is best equipped to create laws that address the state's geologic subtleties, which may necessitate differing operating practices [40]. Despite a specific clause protecting proprietary chemical identity from public release, industry expressed concerns over the disclosure of proprietary chemicals to federal regulators [39]. They feared protection of the information would not be sufficient and release of trade secret information would damage their competitive edge in the natural gas market. Some environmental groups were also critical of the FRAC Act, saying it did not go far enough in regulating hydraulic fracturing. Environmental groups disagreed with the continued protection of proprietary chemical information and cited shortcomings of the information being released about nonproprietary chemicals [36]. Their main concern is the lack of information provided by the MSDS, which often does not include health effects from environmental exposure to chemicals [36]. In addition, MSDS information exists for only a limited number of chemicals; only chemicals deemed hazardous by the Occupational Safety and Health Administration (OSHA) will have an MSDS [26, 41]. The bill was not passed into law; indeed, it did not make it out of committee during either Congressional session.

Fracturing Regulations are Effective in State Hands Act

On March 28, 2012, Senator Inhofe (R-OK) and Senator Murkowski (R-AK) introduced the Fracturing Regulations are Effective in State Hands (FRESH) Act [42]. This act is designed to guarantee that states, not the federal government, have exclusive authority to regulate hydraulic fracturing activities within state boundaries [42]. Justification of sole state regulatory authority is based on a "lack of evidence" that hydraulic fracturing in one state presents a contamination risk to groundwater in another state [42].

FRACTURING REGULATIONS AT THE STATE LEVEL

Arkansas, Colorado, Montana, Ohio, Oklahoma, Pennsylvania, Texas, and Wyoming have enacted fracturing disclosure laws [43, 44]. As of this writing, Ohio's disclosure law is the most recent to pass, effective August 1, 2012, and reflects some lessons learned from other states [44]. We draw on the examples of Texas and Pennsylvania, periodically referring to Ohio, to illustrate the issues of contention among environmental health professionals and advocates, regulators, and industry.

State of Texas

Texas is one of the first states to enact a chemical disclosure regulation specific to fracking. The "Hydraulic Fracturing Chemical Disclosure" rules adopted in Texas have become the blueprint for regulation in other states. Many of the technologies responsible for increasing natural gas yields were borrowed from the Texas offshore oil and gas industry. Hence, Barnett Shale natural gas production increased 3000 percent from 1998 to 2007, making Texas the unofficial leader in energy resource recovery through hydraulic fracturing [4]. Texas has fought aggressively to maintain state control over regulations, with some Texans arguing that potential impacts of hydraulic fracturing such as "groundwater contamination, wastewater disposal, impacts to local character, and seismic impacts are essentially local in nature . . . and do not cross state boundaries," and thus should be regulated at the state instead of at the federal level [45].

The Rail Road Commission (RRC) is the primary agency that regulates Texas' oil and gas industry. Regulations prior to 2012 primarily identified and established a clear definition of well operators (i.e., owners or managers), confirming the financial security of a well operator, and establishing procedures for public notice of new applications for injection well permits received on or after September 1, 2005 [46]. Areas surrounding aquifers, usually protected from drilling activities, may be used for underground injection wells if the well operator applies for an aquifer exemption [46].

In response to public pressure and possibly as a mechanism of preempting federal oversight, the RRC adopted new rules on December 13, 2011, requiring the disclosure of the intended, nonproprietary chemicals used in hydraulic fracturing fluids [47]. These rules apply to treatments occurring on wells that have been issued an initial drilling permit on or after February 1, 2012, but do not place disclosure requirements on wells with prior permits [46]. This regulation requires the operator of the well to provide general information about the well's location and dates of drilling activities, volume of water used, and each intended additive—its CAS number, intended use, and its maximum concentration by mass [46]. There is no requirement to report chemical components of hydraulic fracturing fluid before the fracturing activities begin. Instead, no later than 15 days *after* completion of a hydraulic fracturing treatment, the operator is required to file the chemical disclosure report with the RRC, and this information will be uploaded to the FracFocus website and henceforth be considered public information [46]. The RRC is responsible for enforcement, and violations may result in "monetary penalty and/or lead to the revocation of a well's certificate of compliance" [47].

The chemical disclosure requirements in Texas, as in many of the other states with disclosure rules, have significant loopholes, which provide allowances for incomplete disclosure of the chemicals and quantities used, as well as the disclosure of inaccurate information. First, the rule requires reporting of only "actual or the maximum concentration of each chemical ingredient . . . in percent by mass" [48], instead of the total amount of the chemical used at the site. Second, chemicals that are "unintentionally added" or "occur incidentally" are exempt from disclosure [48]. Another caveat of the disclosure law is that suppliers, service companies, and operators are not held responsible for the reporting of inaccurate information to the RRC [48]. Chemicals entitled to trade secret protection can be entirely exempt from public disclosure, unless disclosure is considered necessary during an emergency situation [47]. In Texas, certain commercial or financial information can be exempted from public disclosure laws if, "based on specific factual evidence, disclosure would cause substantial competitive harm" [49]. The factors that determine if information qualifies for trade secret protection are: the extent to which the information is known by employees within or people outside of the company; the measures taken or amount of money expended by the company in developing and guarding the secrecy of the information; the value of the information to the company; and the ease with which the information could be acquired or duplicated by others [50]. If an emergency situation arises, the presence of additives protected by trade secret must be disclosed to emergency responders or health professionals to allow for proper cleanup and/or medical treatment for exposed individuals [48]. In the case of Texas, first responders must sign a statement of confidentiality, and are allowed to discuss chemical identities only with other first responders or accredited laboratories; they are not permitted to disclose chemical identities to the person(s) receiving medical care [48]. In contrast, Ohio's recently passed law provides that "Doctors may share even proprietary chemical information with the patient and other medical professionals directly involved in treating a patient" [51]. While these state regulations are intended to establish transparency, they each fall short of full chemical disclosure and provide effective immunity to companies reporting inaccurate data.

Commonwealth of Pennsylvania

It has been known since the 1930s that natural gas existed in the Marcellus Shale formation in Pennsylvania; however, conventional vertical drilling was not successful because the gas occurs in "pockets," and therefore flows could not be sustained [2, 52]. In 2003, Range Resources–Appalachia began drilling wells, modifying the horizontal drilling techniques utilized in the Barnett Shale; by 2005, Marcellus gas was flowing [52]. Some assessments estimate more than $500 billion in recoverable natural gas exists in Pennsylvania alone, bringing on a drilling frenzy and leading to the creation of more than 350,000 active and inactive gas wells in Pennsylvania [7].

In Pennsylvania the Public Utilities Commission and the PaDEP are responsible for policing oil and gas activities. In 2008, a state investigation found 18 methane-contaminated wells after drilling activities began in the Susquehanna County area [53]. PaDEP fined the drilling company $120,000 and required potable water be brought in until the company installed gas mitigation devices at each residence [53]. In a 2009 incident, gas migrated into a residential water well and exploded, spewing fracturing fluid, brine, unknown chemicals, and gas into a forest about 90 miles outside of Pittsburgh [4]. These and other spill events have intensified public pressure on the pro-drilling Pennsylvania administration to require disclosure of the chemicals used in hydraulic fracturing fluids.

Pennsylvania General Assembly signed a new reform amendment into law on February 14, 2012, providing updates to the 1984 Oil and Gas Act [54]. The new act is designed to update environmental regulations, drilling fees, and local regulations for conventional and unconventional (i.e., hydraulic fracturing) oil and gas operations in the state. Within 60 days of commencement of drilling activities, well operators must complete a chemical disclosure form and post it to the industry-run registry [55]. The chemical disclosure form requirements are essentially identical to those of Texas; for example, they do not require disclosure prior to the start of fracking activities, they include exemptions from disclosure of proprietary information, and they do not hold operators, vendors, or service providers responsible for providing inaccurate data to the registry [55].

REGULATORY CHALLENGES AND FUTURE REGULATORY PROSPECTS

Enforcement

In some states, including Texas, companies have been slow to comply with the disclosure regulations [56, 57]. The NRDC found that state regulators were consistently accepting disclosure reports that were missing information required by Texas's hydraulic fracturing chemical disclosure rules [56]. Further, other investigations have found that almost half of new wells drilled in Texas go completely unreported and disclosure reports are not submitted to FracFocus [57]. These failures to comply indicate that some states are not providing adequate oversight.

In 22 states, the number of new oil and gas wells grew 45 percent between 2004 and 2009, leaving regulators scrambling to keep up. Complaints of understaffing within the responsible departments persist. Common jobs of state regulators include "policing" gas wells, oil wells, waste injection wells, disposal pits, compressor stations, and access roads. In addition, they are responsible for approving new permits, visiting new wells and old ones before they are sealed, and responding to complaints of all kinds [58]. An example of the insufficiency of state staffing of regulatory agencies can be found in Texas. In 2009, Texas had 273,660 wells and 106 regulators charged with overseeing them. In 2007, the Texas state auditor issued a report on the RRC's enforcement record. The auditor found that between 2001 and 2006, about half of the state's wells had not been inspected. The report also found that 30 percent of all spills were inspected late or not at all. Despite the growing workload, the budget is getting smaller. Between 2005 and 2009 the commission's budget for monitoring and inspections decreased by 10 percent. Even when regulators conduct inspections, there are sometimes flaws in their work [58].

While regulation of chemical disclosure is occurring at the state level, the examples of Texas and Pennsylvania highlight shortcomings and loopholes that result in the provision to the public of inadequate information—or misinformation—regarding the chemical composition of hydraulic fracturing fluids. The above examples also point to a lack of compliance due to failed state oversight. Federal regulation and oversight may be necessary to ensure that sufficient and accurate information is being reported. We suggest that the federal government not preempt state regulation of fracking, but at a minimum require adequate chemical disclosure to federal, state, and local regulators, and to the public.

