NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

Appendices to Response to Comments

FINAL
Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program

Regulatory Program for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs

www.dec.ny.gov

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Table of Appendices
Response to Comments

NO.	TITLE
A	Public Health Review of Shale Gas Development
B	Modeling of Ozone Impacts from Well Pad Activities and Associated Truck Traffic and Compressor Stations for Future Peak Well Development Conditions in the Marcellus Shale Area of New York State
C	Dispersion Modeling Input and Output Data, Sensitivity Analysis and Explanation of NAAQS and Toxics Threshold Establishment Process

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NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

Appendix A

Public Health Review of Shale Gas Development

Final

Supplemental Generic Environmental Impact Statement

Response to Comments

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NEW YORK STATE | Department of Health

A Public Health Review of

High Volume Hydraulic Fracturing for Shale Gas Development

December 2014

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NEW YORK
state department of
HEALTH

Howard A. Zucker, M.D., J.D.
Acting Commissioner of Health

Sally Dreslin, M.S., R.N.
Executive Deputy Commissioner

December 17, 2014

Hon. Joseph Martens
Commissioner
New York State Department of Environmental Conservation
625 Broadway
Albany, NY 12207

Dear Commissioner Martens:

In September 2012, you asked Dr. Shah, then Commissioner of Health, to initiate a Public Health Review of the Department of Environmental Conservation's draft Supplemental Generic Environmental Impact Statement for High Volume Hydraulic Fracturing (HVHF). I assumed responsibility for this review when Dr. Shah left. It became clear during this assessment that DOH's Public Health Review needed to extend beyond the scope of the initial request to consider, more broadly, the current state of science regarding HVHF and public health risks. This required an evaluation of the emerging scientific information on environmental public health and community health effects. This also required an analysis of whether such information was sufficient to determine the extent of potential public health impacts of HVHF activities in New York State (NYS) and whether existing mitigation measures implemented in other states are effectively reducing the risk for adverse public health impacts.

As with most complex human activities in modern societies, absolute scientific certainty regarding the relative contributions of positive and negative impacts of HVHF on public health is unlikely to ever be attained. In this instance, however, the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF to all New Yorkers and whether the risks can be adequately managed, DOH recommends that HVHF should not proceed in NYS.

I appreciate the opportunity to conduct this Public Health Review. It furthers the long history of close collaboration between the two Departments carrying out our shared responsibility to protect human health and the environment.

Sincerely,

Howard Zucker M.D.

Howard A. Zucker, M.D., J.D.
Acting Commissoner of Health

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Errata

A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development

It has come to the attention of the Department of Health (DOH) that the Public Health Review document posted on the DOH web site on December 17, 2014 contained two errors requiring correction:

1. The following text (enclosed in ' ') was inadvertently omitted from the beginning of page 41 and has been added back to the document to complete the sentence started at the end of page 40:

   > [ODNR] 'says that it will develop new criteria and permit conditions for new applications in light of this change in policy. The department will also review previously issued permits for wells that have not been drilled.'

   As a consequence of the omission, the formatting of the next section heading, beginning on page 41, was also incorrect and has been corrected:

   ### Conclusions – Health and Environmental Literature

2. Endnote 4 listed on page 89 referred to a web link that had been removed from the document before it was finalized. That endnote was deleted, and all subsequent endnotes were renumbered accordingly (i.e., original-endnote 5 became new-endnote 4, etc.).

In addition, a number of minor typographical errors have been corrected in the amended version of the document. These include the following changes:

1. deletion of an additional blank space character following periods: pages 21, 25, 48, and 56;
2. addition of a missing blank space character: pages 23, 25, 32, and 36;
3. addition of a missing period character: pages 21 and 29;
4. correction of acronyms for US EPA and US DOL: pages 5, 7, 35, 36, 104 and, 105;
5. correction of the date from 2012 to 2014 for reference to an IOM report: page 43; and
6. correction of the date of the reference to an US EPA document and addition of a missing closing parenthesis in endnote 4 (originally numbered 5): page 89.

None of these corrections to the Public Health Review document result in any substantive change to the meaning of the document or the document's conclusions.