Future Prospects

In the FY2010 Budget, the U.S. House of Representatives Appropriations Conference Committee included funds for a new EPA study on the effects on drinking water of hydraulic fracturing of shale formations [26]. EPA's first action was to request the chemical composition of drilling muds and fracturing fluids from nine of the largest natural gas and hydraulic fracturing companies [59]. The EPA recognized this as the fundamental first step in completing "a more thorough assessment of the potential impact of hydraulic fracturing," which underscores the importance of chemical disclosure [59]. The EPA study is underway and an initial progress report is expected in late 2012.

In March 2011, President Obama instructed the Secretary of Energy Advisory Board (SEAB) to create a subcommittee focused on exploring options for improving the safety of and public support for shale gas development [40]. From this charge, the Shale Gas Production Subcommittee completed two reports in which disclosure of fracturing fluid composition is a recommendation on the list "for immediate implementation" [40]. The Subcommittee recognized the work done by industry on the FracFocus.org website as a first step and believes that "disclosure should include all chemicals, not just those that appear on MSDS" [40]. They also envision that disclosure of the chemical composition of fracturing fluid will appear on a well-by-well basis and that this information will be made publicly available via a website. While this call for complete disclosure is encouraging, the Subcommittee's implementation plan is lacking.

The Subcommittee recommends relying on the Department of Interior to design and implement a plan for requiring chemical identity disclosure of fracturing fluids on federal lands [40].

The Department of Interior Bureau of Land Management controls all federal and public lands and has historically allowed natural gas extraction, including the use of hydraulic fracturing on public lands. In May 2012 the Bureau of Land Management issued a proposed rule [33] that would have required industry to report fracturing fluid composition prior to drilling on public lands, but the Obama Administration reportedly backed off from this demand, agreeing to allow companies to reveal the contents of drilling fluids after the fact [61].

Efforts also continue to update federal regulations to include hydraulic fracturing under some of the major environmental laws. In August 2011, the environmental group Earthjustice petitioned the EPA on behalf of over 100 community and environmental groups across the country [62] calling for EPA to pursue regulation of hydraulic fracturing (including drilling muds and fracturing fluids) under Section 4 and Section 8 of the Toxic Substances Control Act (TSCA) (15 USC § 2620) in order to protect "public health and the environment from the serious risks posed by chemical substances and mixtures used in oil and gas exploration and production" [62]. The group requested that EPA pursue, under TSCA Section 4, a requirement for manufacturers and users of fracturing fluids to identify all chemicals used and to conduct toxicity testing on those chemicals [62]. The information gained from the disclosure of chemicals and toxicity testing would be used to evaluate impacts on human health and the environment. Under TSCA Section 4, the EPA has "authority to require testing of chemicals which may present a significant risk or which are produced in substantial quantities and result in substantial human or environmental exposure" [26]. Additionally, Earthjustice asked EPA to adopt a rule under TSCA Section 8(a) requiring manufacturers and users of fracturing fluids to maintain, update, and submit records to EPA regarding specific chemical identities, proposed categories of use, potential byproducts, and existing and/or new environmental and health effects data [62]. Under TSCA Section 8 the EPA can implement "recordkeeping and reporting requirements to ensure that the EPA administrator would continually have access to new information on chemical substances" [26].

In November 2011, the EPA Assistant Administrator Stephen Owens responded to the Earthjustice petition in two separate memos [63, 64]. First, the EPA denied the petition's first request for adoption of a rule under TSCA Section 4 requiring toxicity testing for all chemicals used in fracturing fluid [63]. The EPA stated that the petition "did not set forth facts sufficient to support the required findings under TSCA Section 4(a)(1)(A) or 4(a)(1)(B) for issuance of a test rule" [63]. The EPA response memo suggests Earthjustice did not sufficiently identify a "risk trigger" (TSCA Section 4(a)(1)(A)) or an "exposure trigger" [26]. A *risk trigger* is defined under TSCA as a chemical that the EPA determines presents an "unreasonable risk of injury to human health or the environment"

[26]. An *exposure trigger* is defined under TSCA as chemical that is "produced or released into the environment in substantial quantities" [26].

The burden for EPA of proving that a chemical (or a group of chemicals) is either a risk trigger or exposure trigger is very high. The catch-22 for both of these rules is that often data do not exist that would allow the EPA to conduct a risk determination for a chemical. While the EPA can require testing if it finds that insufficient data exist, often the agency must still prove "unreasonable risk" for the risk trigger and "substantial quantities" for the exposure trigger. In essence: no data, no risk; no risk, no data.

In the EPA's second memo, it partially granted petitioners' request for initiating a "rulemaking process" under TSCA Section 8(a) requiring some reporting on chemicals used in fracturing fluids [64]. As a first step, the EPA will convene a "stakeholder process" to determine an approach for reporting that will involve minimal cost and duplication of effort while maximizing information, transparency, and public understanding [64]. States, industry, and public interest groups will be allowed to participate in the dialogue [65].

While there is some movement toward regulating hydraulic fracturing, and mandating chemical disclosure appears to be high on the list of priorities for environmental and community groups as well as some federal legislators, the process of changing federal regulations is slow and will continue to be challenged by industry and some lawmakers.

CONCLUSIONS

Advancements in natural gas recovery technologies and attractive prices have spurred a modern day "gas rush," leading to a 48 percent increase in U.S. shale gas production from 2006 to 2010 [1]. Natural gas extraction using hydraulic fracturing does provide benefits, such as a domestic energy source that may be cleaner than coal. However, these benefits should not exempt the industry from federal environmental laws that are put in place to protect public health and the environment. Hydraulic fracturing activities come with a cost—incidents of leaking pipelines, wellhead explosions, lack of wastewater treatment, and toxic air emissions, which can lead to significant cleanup costs and environmental health impacts—so regulation is necessary [4]. To mitigate these environmental and human health costs, all hydraulic fracturing activities should be better regulated. The SEAB recommended regulations to reduce air emissions from hydraulic fracturing practices and also regulations to ensure water management and groundwater safety [40]. We view regulation of hydraulic fracturing fluid chemical disclosure as a first step towards other hydraulic fracturing regulations. To create an enforceable and protective regulatory program, lawmakers should first have knowledge of the chemicals used in these processes and then determine whether the chemicals require regulation to protect public health and safety and the environment.

Shortcomings of state regulations, their variable enforcement, and limitations of the current voluntary reporting mechanism lead us to recommend federal regulations requiring full disclosure of chemical additives in hydraulic fracturing fluids. A federal law that both lifts current federal exemptions for hydraulic fracturing and mandates complete disclosure of chemicals (including proprietary and nonproprietary chemicals, and MSDS and non-MSDS chemicals) is essential. Federal regulations are crucial for setting a baseline of disclosure requirements that all states are required to follow. The foundation for creating federal regulation is a strong scientific base and the consideration and protection of human dignity, equity, and distributional impacts that are not requirements for state regulations or voluntary guidance [66]. Without information on the chemicals of concern, our regulations cannot be informed by scientific information or other knowledge regarding health risks. Oversight at the federal level could ensure that a standard set of regulations will be applied to hydraulic fracturing operations across the country.

Lastly, federal oversight of hydraulic fracturing will standardize and streamline regulatory processes, which can lead to economic benefits. In fact, the U.S. Office of Management and Budget recently reported the estimated cost and benefits associated with federal regulations [66]. The report concluded that, over the course of a decade (FY2001-FY2010), major federal regulations provided an estimated $132-$655 billion in net positive benefits while costing taxpayers between $44 billion and $62 billion [66]. Federal regulations enforcing the EPA's Clean Water Act, SDWA, and Clean Air Act were among the regulations that produced the highest net benefits compared to costs [66].

The current status of disclosure prevents the public, lawmakers, and scientists from understanding possible health and environmental effects, and also prevents proper monitoring of chemical contamination as a result of hydraulic fracturing operations. We believe federal regulations are essential to ensure that air and water quality will not be compromised, minimum requirements for chemical disclosure will be standardized across all states, and responsible parties will be held accountable if the natural environment or public health is harmed.

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AUTHORS' BIOGRAPHIES

EUGENE B. BENSON is an attorney who works with community groups on environmental justice issues and teaches environmental law and policy courses at several Boston area universities. Email him at ebbenson@verizon.net

ISAAC J. BURROWS is a recent graduate of Boston University's School of Public Health and its MPH program. Email address is isaacj81@gmail.com

COLLEEN MARIE MAKEY has her Master's of Science in Public Health and is a doctoral student at Boston University's School of Public Health. Contact her at cmakey@bu.edu

ALEXIS L. MAULE has her Master's of Public Health and is presently an Environmental Health doctoral student at Boston University. She's at lex0210@gmail.com on the internet.

MADELEINE KANGSEN SCAMMELL is an Assistant Professor of Environmental Health in the School of Public Health at Boston University. Her research includes the use of qualitative methods in the area of community-driven environmental health, epidemiologic studies, and cumulative risk analysis. Send email to her at mls@bu.edu

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Direct reprint requests to:

Madeleine Kangsen Scammell
Boston University School of Public Health
715 Albany Street, T4W
Boston, MA 02118
e-mail: MLS@bu.edu

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Features

MARCELLUS SHALE DRILLING'S IMPACT ON THE DAIRY INDUSTRY IN PENNSYLVANIA: A DESCRIPTIVE REPORT

MADELON L. FINKEL
JANE SELEGEAN
JAKE HAYS
NITIN KONDAMUDI

ABSTRACT

Unconventional natural gas drilling in Pennsylvania has accelerated over the past five years, and is unlikely to abate soon. Dairy farming is a large component of Pennsylvania's agricultural economy. This study compares milk production, number of cows, and production per cow in counties with significant unconventional drilling activity to that in neighboring counties with little or no unconventional drilling activity, from 1996 through 2011. Milk production and milk cows decreased in most counties since 1996, with larger decreases occurring from 2007 through 2011 (when unconventional drilling increased substantially) in five counties with the most wells drilled compared to six adjacent counties with fewer than 100 wells drilled. While this descriptive study cannot draw a causal association between well drilling and decline in cows or milk production, given the importance of Pennsylvania's dairy industry and the projected increase in unconventional natural gas drilling, further research to prevent unintended economic and public health consequences is imperative.

QA: Please supply 3-5 key words

Keywords: fracking, dairy industry

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The search for clean, efficient, and economic energy sources is a high priority for most nations, industrial and emerging. While oil and coal remain the predominant energy sources worldwide (34% and 30%, respectively), each has its advantages and disadvantages. Natural gas (24% of the world's energy source), hydropower (6%), and nuclear energy (5%) are being promoted as energy options [1]. While there are pros and cons to each of these energy sources, natural gas in particular is abundant around the world and has a "clean" reputation—in that it burns cleaner than coal, for example. It is easy to transport, reasonably economical, requires comparatively quick construction timelines and low capital costs, and has the added advantage of bringing jobs to economically depressed regions where natural gas reserves are plentiful. Because of these benefits, natural gas has emerged as a key energy source around the world.

Most natural gas is currently extracted from conventional deposits, where it has migrated from a source rock and been trapped. However, a significant amount of natural gas is found distributed in relatively impermeable rock formations such as shale. Shale gas, once extracted, is identical to conventional natural gas.

For years, extracting natural gas from vast shale deposits was too costly and technologically challenging. Technical advances, however, have allowed the extraction of fossil fuels that in the past were logistically impossible and/or economically prohibitive (e.g., deep-ocean drilling for gas and oil, extracting oil from tar sands, and deep mining for coal, minerals, and ore). Today, extracting natural gas from vast shale deposits is possible by means of high-volume hydraulic fracturing of shale formations, using slick-water and multiple long, horizontal laterals from clustered, multi-well pads generally referred to in the media as fracking, hydraulic fracturing, or unconventional drilling.

In 2001, shale gas accounted for 2 percent of total natural gas production. As of 2010, it accounted for 23 percent of U.S. natural gas production, and this share is projected to increase to nearly half of the total production by 2035. Ironically, the shale gas boom has positioned the United States to become an overall net exporter of natural gas [2]. Indeed, the natural gas industry now has a glut so vast that import facilities are applying for licenses to export gas to Europe and Asia [3].

Unconventional drilling injects under high pressure huge volumes of fracturing fluid (referred to as slick-water), which is comprised of water, sand, and chemicals, many known to be toxic, several thousand feet underground to create or re-open cracks or fissures in the shale formation to release trapped shale gas. Gas operators in the United States are allowed to protect their proprietary formulas, and they do not have to disclose the chemical compounds used in the drilling process, thus making it difficult if not impossible to assess the full scope of the contents of the fluid that is returned to the surface ("flowback" fluid). Thirty to 70 percent of the fluid will resurface, bringing back with it toxic substances, including heavy metals, naturally occurring radioactive materials (NORMs), and toxic and volatile organic compounds including benzene, a known carcinogen. Flowback waste fluids, held in open reserve pits or in non-airtight metallic containers, must be disposed of safely because they can potentially contaminate air and soil as well as waterways and watersheds. Despite a recent Environmental Protection Agency (EPA) study of groundwater contamination near the town of Pavillion, Wyoming, that suggests a pathway for exposure [4], no state has adequate regulations on drilling, particularly related to the disposal of the toxic wastewater fluids.

Despite the paucity of studies evaluating the potential impact on human health, unconventional drilling has accelerated at a rapid pace in many areas in the United States. In particular, Pennsylvania, through which the Marcellus Shale extends, has embraced an aggressive policy of unconventional drilling. Almost 6,000 wells have been drilled in a six-year period, and thousands more drilling permits have been issued [5]. In 2011 alone, 2,096 drilling permits were issued in five counties in which there already is substantial ongoing unconventional drilling activity (Bradford, Lycoming, Susquehanna, Tioga, and Washington). Tens of thousands of permits are expected to be issued over the next decade in Pennsylvania.

Agricultural activity in Pennsylvania is important to its economy, and dairy farming is a large component of the state's agricultural economy. The state ranks fifth in milk production in the United States after California, Wisconsin, Idaho, and New York [6]. One of the top milk-producing counties, Bradford, happens to be located within the Marcellus Shale and as of 2011 has the greatest number of unconventional wells drilled of all Pennsylvania counties.

The economic implications of unconventional drilling activity have not been well studied, nor have studies been conducted to assess the impact on the environment or on human and animal health. In the absence of health impact assessments for human health, animal studies can shed light on the potential harmful effects of drilling. Like the canary in the coal mine, cows, horses, poultry, and other wildlife can be used as sentinels to foreshadow impacts to human health. Animals tend to suffer more direct exposure and have shorter life and reproductive cycles, making it easier to document effects.

A recent qualitative study, published in a peer-reviewed journal, focused on the impact of gas drilling on animal health (interviews conducted with animal owners in Colorado, Louisiana, New York, Ohio, Pennsylvania, and Texas), documenting reproductive (irregular cycles, failure to breed, stillbirths), neurological (seizures, incoordination, ataxia), gastrointestinal (vomiting, diarrhea), and dermatological (hair and feather loss, rashes) problems among livestock [7].

Another recently completed study investigating changes in milk production and cow numbers in Pennsylvania counties between 2007 and 2010 found an association between drilling and declining cow numbers, with higher drilling activity associated with larger average declines in cow numbers. Further, counties with 150 or more Marcellus Shale wells on average experienced an 18.5 percent decrease in total milk production compared to an average increase of 0.9 percent in counties with no Marcellus Shale wells drilled [8]. While the study could not fully explain the findings, the implications for Pennsylvania, with its large dairy industry, need to be more fully investigated.

This descriptive study seeks to lay the basis for observing trends in a longitudinal approach and to raise questions that can be tested in a more analytic manner. We focus on Pennsylvania primarily because there has been an explosive increase in unconventional drilling in this state since 2006 (unlike in neighboring New York, which as of 2012 has a moratorium on drilling in place), and because the implications for its agricultural and dairy industries could be significant.

METHODS

From 1996 through 2006 there was essentially no unconventional drilling for natural gas in any county in Pennsylvania. From 2007 forward, however, there was a substantial increase in the number of wells drilled in counties that have Marcellus Shale beneath them. We focus on comparing milk production (in thousand of pounds), number of cows, and average milk production per cow in counties with the most unconventional drilling activity to neighboring counties with less unconventional drilling activity (defined as fewer than 100 wells drilled) from 1996 through 2011, with particular focus on the years 2007 through 2011. Five counties with the greatest amount of drilling activity were selected (Bradford, Lycoming, Susquehanna, Tioga, and Washington) and six neighboring counties with fewer than 100 wells drilled were chosen for comparison (Beaver, Clinton, Lackawanna, Potter, Somerset, and Sullivan). Data on milk production per cow, total milk production, and total number of milk cows, by county by year, were obtained from the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) [9]. The number of drilled wells, measured through spud well data provided by the Pennsylvania Department of Environmental Protection, was obtained for each county by year [10]. In oil and gas parlance, *spud* refers to the actual start of drilling of an unconventional gas well, and this is how Pennsylvania drilling data are compiled.

As noted above, NASS updates statistics on milk production yearly, and Pennsylvania census data on the number of farms become available every five years (the next update is expected in 2014). However, a finer-grained analysis that would relate milk production or herd numbers to distance to active wells is not possible because data are not reported on the level of individual farms.

FINDINGS

Figure 1 shows the increase in number of wells drilled by county by year for the five counties with the most wells. Of counties with drilling activity, Bradford has the greatest number of wells by far.

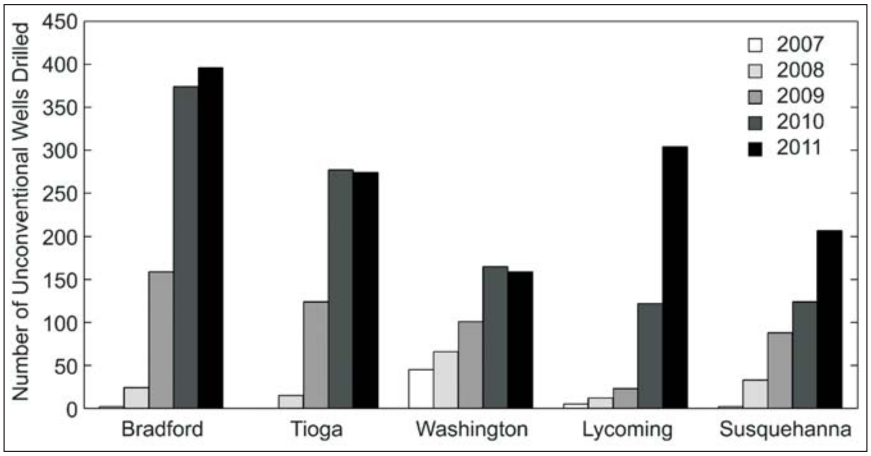

Figure 1. Unconventional wells drilled by county by year.