2/13/2015

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Table of Contents

| Executive Summary 1

Scope of the Public Health Review 2

Public Health Review Process 3

Major Findings 4

Air Impacts 5

Water-quality Impacts 5

Seismic Impacts 6

Community Impacts 6

Health Outcomes near HVHF Activity 7

Substantial Gaps Remain 8

Conclusions 11

| Background 13

Scope of the Review 15

Public Health Review Process 15

| Results Evaluation of Scientific Literature Relevant to the Objectives of the Public Health Review 17

HVHF Health Outcome Studies 18

Birth Outcomes 19

Case Series and Symptom Reports 22

Local Community Impacts 24

Cancer Incidence 25

Non-peer-reviewed Information 26

HVHF Environmental Studies 26
Air Quality Impacts 26
Water Quality Impacts 35
Induced Earthquakes 39
Conclusions – Health and Environmental Literature 41

| Results Information Gathered from Outside Authoritative Organizations, Public Health Experts, and Formal Health Impact Assessments 42
Health Impact Assessments 42
Meetings with Other State Agencies 49
California 50
Texas 51
Illinois 53
Public Health Expert Consultation 55

| Overall Conclusions 85

| Endnotes 89

| References 92

| Appendix 1 109
Supplemental Literature Considered for the Public Health Review 109

| Appendix 2 Radon Screening Analysis 172
Radon from Natural Gas 173

| Executive Summary

The New York State Department of Health (DOH) is charged with protecting the public health of New Yorkers. In assessing whether public health would be adequately protected from a complex activity such as high volume hydraulic fracturing (HVHF), a guarantee of absolute safety is not required. However, at a minimum, there must be sufficient information to understand what the likely public health risks will be. Currently, that information is insufficient.

In 2012, the New York State Department of Environmental Conservation (DEC) requested that DOH review and assess DEC's analysis of potential health impacts contained in DEC's draft supplemental generic environmental impact statement (SGEIS) for HVHF. In response to the original request from DEC, DOH initiated an HVHF Public Health Review process. In conducting this public health review DOH: (i) reviewed and evaluated scientific literature to determine whether the current scientific research is sufficient to inform questions regarding public health impacts of HVHF; (ii) sought input from three outside public health expert consultants; (iii) engaged in field visits and discussions with health and environmental authorities in states with HVHF activity; and (iv) communicated with multiple local, state, federal, international, academic, environmental, and public health stakeholders. The evaluation considered the available information on potential pathways that connect HVHF activities and environmental impacts to human exposure and the risk for adverse public health impacts.

Based on this review, it is apparent that the science surrounding HVHF activity is limited, only just beginning to emerge, and largely suggests only hypotheses about potential public health impacts that need further evaluation. That is, many of the

published reports investigating both environmental impacts that could result in human exposures and health implications of HVHF activities are preliminary or exploratory in nature. However, the existing studies also raise substantial questions about whether the risks of HVHF activities are sufficiently understood so that they can be adequately managed. Furthermore, the public health impacts from HVHF activities could be significantly broader than just those geographic locations where the activity actually occurs, thus expanding the potential risk to a large population of New Yorkers.

As with most complex human activities in modern societies, absolute scientific certainty regarding the relative contributions of positive and negative impacts of HVHF on public health is unlikely to ever be attained. In this instance, however, the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF to all New Yorkers and whether the risks can be adequately managed, DOH recommends that HVHF should not proceed in New York State.

Scope of the Public Health Review

DOH evaluated whether the available scientific and technical information provides an adequate basis to understand the likelihood and magnitude of risks for adverse public health impacts from HVHF activities in New York State. DOH reviewed how HVHF activities could result in human exposure to: (i) contaminants in air or water; (ii) naturally occurring radiological materials that result from HVHF activities; and (iii) the effects of

HVHF operations such as truck traffic, noise, and social changes on communities. DOH also reviewed whether those exposures may result in adverse public health outcomes.

Public Health Review Process

The initial component of the Public Health Review focused on understanding how public health concerns were addressed in the draft SGEIS. Three nationally recognized experts participated as consultants to the initial phase of the review process. The expert consultants reviewed elements of the draft SGEIS and documentation developed by DOH, and provided extensive input through multiple rounds of communication.