Table 1 shows, by county, the percent change from 2007 to 2011 in number of milk cows and total milk production (in thousands of pounds), and also the number of wells drilled during these years. The number of milk cows in each of the counties with the most wells drilled declined substantially during this time period, ranging from –18.3 percent in Tioga county to –46.7 percent in Washington county. In the counties with fewer than 100 wells, the percentage change in number of milk cows varied, showing no change in two of the counties, a modest decrease in three of the counties, and an 11.5 percent increase in Potter County. For those counties that showed a decrease in the number of milk cows, there was a corresponding decrease in the total milk production. Similarly, each county in the group with the most drilled wells posted a decrease in total milk production, whereas the change among the adjacent counties with fewer than 100 wells was varied. In this group, the three counties that had a reduction in the number of milk cows also had a reduction in milk production. The two counties with no change in the number of milk cows posted increases in total milk production, and the only county to show an increase in the number of milk cows also showed an increase in total milk production. There does not seem to be a clear relationship between the percentage changes in dairy indicators and the number of wells drilled. For example, Washington County showed the largest decline in the number of milk cows and total milk production, but has far fewer drilled wells than Bradford County. The following tables present the data with more detail.

Tables 2a and 2b show the mean, median, standard deviation, and range in the annual number of milk cows for each county. In all five counties with the most wells drilled, the data show a substantial decrease in the number of milk cows

Table 1. Percent Change in Number of Milk Cows, Total Milk Production, and Number of Wells Drilled by County, 2007-2011

County	Percent change in number of milk cows	Percent change in total milk production (pounds)	Number of wells drilled
Counties with most wells drilled (*N* = 5)			
Bradford	–25.6	–20.6	955
Tioga	–18.3	–16.8	690
Washington	–46.7	–28.9	536
Lycoming	–36.0	–26.5	466
Susquehanne	–25.0	–23.9	454
Adjacent counties with fewer than 100 wells drilled (*N* = 6)			
Sullivan	–5.3	–2.5	41
Clinton	0	+ 1.4	88
Potter	+ 11.5	+ 8.7	72
Lackawanna	0	+ 10.0	2
Somerset	–12.1	–10.5	19
Beaver	–11.1	–10.1	7

both from 1996 through 2006 (prior to active drilling) and from 2007 through 2011. With the exception of Clinton County, adjacent counties with fewer than 100 wells drilled also showed a decrease in the number of milk cows from 1996 through 2006. From 2007 through 2011, the outcome was more mixed: some of the counties experienced a modest decrease (Sullivan, Somerset, Beaver), some experienced no change (Clinton, Lackawanna), and one experienced a modest increase (Potter). Overall, these findings seem to indicate that drilling did not accelerate a decline in the number of milk cows, as the decline was underway before wells were drilled; however, even though drilling had not commenced prior to 2007, the sale and leasing of land most certainly had.

A decrease in the number of cows could explain a decrease in milk production. Tables 3a and 3b show the mean, median, standard deviation, and range in total milk production (in thousands of pounds) by county by year. Data show that during the years 1996 through 2006 in counties with the most wells drilled, there was a decline in total milk production ranging from –15.7 percent in Bradford county to –53.3 percent in Washington County. Only Lycoming County showed a modest increase (+7.6%). From 2007 through 2011 the trend continued, with every county showing a decline in total milk production. Among adjacent counties with fewer than 100 wells drilled, the picture is more mixed (Table 3b). From 1996 through 2006, some counties posted increases (notably Clinton with

Table 2a. Number of Milk Cows in the Five Counties with Most Wells Drilled, 1996-2011

	Counties				
	Bradford	Tioga	Washington	Lycoming	Susquehanna
Mean	25,843.8	13,387.5	4,640[a]	6,706.7[a]	12,481.3
Median	24,850	12,250	4,200	6,800	11,300
SD	3638.9	2555.7	1105.7	859.0	2889.1
Range	19,500-31,500	10,400-18,000	3,000-6,600	5,000-7,900	8,400-16,800
Percent change, 1996 to 2006	–30.7%	–52.5%	–73.7%	–16.2%	–58.5%
Percent change, 2007 to 2011	–25.6%	–18.3%	–46.7%	–36.0%	–25.0%

[a]Missing data for some years.

Table 2b. Number of Milk Cows in Six Adjacent Counties with Fewer than 100 Wells Drilled, 1996-2011

	Counties					
	Sullivan	Clinton	Potter	Lackawanna	Somerset	Beaver
Mean	2,243.8	5,593.3[a]	5,062.5	1,531.3	18,881.3	2,450
Median	2,100	5,600	5,100	1,500	19,250	2,300
SD	316.2	584.9	239.1	343.9	1098.0	539.1
Range	1,900-2,800	4,700-6,500	4,600-5,400	1,100-2,300	16,500-20,100	1,800-3,300
Percent change, 1996 to 2006	–19.0%	+20.3%	–10.4%	–81.8%	–10.4%	–60.0%
Percent change, 2007 to 2011	–5.3%	0%	+ 11.5%	0%	–12.1%	–11.1%

[a]Missing data for some years.

Table 3a. Total Milk Production (in Thousand Pounds) by Year in the Five Counties with Most Wells Drilled, 1996-2011

	Counties				
	Bradford	Tioga	Washington	Lycoming	Susquehanna
Mean	471,144.4	229,336.9	69,472[a]	105,249.3[a]	204,142.5
Median	463,795	216,110	64,500	114,600	195,950
SD	51,612.1	31,449.8	13,289.6	25,953.1	42,612.8
Range	380,000-539,300	190,000-282,400	52,000-93,800	95,000-122,700	155,000-275,800
Percent change, 1996 to 2006	–15.7%	–27.7%	–53.3%	+ 7.6%	–45.9%
Percent change, 2007 to 2011	–20.6%	–16.8%	–28.9%	–26.5%	–23.9%

[a]Missing data for some years.

Table 3b. Total Milk Production (in Thousand Pounds) for Six Adjacent Counties with < 100 Wells Drilled, 1996-2011

	Counties					
	Sullivan	Clinton	Potter	Lackawanna	Somerset	Beaver
Mean	38,821.9	161,134.7[a]	92,185	23,540.6	304,555.6	39,385.6
Median	38,200	100,800	94,320	22,250	305,200	37,650
SD	3,604.9	260,086.5	6,057.6	4,552.8	12,569.5	4,709.6
Range	34,400-45,600	69,600-110,050	82,700-102,200	18,000-33,200	285,000-327,000	33,500-46,600
Percent change, 1996 to 2006	–7.9%	+ 32.7%	+ 3.0%	–67.5%	+ 7.8%	–23.1%
Percent change, 2007 to 2011	–2.5%	+ 1.4%	+ 8.7%	+ 10.0%	–10.5%	–10.1%

[a]Missing data for some years.

a 32.7 percent increase during this time period) while other counties showed declines (notably Lackawanna with a 67.5% decrease). From 2007 through 2011, some counties posted modest increases (Clinton, Potter, Lackawanna) while others showed declines ranging from 10.5 and 10.1 percent declines in Somerset and Beaver Counties, respectively, a to 2.5 percent decline in Sullivan county.

To understand better the implications of these findings, data on average milk production per cow were obtained for the years 1996 through 2011. Table 4 compares the five counties with the most drilling to the adjacent counties with fewer than 100 wells drilled. Average annual milk production per cow remained fairly constant from year to year in the five counties with the most wells drilled and the six adjacent counties with fewer than 100 wells drilled. Tables 5a and 5b show the data in greater detail. In all counties with the most wells drilled there were modest increases in average milk production per cow between 1996 through 2006, and this trend continued during the 2007 through 2011 time period. In adjacent counties with fewer than 100 wells drilled, a similar picture emerges for the period 1996 through 2006, when every county posted an increase; however, for the time period 2007 through 2011, the situation is more mixed. Lackawanna county showed a greater increase in average milk production per cow (+10%) than the other counties, which either showed very modest increases or in the case of Potter and Sullivan Counties a slight decrease (–3.3%).

Table 4. Average Milk Production per Cow, by Year and County Group, 2007-2011

	Average milk production per cow	
Year	Counties with most wells drilled (N = 5)	Adjacent counties with fewer than 100 wells drilled (N = 6)
2007	17,949.4	17,734.8
2008	18,407.0[a]	17,868.6[a]
2009	17,848.2	17,561.5
2010	18,763.7	18,308.5
2011	18,970.3	17,931.2
Average, 2007-2011	18,386.1	17,881.3

[a]Missing data for some counties.
Note: t-value = 2.33, p = 0.05.

Table 5a. Average Annual Milk Production per Cow, for Five Counties with Most Wells Drilled 1996-2011 ($N = 5$)

	Counties				
	Bradford	Tioga	Washington	Lycoming	Susquehanna
Mean	18,311	17,291	15,181[a]	16,864[a]	17,236
Median	18,076	17,100	14,450	16,500	16,750
SD	834.43	996.22	1400	1293	1020.5
Range	17,000-19,744	15,400-18,868	13,881-18,667	15,000-19,400	16,000-18,966
Percent change, 1996 to 2006	+ 11.8%	+ 16.3%	+ 11.8%	+ 15.7%	+ 8.1%
Percent change, 2007 to 2011	+ 4.0%	+ 1.2%	+ 12.1%[a]	+ 7.0%	+ 1.4%

[a]Missing data for some years.

Table 5b. Average Annual Milk Production per Cow for Six Adjacent Counties with Fewer than 100 Wells Drilled, 1996-2011 ($N = 6$)

	Counties					
	Sullivan	Clinton	Potter	Lackawanna	Somerset	Beaver
Mean	17,345.6	16,959[a]	18,289.4	15,484.5	16,184.5	16,413.1
Median	17,400	16,900	18,402	15,000	16,050	16,063
SD	941.2	1237.8	1035.1	961.6	1195.0	1724.4
Range	15,700-18,648	14,800-18,750	16,200-19,800	14,400-17,500	14,400-18,155	14,000-18,611
Percent change, 1996 to 2006	+ 15.1%	+ 19.6%	+ 18.2%	+ 7.9%	+ 16.7%	+ 23.1%
Percent change, 2007 to 2011	–3.2%	+ 1.4%	–3.3%	–10.0%	+ 1.5%	+ 0.9%

[a]Missing data for some years.