As a result of this input, as well as broader consideration, it became clear that DOH's Public Health Review needed to extend beyond this initial assessment to consider, more broadly, the current state of science regarding HVHF and public health risks. This required an evaluation of the emerging scientific information on environmental public health and community health effects. This also required an analysis of whether such information was sufficient to determine the extent of potential public health impact of HVHF activities in NYS and whether existing mitigation measures implemented in other states are effectively reducing the risk for adverse public health impacts.

In addition to evaluating published scientific literature, former Commissioner Shah, Acting Commissioner Zucker, and DOH staff consulted with state public health and environmental authorities to understand their experience with HVHF. Former Commissioner Shah, Acting Commissioner Zucker, and DOH staff also engaged in a number of discussions and meetings with researchers from academic institutions and government agencies to learn more about planned and ongoing studies and assessments of the public health implications of HVHF. In total, more than 20 DOH

senior Research Scientists, Public Health Specialists, and Radiological Health Specialists spent approximately 4500 hours on this Review.

Major Findings

Summarized below are some of the environmental impacts and health outcomes potentially associated with HVHF activities:

- **Air impacts** that could affect **respiratory health** due to increased levels of particulate matter, diesel exhaust, or volatile organic chemicals.
- **Climate change impacts** due to methane and other volatile organic chemical releases to the atmosphere.
- **Drinking water impacts** from underground migration of methane and/or fracking chemicals associated with faulty well construction.
- Surface spills potentially resulting in **soil and water contamination**.
- **Surface-water contamination** resulting from inadequate wastewater treatment.
- **Earthquakes** induced during fracturing.
- **Community impacts** associated with boom-town economic effects such as increased vehicle traffic, road damage, noise, odor complaints, increased demand for housing and medical care, and stress.

Additionally, an evaluation of the studies reveals critical information gaps. These need to be filled to more fully understand the connections between risk factors, such as air and water pollution, and public health outcomes among populations living in proximity to HVHF shale gas operations (Penning, 2014; Shonkoff, 2014; Werner, 2015).

Some of the most significant environmental and health-outcome studies are briefly summarized here.

Air Impacts

Studies provide evidence of uncontrolled methane leakage, emissions of other volatile organic chemicals, and particulate matter from well pads and natural-gas infrastructure. State authorities in both Texas and Pennsylvania have documented methane leakage from natural gas infrastructure by the use of infrared cameras. A recent West Virginia study also determined that heavy vehicle traffic and trucks idling at well pads were the likely sources of intermittently high dust and benzene concentrations, sometimes observed at distances of at least 625 feet from the center of the well pad (McCawley, 2012, 2013; WVDEP, 2013). These emissions have the potential to contribute to community odor problems, respiratory health impacts such as asthma exacerbations, and longer-term climate change impacts from methane accumulation in the atmosphere (Allen, 2013; Bunch, 2014; CDPHE, 2010; Macey, 2014; Miller, 2013; Petron, 2012; Weisel, 2010).

Water-quality Impacts

Studies have found evidence for underground migration of methane associated with faulty well construction (Darrah, 2014; US EPA, 2011). For example, a recent study identified groundwater contamination clusters that the authors determined were due to gas leakage from intermediate-depth strata through failures of annulus cement, faulty production casings, and underground gas well failure (Darrah, 2014). Shallow methane-migration has the potential to impact private drinking water wells, creating safety concerns due to explosions.

Other studies suggest additional sources of potential water contamination, including surface spills and inadequate treatment and disposal of radioactive wastes (Warner, 2013). A recent review paper presented published data revealing evidence for stray gas contamination, surface water impacts, and the accumulation of radium isotopes in some disposal and spill sites (Vengosh, 2014). One recent study also suggests that chemical signals of brine from deep shale formations can potentially be detected in overlying groundwater aquifers (Warner, 2012). These contaminants have the potential to affect drinking water quality.