DISCUSSION

Data based on U.S. Department of Agriculture statistics show a greater decrease in milk production (in thousands of pounds) and number of milk cows in counties with the most drilling activity compared to neighboring counties with fewer than 100 wells drilled. Similar findings were reported in the Kelsey report [11]. Our study shows that between 1996 and 2006, prior to active well drilling, there was a decrease in the number of cows and in milk production in counties with the most drilling and a more mixed picture in adjacent counties with fewer than 100 wells drilled. Counties with the most wells drilled during 2007 through 2011 uniformly had declines in total milk production ranging from –16.8 percent in Tioga county to –28.9 percent in Washington county. The number of wells drilled did not appear to explain the differences in this decline. Bradford County, for example, had the greatest number of wells drilled yet did not have the highest percent change in either the number of milk cows or total milk production. In fact, Washington County, with fewer wells drilled, posted the highest percentage changes.

This study could not determine whether milk production on farms whose owners had leased or sold land to drilling companies was less than on farms whose owners had not leased or sold part of their land. We do not know either the proportion of farms whose owners have leased or sold land or the proportion on which wells have been drilled. Our data could not explain the extent to which milk production and number of cows on farms in counties with the most drilling decreased compared to the same measures on farms where land had not been leased or sold in adjacent counties with less drilling activity.

Our analysis cannot explain whether dairy farmers downsized their herds, quit dairy farming, or some combination thereof. We also cannot determine how many dairy farmers in counties with the most active well drilling "took the money and ran." That is, with money earned from selling or leasing their land, what proportion of dairy farmers downsized or left the dairy business entirely? While our data clearly show differences among counties, this descriptive study cannot assume that there is a causal association between well drilling and decline in cow numbers or milk production. Clearly, further investigation should be initiated to better understand what is happening in Pennsylvania counties.

The dairy industry is very important in Pennsylvania, and implications for milk prices could be significant. Many factors probably influence the number of cows, milk production, and even milk prices; yet, the impact a downsized dairy industry would have on the economics of Pennsylvania should be analyzed. Given that the other major milk-producing state in the Northeast, New York, seems poised to begin allowing unconventional gas drilling, the effects on the dairy industry could become a major area of regional, if not national, concern. What is clear is that well drilling in Pennsylvania, based on the number of permits already issued, will continue, if not accelerate, over the next few years. It will be important for the State of Pennsylvania to monitor changes in milk production over time to see if the downward trend continues, both in counties with more wells drilled and in counties with fewer wells drilled, and to assess the potential effect of this situation on the state's economy.

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AUTHORS' BIOGRAPHIES

MADELON FINKEL is Professor of Clinical Public Health, Director Office of Global Health Education, Weill Cornell Medical College in New York City. Dr Finkel's professional career has been spent at Cornell University's medical college. She holds the rank of Professor of Clinical Public Health as well as Course Director for the Department (Epidemiology, Biostatistics, Evidence-Based Medicine, Introduction to the Health Care System, and Clinical Clerkship in Health Care Policy). She was named the medical school's first Director of the Office of Global Health Medical Education in 2004. She was instrumental in establishing Cornell Analytic Consulting Services, a division within the Department of Public Health designed to provide epidemiological consulting services. Dr. Finkel has been involved in epidemiological research and health care policy studies. Her pioneering work on second surgical opinion programs led to the widespread adoption and implementation of the second-opinion benefit required by almost all insurance companies, corporations, and unions. She has been examining the epidemiologic and public health implications of unconventional natural gas development for two years. Her address is maf2011@med.cornell.edu

JAKE HAYS is Program Director of Physicians, Scientists, and Engineers (PSE) for Healthy Energy in Ithaca, New York. He is the program director for the public-health energy nexus of PSE. He has worked as a research associate for Weill Cornell Medical College in New York City on several projects concerning unconventional natural gas development. He will continue to examine various public health aspects of shale gas development and other novel energy production methods. Contact him at jake.hays@gmail.com

NITIN KONDAMUDI is a second-year medical student at the University of Medicine and Dentistry of New Jersey (UMDNJ) in Newark. He is unsure about the specialty he wishes to pursue, but wants to affect policy regarding medical issues. He hopes to continue research that is related to public health policies. Write to him at sunnyd1026@gmail.com

JANE SELEGEAN is an Eleanor Roosevelt Scholar at the Public Policy Institute at Hunter College, New York, NY. She is an undergraduate student at Hunter College-City University of New York. She is studying to acquire degrees concentrated in neuroscience, public policy and the special honors curriculum

with minors in chemistry and English. She hopes to continue researching environmental and public health with relation to current political policy issues. Email her at jselegean@gmail.com

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Direct reprint requests to:

Madelon L. Finkel, Ph.D.
Weill Cornell Medical College
402 East 67th Street, LA-213
New York, NY 10065-6304
e-mail: maf2011@med.cornell.edu

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Voices

INSIGHTS ON UNCONVENTIONAL NATURAL GAS DEVELOPMENT FROM SHALE: AN INTERVIEW WITH ANTHONY R. INGRAFFEA

ADAM LAW
JAKE HAYS

ABSTRACT

Adam Law, M.D., interviewed Anthony R. Ingraffea, Ph.D., P.E., as part of a series of interviews funded by the Heinz Endowment. Dr. Ingraffea is the Dwight C. Baum Professor of Engineering at Cornell University, and has taught structural mechanics, finite element methods, and fracture mechanics at Cornell for 33 years. He discusses issues related to hydraulic fracturing, including inherent risks, spatial intensity, and the importance of a multi-disciplinary organization in establishing a chain of evidence.

Keywords: hydraulic fracturing, fracking, shale gas, spatial intensity, unconventional gas drilling

LAW: Tony, I wanted to discuss hydraulic fracturing and shale gas development with you since you're an engineer and a long-standing researcher in how objects and faults fracture. Specifically, I am interested in what insights you might have in addition to the information you typically provide regulators, policy makers, and others.

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INGRAFFEA: There is one very important aspect of unconventional gas developed from shale that hardly anybody understands, and I'm talking about the general public, policymakers, even regulators. The only entities that get it are the operators and a few individuals like myself who really understand the nexus between geology, geochemistry, engineering, science, and technology. And let me tell you what that issue is. It's called *spatial intensity*.

As you know, people are a bit upset about how things have progressed with shale gas development in a place like Pennsylvania. What people don't understand yet is that we haven't even started. Pennsylvania's been developing shale gas since 2007. And in that period of time there've been roughly 5,500 wells drilled, and people think, well, that's a lot.

But of those 5,500 wells that have been drilled, only about half have been fracked. And that half that's been fracked constitute about 2 percent of the eventual so-called build-out of Pennsylvania. So someone could fly over all of the areas of Pennsylvania right now that have been developed in Marcellus and say, that's not so bad, that's not like mountaintop removal in West Virginia. Well, not yet. Only about 2 percent of the wells that are going to be fracked have been fracked.

Yet, if we look at the consequences already—the number of individual private water wells that have already been contaminated, the number of health incidents that have occurred, the number of spills that have occurred, the number of truck accidents that have occurred—it's pretty simple now to start forecasting and crystal-ball–gazing and say what's it going to be like. If it's like this with 2 percent, what's it going to be like at 10 percent? What's it going to be like at 20 percent? It's going to be hellacious. The industry knows it. The gas is everywhere there's shale. Not in uniform quantities, of course. They still have to drill exploration wells to find their so-called hot spots—a county here, a county there.

But all of the prognoses that I'm reading out of the industry literature are that New York, Pennsylvania, Ohio, West Virginia, Maryland, a little bit of Virginia, are going to be subjected to at least 200,000 Marcellus Shale gas wells. And that's just the Marcellus. Of course they promise us there's also the Utica and a couple of others. So I'm repeating myself, but the single most important aspect that nobody gets is that it hasn't even started yet.

LAW: For those of us following up on this who are in the health care area, one of the big concerns has to do with pathways of exposure. In other words, in either the chemicals that we're putting into slick water or into drilling muds, or the flowback-produced waters, or the emissions coming back out as fugitive emissions—is there any way people can be exposed to that?

INGRAFFEA: Sure. The pathways are numerous and obvious. I categorize them as: from deep underground, from the surface, and from the air. And this kind of intense spatial development, number one, as I just said, is going to poke a few hundred holes in the ground that weren't there. Three hundred and thirty million years of sequestration of hydrocarbons, heavy metals, salts, and naturally occurring radioactive material is being de-sequestered. We're taking all that out and putting fresh water down.

Brilliant. What an exchange. What we just spent the last 30 or 40 million years doing, which is sequestering a lot of carbon dioxide, and putting a lot of water, drinkable water on the surface of the earth—we're reversing it. So yeah, poking a couple hundred thousand holes in the Marcellus, every one of those holes has to have a gasket. It's called a cement job. And we know that those gaskets fail at an alarming rate initially because they're really hard to put in place.

And most of them will fail eventually. By "eventually," I mean within a lifetime of a human, which means we're going to have tens of thousands of leaky gaskets. Which means that everything [that] was down there sequestered now has a pathway upwards into an underground source of drinking water or all the way to the surface. So that's pathway number one—poking all those holes and not being able to gasket them while they're operating and then successfully plug them when all these wells go out of operation. So we're postponing a major part of the problem.

At the surface, you have to bring chemicals to a well pad, and then you have to bring those chemicals and all the other waste products away from the well pad. That means transporting and storing. Anytime you transport and store hazardous material, you run the risk of spills. And obviously since it's spatially intense, we're going to have a lot of trucks, we're going to have lots of waste pits, we're going to have lots of pipelines, all of which at some point or another are going to cause some level of problem.

And then finally, air. What comes up out of the well is a gas, not just one gas, but all the other sisters and brothers of methane that want to come along for the ride. And not all of it goes into the pipeline, right? As we know, and as we're learning, a significant amount of it gets into the air in the form of hydrocarbon-based pollutants near the well pads that is capable of influencing people within a few miles, but also on a global scale. Again, spatial intensity. You've got the 200,000 wells in Pennsylvania, New York, West Virginia, Ohio, all those wells and all their ancillary infrastructure—compressor stations, processing stations, pipelines, storage units—they leak.

So we're going to be contributing to climate change in a way and at a time that we can least afford to. And to then say that this is the transition fuel that gets us to a sustainable and clean and climate-friendly future is absurd. It's walking the plank. It's not a bridge. A bridge has a near end and a far end. You want to get to the other end. This is a plank. Here we are, that's where we're going with this.

LAW: You're one of the founding board members of Physicians, Scientists, and Engineers for Healthy Energy (PSE), alongside myself. This organization is conceived as a multi-disciplinary group with people from a range of different backgrounds. How would you say this type of collaboration is important in addressing the science and the evidence of this new technology?

INGRAFFEA: It's fundamentally the right combination of expertise. As I tell the various aggrieved landowners, sometimes their lawyers who contact me for information, how can we prove the case? No one person has all the expertise.

Case in point, any one of these 200,000 wells that are going to be drilled in the Marcellus over the next *N* years can leak initially. Well, somebody has to be able to say, I understand the technology and the engineering of drilling, casing, cementing, and fracking a well. And I understand all the things that can go wrong, I understand why they go wrong, I understand when they go wrong, and I understand where they go wrong.

So if I read a well record, a daily diary that's kept by the operator of every single thing that happens on the well, then I can pinpoint, this is what went wrong, this is why it went wrong, this is where it went wrong, and this is when it went wrong. But that's insufficient. OK. The next thing you have to have is a geohydrologist who can say, well, if that went wrong there, then here are the consequences from the groundwater flow point of view.

If the gas well is upgradient of somebody's water well and I can say what leaked from this well, when it started leaking, and where it started leaking, then the next person in the chain, another kind of engineer, or scientist, geohydrologist, can say: and one, two, three days later, or three weeks later, or one year later, we can expect this concentration of contaminants to arrive in this person's well water. And *that's* not sufficient. OK, so—

LAW: What else do we need?

INGRAFFEA: Well, we need an engineer to say what went wrong, we need a scientist to say what the consequence was, and somebody down there has to be a professional who says, I can match up the contaminants, the chemistry of those contaminants, the hazardous nature of those contaminants with the health consequences of the people who drank the water or breathed that air. That's called chain of evidence, from my point of view. OK? You got at least those three, engineer, scientist, physician, working together to show causality.

There's a lot of coincidence-making—the industry always says, well, it's just a coincidence. Your well was always contaminated; you just noticed it now because we came into town. And on the other side, the extremist environmentalists, the people who don't think it all through, immediately draw causality conclusions from what might just be coincidence. But you really need an organization like PSE and its constituents, its advisors, its board, its members, who have all the kinds of technical expertise necessary to observe, determine the cause, and prove effect.

LAW: And one of the things that PSE is very concerned about as an organization is that the evidence is presented in vetted, peer-reviewed publications. Why is that so important?

INGRAFFEA: It's fundamentally important because in our society, in our civilization, the cornerstone, the wellspring, the gold standard of evidence is anonymous peer review. Without it, we're all bloggers. We're just opinionators. My opinion's as good as yours. My blog has fancier graphics, more people read my blog, therefore I should be believed. I'm sorry, no, that's not the way it works.

I'm very concerned that not only do we have the kinds of pollution that we've all been talking about—water pollution, air pollution, people pollution—we're seeing science pollution. The diminution of the importance of anonymous peer review, as exercised by the very best journals, administered by the best editorial boards. People who have not, are not going to be influenced by financial conflict of interest or by personal aggrandizement.

On average, that's the whole idea. You have enough people working at any journal on the editorial boards in their reviewer suite and in their publisher to know that they have, in that journal, a very grave responsibility for society. It's at least as important as the responsibility that the media have. I would argue it's even more important, because without the ability for—I'm bringing the conversation to an end here—the people, the citizenry, the policymakers, the legislators, the regulators to discern best science from somebody's opinion, it's hopeless.

LAW: Thanks very much, Tony.

AUTHORS' BIOGRAPHIES

JAKE HAYS is Program Director of Physicians, Scientists, and Engineers (PSE) for Healthy Energy in Ithaca, New York. He is the program director for the public-health energy nexus of PSE. He has worked as a research associate for Weill Cornell Medical College in New York City on several projects concerning unconventional natural gas development. He will continue to examine various public health aspects of shale gas development and other novel energy production methods. Contact him at jake.hays@gmail.com

ADAM LAW is a specialist in endocrinology and diabetes in Ithaca, New York. Dr. Law, a Fellow of the U.K.'s Royal College of Physicians, is also Clinical Assistant Professor of Medicine at Weill Cornell Medical College. He trained in medicine at The Middlesex Hospital Medical School at the University of London, where he won all eight major clinical prizes offered by the

school. After gaining membership in the Royal College of Physicians, he turned his attention to medical science, and received a master's degree in biochemistry and a doctorate from the University of London. He has held post-doctoral fellowships at the University of California, San Francisco, and Cornell and has published 13 research papers in clinical medicine and basic molecular biology. He has been in clinical practice in Ithaca since 2004. In January 2007, he took a two-year appointment as Chair of the Department of Medicine at Ithaca's Cayuga Medical Center, and led the medical staff in 2009. Send mail to him at law@ithacamed.com

Direct reprint requests to:

Jake Hays
Program Director
Physicians Scientists & Engineers for Healthy Energy
452 W. 57th St., Apt 3E
New York, NY 10019
e-mail: hays@psehealthyenergy.org

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Movement Solutions

NAVIGATING MEDICAL ISSUES IN SHALE TERRITORY

POUNÉ SABERI

ABSTRACT

The introduction of natural gas drilling with high-volume hydraulic fracturing to Pennsylvania and neighboring states since 2004 has been accompanied by numerous reports of varied symptoms and illnesses by those living near these operations. Pollutants with established toxic effects in humans may be introduced into the environment at various points during gas extraction and processing. Some community residents, as well as employees of the natural gas industry, believe that their health has deteriorated as a result of these operations and have sought medical care from local practitioners, who may have limited access to immediate toxicological consultations. This article reviews taking an environmental exposure history in the context of natural gas activities, underscoring the importance of thorough and guided history-taking in the discovery of environmental exposure clusters. It also highlights the critical need for funding, research, and peer-reviewed studies to help generate the body of evidence that is needed by practitioners.

Keywords: hydraulic fracturing, exposure history, natural gas, health symptoms

Most health care practitioners know what to do when they do not have the answer to a set of symptoms presented by a patient or when they are puzzled about a clinical case. They discuss it with a colleague, look it up in a medical library or online resource, or send the patient to a specialist for a formal consultation.

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But what happens when there is no expert or consultant to give advice about the problem the patient is facing? What happens when there is no literature to reference and most colleagues are just as baffled about the problem? That is the situation facing some health care practitioners in Pennsylvania who work in counties where high-volume hydraulic fracturing (also referred to as "fracking" in popular media) for natural gas along with related activities (chemical mixing; silica sand use; waste storage and handling; pipeline drilling, gas processing, compressor stations, and more) is occurring.

These practitioners have patients—both workers and residents—who report symptoms they believe are related to some part of the chain of shale gas operations. The practitioners hear about symptoms such as shortness of breath associated with odors in ambient air occurring after seismic testing; palpitations associated with being in the vicinity of a hydraulic fracturing flow-back waste impoundment; or black particles observed in tap water after a gas well was drilled, followed by an outbreak of a rash when showering. But are these actually related to fracking? The practitioners don't know, and they don't know whom to ask. There are no textbooks to consult, no experts to call upon, no adequate body of research to evaluate. They are stumped.

The underlying problem results from several factors. First of all, several of the special techniques essential to unconventional oil and gas extraction are nascent, with less than 10 years of use in Pennsylvania. While data exist on some of the routes of exposure resulting from these techniques, such as the vibration of compressor stations or the noise of truck traffic, the comprehensive environmental monitoring that could lead to informed exposure profiles is lacking. In addition, epidemiological longitudinal studies that would assist in the development of evidence-based clinical recommendations, at this time, have not been funded, conducted or published. Lastly, very few health care providers are trained in how to obtain an occupational history and fewer still are trained in obtaining an environmental exposure history, resulting in a general dearth of experience to guide practitioners in addressing their patients' symptoms and concerns.

TAKING AN ENVIRONMENTAL HISTORY IN SHALE TERRITORY

This article does not engage in a full discussion of the first two factors. Here, we will attempt to address the third in more detail: how does a health care provider take an environmental history when faced with a health complaint the patient, the provider, or both believe is due to shale gas extraction, processing, or transport infrastructure? Pennsylvania and the Marcellus Shale are chosen as the setting to address the health concerns that have surfaced in recent years. But health practitioners in any region where unconventional extractive techniques are in effect may use the principles outlined as a guide. Natural gas output from

Marcellus has increased tenfold since 2009 [1], and pipeline plans for domestic and global transportation have been expanding daily. I intend to illustrate the point that given the increase in this extractive industry, education about health concerns would be very timely for many clinicians.

To this end, in this article, I will review when and how the health care professional should obtain an environmental history. I hope to demonstrate that obtaining an accurate environmental history is a fundamental step in establishing the epidemiology of specific health issues, and it follows that the step taken by the health professional will be vital in building this foundation. I will end with a brief commentary on the current state of public health research and make the case that all literature related to shale gas, generated in academic and non-academic settings, should be given priority for peer reviewing and analysis to help generate the body of evidence that is needed by practitioners.

A note about terminology is in order. First, while generally "hydraulic fracturing" is used as a catch-all term for the unconventional extraction of methane gas (commonly referred to as "natural gas") or oil, the more appropriate term would be "natural gas activities" or even more broadly, "unconventional resource extraction." The message here is that the extraction, production, and transmission of fossil fuels, in this case natural gas, involve many steps during which exposure of residents and workers can occur, and it is important to utilize terminology that includes impacts from the entire life cycle of shale gas production.

Second, while we refer to "chemical" exposure, toxic and hazardous substances, and so forth, it is important for the clinician to realize that despite the attention to the additives in hydraulic fracturing fluid (also referred to as flow-back), an appreciable portion of the mixtures in drilling muds, drill cuttings, flow-back or other waste products are in fact endogenous to the subterranean layer and are therefore considered "naturally occurring." These substances range from radioactive compounds such as radon, to hydrocarbons such as benzene, heavy metals such as arsenic, or salts (e.g., strontium salts), and can be as hazardous as the additives. The attention given to the additives may be due to the proprietary nature of the mix, but just as many of the chemicals are naturally occurring. What may make them hazardous is that they are mobilized to the surface by the processes involved in the extraction of natural gas [2]. Thus, the practitioner must be alert to all possibilities with regards to the scope of substances and potential migratory pathways. I will expand more on this concept below.

> *Vignette:* A health care professional sees a patient who works for the natural gas industry on site. The worker wants a blood test for a certain chemical. The review of physical symptoms is negative. The worker is concerned because he has worked with a mixture of fluids without gloves. He does not know the name of the mixture. What should the health professional do?

The first and most fundamental concept to follow as a guide is the distinction between a hazard and a health risk. For a hazardous substance to pose a health risk it must first be transported through the environment, creating an exposure point where it can be absorbed through inhalation, ingestion, or dermal contact. The range of potential migratory pathways can be demonstrated by the cases that Bamberger and Oswald report [3]: failed well casings, leaking flow-back waste impoundments, dumping of toxic liquids in waterways, and emissions from compressor stations.

The goal is not always to nail down a "smoking gun" chemical to blame for a reported symptom. Insist on performing the routine history and physical exam, because a health problem may very well be uncovered that is unrelated to any environmental exposure. At the same time, incorporate questions about environmental exposures, since the testing should be guided by what the worker was exposed to.

Establishing the chronology of symptoms in the context of external exposures is vital. Precise questions that guide in the determination of the temporal relation between the introduction of an exposure and the appearance of health symptoms will help both the patient and the provider. The patient will recall the events in better detail and the provider is better able to generate possible connections that are biologically valid. Most patients remember that there was a gas well drilled, seismic testing was done, pipelines were dug in their vicinity, etc. They also remember their symptoms, but to fine-tune the temporal relation between these two events is crucial.

On the other hand, some operations are less obvious; for example, people may not be able to tell the approximate date a well is fractured, or be aware that a large out-of-sight waste impoundment is close by. Other examples of less evident connections are those between symptoms that are noticed in daytime but in fact result from exposure to night-time activities such as flaring. Examples of some of the questions are:

- When did you move into your current residence?
- When was the well drilled? When fractured, if known?
- When was the impoundment pit created, the compressor station built, or the wastewater spilled?

The challenge is then to see whether that background information correlates with specific environmental observations, using questions such as these:

- When did you notice your water's color changing?
- When did you notice the odors in the air?

Clearly medical events that precede the exposure, or illnesses that require a longer lead time than was experienced, will not be related to the exposures under discussion. For example, it is biologically plausible for certain cancers to develop within a given time frame, while for other cancers it is not. A caveat to the issue of timing deserves mention. The veterinary literature indicates that animal health is a sentinel for human health [3, 4]. Many companion animals may share the same exposures but manifest symptoms more rapidly. While many health care practitioners may not feel comfortable with zoological conditions, simple questions about the health of animals in the household and their behavior can be illuminating. Inquiring after diagnoses given by veterinarians is also helpful in establishing clues.

After obtaining subjective data, obtaining objective data is standard. The physical exam is dictated by the history and review of symptoms. Documenting vital signs as always is essential. For example, some chemicals have cardiotoxic effects that may not be apparent in the short term. But once the trend is reviewed over time it may reveal persistently increasing heart rate and necessitate further workup by electrocardiography. For example, long-term exposure to carbon monoxide, measured in air by well pads and compressor stations [5], worsens symptoms in people with prior cardiovascular disease [6]. Supplemental aids such as obtaining pictures of dermatological rashes can also be helpful.

In assessing the clinical scenario, one of the major pitfalls in interpreting toxicological data is the assumption that the same level of evidence can be applied to these data as to routine laboratory testing. The existing data bank for routine blood work is significantly larger, and therefore the strength of evidence for recommendations on when to order the test, how and when to collect it, and how to interpret it, is similarly much greater. Given the challenges in applying the results of toxicological data to a clinical case, the health care provider must carefully consider the reasons for ordering a test and do so only when sufficient suspicion for an exposure and a potential route of absorption exists. Having a sense of the pre-test probability of a health condition is useful to clinicians in understanding the predictive value of a negative or positive test result.

The health care provider may feel pressured to obtain biomonitoring as promptly as possible, given the time limits of the patient-doctor visit, the time-sensitive nature of the tests, and the desire to alleviate patient concerns. Biomonitoring is the assessment of human exposure to chemicals by measuring the chemicals or their metabolites in human specimens such as blood or urine [7]. It is challenging to balance prompt ordering with unearthing the appropriate tests. Generally in ordering blood and urine tests, obtaining the sample as close as possible to the time of exposure increases the validity of the result. On the one hand, some chemicals have such short half-lives in the body that a negative result obtained long after the exposure will provide false reassurance that the individual was not exposed. On the other hand, some exposures are so ubiquitous in the environment that a positive result obtained long after the exposure of concern may reflect only an unrelated environmental exposure. A key to reaching this balance, and to avoiding missed opportunities by ordering the wrong panel, is establishing a system of fact-finding with a network of medical toxicology consultants in advance. Governmental labs, such as that of the U.S. Centers for Disease Control and Prevention (CDC) and state labs, as well as private labs, may perform services for specialized biomonitoring tests. For example, National Medical Services performs a significant amount of toxicological testing, and toxicologists at the laboratory can be contacted with clarifying questions to help with appropriate testing (www.nmslabs.com). The website lists the phone number for client services, and providers can speak to support staff or request consultation. As with all other consultations, focused questions will receive more useful answers.

The cost of specialized testing may be a barrier for residents who are uninsured. The cost of the testing is variable depending on the type of testing requested, and providers may contact their chosen lab for the exact price. Depending on the test the price may vary from a few hundred to a few thousand dollars no matter which lab performs it. Specialized testing may not be covered by all medical insurances, and many insured residents may find themselves having to pay the expenses out of pocket.

The balancing act by the health care provider extends to recognizing the importance of mental health impacts of the natural gas activities. In the health impact assessment performed by Witter et al. [8] in Colorado in 2007, fear of unknown chemicals was listed as a stressor identified by community members. This illustrates the awareness that the health care provider must have toward appropriate counseling about environmental exposures. The balance lies in not disregarding the concerns raised by the patient and not causing undue alarm at the same time.

SOME CONCERNS

The symptoms, alone and in clusters, that have been repeatedly seen in different parts of the state of Pennsylvania may be cause for concern. The Environmental Health Project has documented dermal, gastrointestinal, and respiratory symptoms as the most commonly occurring complaints [9]. Bamberger and Oswald [3] have reported similar profiles: burning of the nose, throat and eye, headaches, gastrointestinal symptoms such as vomiting and diarrhea, rashes, and nosebleeds.

The following summarizes the problems most commonly reported to me and to other researchers by residents and workers, in order of frequency with the most common problems listed first [10]. As of July 2012, there were about 50 such reports. When evaluated in the context of a possible natural gas operation exposure, these symptoms may be noted as potential “sentinel” symptoms for toxic agents with more serious, but possibly delayed, clinical impacts:

- rashes or skin irritation,
- abdominal pain and cramping,

- shortness of breath,
- recurrent sinusitis, and
- diarrhea.

Looking back at the history of environmental health hazards, a health professional may pause to consider the future implications of toxic exposure from unconventional natural gas operations. For instance, the history of asbestosis shows a lag time between clinical observation (first case of asbestosis documented in the 1920s) and epidemiological proof (asbestosis is shown to cause lung cancer in the 1950s), and regulatory enforcement. Asbestos production plants were shut down in the 1980s after numerous unnecessary deaths from asbestosis and asbestos-related cancers had occurred. Even today, new diagnoses of asbestosis, mesothelioma, and other asbestosis-related cancers are still being made.

A reasonable concern is that in 10 to 80 years, the public will be paying for exposure to both established and new toxic substances, when current symptoms and the lack of public health scrutiny should have been red flags. McKenzie et al. [11], for example, concluded that residents who live closer to gas pads have higher predicted risks of respiratory and neurological conditions in addition to excess lifetime risk of developing cancer. A March 2012 press release issued by the Environmental Protection Agency (EPA) addressed a groundwater investigation in Pavillion, Wyoming, stating [12]: "We believe that collaboration and use of the best available science are critical in meeting the needs of Pavillion area residents and resolving longstanding issues surrounding the safety of drinking water and groundwater." The collaboration among the EPA, United States Geological Survey (USGS), and the State of Wyoming was an excellent example of using best available science in a speedy manner to identify red flags for the community residents. The EPA report showed benzene concentrations in an aquifer at 50 times the Maximum Contaminant Level (MCL) [13]. What happened subsequently may provide a clue as to the lag time between scientific findings and policy, as seen with the timeline of asbestos regulations. EPA and USGS were made to resample and repeat their findings; their results were questioned, and eventually the oil and gas industry demanded that new tests be done [14].

This story raises several points. One is that when the stakes are so high that the health of residents is dependent on them, red flags should be sufficient to protect the people rather than wait for conclusive evidence. The second point is that conducting health impact studies prior to engaging in operations with potential high-stake outcomes allows dialogue for establishing safeguards ahead of time. Lastly, despite the amount of time spent on hazard assessment, experts remain unable to provide clinicians with guidance for risk communication to patients.

No state to date has attempted a health impact assessment prior to allowing unconventional extraction of shale to begin, nor has any state engaged in creating a disease or health complaint registry after the process has begun. Unlike the use of asbestos, which exposed workers to a single substance, in unconventional natural gas operations, populations are exposed to a multitude of chemicals that vary both within and between shale gas fields. Time is passing, and there is a strong need for health impact studies in states and areas where natural gas activities have not yet begun, for collaborations to screen for red flags in areas where natural gas activities have begun, and for comprehensive studies that offer both policy recommendations and clinical guidelines.

SPECIAL CHALLENGES AND SPECIAL POPULATIONS

There are special populations with added vulnerability that deserve different considerations by medical professionals [15]. Pregnant women, people whose occupation is working in the industry, and children are examples of such populations. The teratogenicity of many compounds, such as mercury, which occur naturally in the deeper geological formations but are brought up either with natural gas operations or burning of coal, has been firmly established. The adverse embryonic effects of the same chemical may be different depending on the gestational age at exposure. Institutions that are dedicated to such special populations include Pediatric Environmental Health Specialty Units (PEHSU) (http://aoec.org/pehsu). A large body of data demonstrates disproportionate impacts on another vulnerable population, the elderly. Ground-level ozone, for example, has been linked to premature death in this cohort [16].

While some special populations, such as pregnant women or children, are rarely unrecognized as such by health care providers, many practitioners may not be aware of regulations surrounding providing care for the workers. The National Institute for Occupational Safety and Health (NIOSH) (http://www.cdc.gov/niosh) has an important hazard alert for health care professionals regarding worker exposure to silica during hydraulic fracturing [17]. Medical practitioners should ask patients who are natural gas operation workers if they are involved in dusty drilling operations, and if so, a pulmonary evaluation should be recommended and an onsite inspection made, as explained below.

The Occupational Safety and Health Administration (OSHA) has specific rules and regulations regarding reporting work-related injuries and hazards in the workplace. OSHA requires that most industries keep logs of occupational injuries and illnesses, which must be made available to OSHA during inspections. Injuries that result in fatalities or multiple hospitalizations must be immediately reported to OSHA. The health care practitioner may act as the representative of a worker when faced with the knowledge of a workplace hazard and file a request for onsite work inspections (www.osha.gov/as/opa/worker/complain.html). For example, an emergency medicine provider may treat several workers for heat stroke and recognize that the recurrent episodes are related to working extended hours in the heat on a well pad. The physician may then contact the regional office of OSHA, anonymously or otherwise, to report the hazardous working conditions. Studying the logs will help locate areas where possible exposures are occurring with the goal of preventing them.

SOME RESOURCES

The environmental medicine literature demonstrates the importance of including questions about potential toxic exposure when taking a clinical history. Authors give examples of common symptoms that are found to be due to an environmental exposure [18]. For example, a recurrent headache leads to the discovery of indoor carbon monoxide levels, or a non-resolving rash points to the patient's hobby of working with treated wood. Environmental medicine authorities point out that the key to solving the puzzle is to include the environmental or occupational exposure in the differential diagnosis and ask the relevant questions [19]. If the health care practitioner sees patients in an area where there is natural gas activity, it is reasonable to consider the steps involved in the exposure as a possible etiological factor.

Establishing a connection between an environmental exposure and health symptoms is easier when population-based data are available. At this time in our medical knowledge of the health effects of unconventional shale operations, the relevant questions are far broader than are usually considered in the outpatient setting, and the conclusions not tremendously gratifying. That is why the significance of clinicians participating in the collection of population-based data cannot be understated. A solid investigation at the individual level appreciably contributes to population-level data gathering for such phenomena as cluster investigations or disease registries.

> *Vignette:* Two small children are brought in for rashes on their hands. The well nearest to their home has been flared for the last week. The family believes that the rashes are due to flaring, as the symptoms did not exist prior to this event.

This case illustrates the importance of remembering to follow the medical teachings of entertaining all possible differential diagnoses. Childhood viral exanthems (rash) are common, as are other possibilities such as irritant dermatitis in reaction to a new compound in the environment. Some of the resources available are online and include the Case Studies in Environmental Medicine prepared by the federal Agency for Toxic Substances and Disease Registry (ATSDR) (http://www.atsdr.cdc.gov/csem/csem.html). They guide the practitioner step by step on how to take an exposure history, and include monographs on a variety of chemicals. ATSDR has also created a summary of key questions to ask, which can either be incorporated into a visit or asked by the ancillary staff. Various environmental organizations also offer questionnaires that may be helpful. For example, the Southwestern Pennsylvania Environmental Health Project contains some good examples of medical history questions to ask in the context of natural gas operations (http://www.environmentalhealthproject.org/). This website also lists resources for environmental monitoring and recommendations for minimizing exposure to many of the sources present in activities associated with the life cycle of hydraulic fracturing. The site also offers helpful brochures explaining how to interpret water test results and other instruction sheets that clinicians can give to their patients (3 Good Things To Do: http://www.environmentalhealthproject.org/health/steps-you-can-take-now/). For example, practical advice for the family in the above scenario may be to take steps to purify the indoor air, in order to reduce the load of particulates and other pollutants that have migrated into the home from outside air.

REGULATIONS

Health care providers are no stranger to the interface of legal matters and medicine. Most education about the medical/legal field achieves the goal of protecting the provider from inadvertently breaking a law. In the context of unconventional natural gas activities, however, it behooves the clinician to become well versed in the intricacies of the legalese that protect both the patient and the patient-doctor relationship. At the time of writing this article, in Pennsylvania, Act 13, the 2012 state law addressing shale gas extraction issues, contains medical provisions addressing disclosure of proprietary chemical mixtures by the industry. If a provider suspects potential exposure to an unknown compound, he or she may request release of data in writing in order to appropriately treat the exposed patient, but must agree not to disclose the information received. Similar regulation is also in effect in other states such as Colorado and is modeled after OSHA's Hazard Communication Standard.

The medical provisions in Act 13 bring up several issues. OSHA regulations have been written to protect workers in their workplace. Historically EPA has been tasked with having a similar role for residents in their living environment. In the context of natural gas exploration and extraction, the bulk of enforcing power has fallen on state government agencies. The federal Energy Policy Act of 2005 has minimized EPA's oversight by exempting the oil and gas companies engaged in hydraulic fracturing from key portions of some fundamental environmental laws. Despite the limitation of jurisdiction, EPA asserts that it has acted when stakeholders have made inquiries.

In Pennsylvania, the application of the medical provision of Act 13 is not well understood, since it has not been effectively tested. Very few providers desire to be the pioneers in applying the complexities of legal procedures such as sharing the data obtained from the company with their patients. Efforts made by medical professionals to understand the scope of action permitted under the law will improve their capacity to help patients obtain valuable chemical information. The Network for Public Health Law is one resource. While its staff are not able to provide direct advice about the application of the law to a specific circumstance, they can provide technical legal assistance to access and understand the law. They can be contacted via phone at 410-706-5575 or email at eastern@networkforphl.org. If a provider has questions about local application of the law, The American Medical Association Litigation Center, (http://www.ama-assn.org/ama/pub/physician-resources/legal-topics/litigation-center/about-us.page?) may be able to direct inquiries to lawyers in the state who can provide answers.

CONCLUSION

In summary, what does a practitioner do when the patient says a health problem is due to unconventional gas drilling operations? The practitioner must be adept at taking a relevant exposure history, and include toxic exposure as a potential cause for the patient's symptoms, while not prematurely arriving at a conclusion of causation. Clinicians may need to think about multiple exposures to chemicals, each of which can create multiple overlapping symptoms, and to deal with the frustration brought on by the uncertainty about which substances are involved. Despite the multiple barriers to obtaining high-quality epidemiological data, every health practitioner who takes a complete case history, including a history of environmental exposure, is providing a tremendous service both for the patient and for public health. The documentation by clinicians has been the foundation of such established and widely used databases as the Surveillance Epidemiology and End Results (SEER) registry. The present-day effort will result in tomorrow's payback of information that will be reliably used in evaluating puzzling environmental clinical scenarios. Health care providers are empowered to see themselves as a vital link in the chain of constructing future epidemiological data banks. The field of public health will ideally be transformed from the perspective of collection of disease counts to one with infrastructure for monitoring and mitigating toxic substances before they have had the chance to cause harm.

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AUTHOR'S BIOGRAPHY

POUNÉ SABERI, M.D., M.P.H., is adjunct faculty in the Occupational and Environmental Medicine section of the Emergency Department at the University of Pennsylvania. She has ten years of clinical experience as a family physician. Her passion is learning and teaching about the effects of environmental factors and toxicology on personal health. She is conducting a study at the Center of Excellence in Environmental Toxicology about health perceptions of environmental exposures. As a public health specialist and advocate for clean air and water, she works to bridge the gap between policy and research. Write to her at pounesaberi@yahoo.com

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Direct reprint requests to:

Pouné Saberi, MD, MPH
One Convention Ave.
4 Penn Tower
Philadelphia, PA 19146
e-mail: poune@psrphila.org