Seismic Impacts

Recent evidence from studies in Ohio and Oklahoma suggest that HVHF can contribute to the induction of earthquakes during fracturing (Holland, 2014; Maxwell, 2013). Although the potential public health consequence of these relatively mild earthquakes is unknown, this evidence raises new concerns about this potential HVHF impact.

Community Impacts

There are numerous historical examples of the negative impact of rapid and concentrated increases in extractive resource development (e.g., energy, precious metals) resulting in indirect community impacts such as interference with quality-of-life (e.g., noise, odors), overburdened transportation and health infrastructure, and disproportionate increases in social problems, particularly in small isolated rural communities where local governments and infrastructure tend to be unprepared for rapid changes (Headwaters, 2013). Similar concerns have been raised in some communities where HVHF activity has increased rapidly (Stedman, 2012; Texas DSHS, 2010; Witter, 2010; WVDEP, 2013).

A recent study from Pennsylvania also reports that automobile and truck accident rates in 2010–2012 from counties with heavy HVHF activity were between 15% and 65% higher than accident rates in counties without HVHF. Rates of traffic fatalities and major injuries were higher in 2012 in heavy drilling counties in southwestern Pennsylvania compared to non-drilling counties (Graham, 2015).

Health Outcomes near HVHF Activity

Although well-designed, long-term health studies assessing the effect of HVHF activity on health outcomes have not been completed, there is published health literature that examines health outcomes in relation to residential proximity to HVHF well pads. One peer-reviewed study and one university report have presented data indicating statistical associations between some birth outcomes (low birth weight and some congenital defects) and residential proximity of the mother to well pads during pregnancy (Hill, 2012; McKenzie, 2014). Proximity to higher-density HVHF well pad development was associated with increased incidence of congenital heart defects and neural-tube defects in one of the studies (McKenzie, 2014).

Several published reports present data from surveys of health complaints among residents living near HVHF activities. Commonly reported symptoms include skin rash or irritation, nausea or vomiting, abdominal pain, breathing difficulties or cough, nosebleeds, anxiety/stress, headache, dizziness, eye irritation, and throat irritation in people and farm animals within proximity to HVHF natural gas development (Bamberger, 2012; Finkel, 2013; Steinzor, 2012). Federal investigators have also reported that sub-standard work practices and deficient operational controls at well pads contributed to elevated crystalline silica exposures among workers during HVHF operations (US DOL, 2012). While this report focused on worker exposures, it highlights

a possible exposure concern for residents living close to HVHF operations if silica emissions from onsite operations are not properly controlled.

Substantial Gaps Remain

Systematic investigations studying the effects of HVHF activity on groundwater resources, local-community air quality, radon exposure, noise exposure, wastewater treatment, induced seismicity, traffic, psychosocial stress, and injuries would help reduce scientific uncertainties. While some of the on-going or proposed major study initiatives may help close those existing data gaps, each of these alone would not adequately address the array of complex concerns related to HVHF activities.
For example:

Marcellus Shale Initiative Study

Geisinger Health System, the lead organization in the collaborative Marcellus Shale Initiative, cares for many patients in areas where shale gas is being developed in Pennsylvania. They began pilot studies in 2013 using well and infrastructure data to estimate exposures to all aspects of Marcellus shale development in Pennsylvania. According to the National Institutes of Health (NIH) abstract, they will use these exposure estimates to evaluate whether asthma control and pregnancy outcomes are affected by Marcellus shale development by studying 30,000 asthma patients and 22,000 pregnancies in the Geisinger Health System from 2006-13. Results from this study are not expected to be available for several years.

University of Colorado at Boulder, Sustainability Research Network

A five-year cooperative agreement funded by the National Science Foundation (NSF) under NSF's Sustainability Research Network competition, this program involves a multidisciplinary team of investigators and is intended to address:

> *"the conflict between natural gas extraction and water and air resources protection with the development of a social-ecological system framework with which to assess the conflict and to identify needs for scientific information. Scientific investigations will be conducted to assess and mitigate the problems. Outreach and education efforts will focus on citizen science, public involvement, and awareness of the science and policy issues"* (Univ. Colorado, 2012; Shonkoff, 2014).

Published research has been produced from this program investigating associations between HVHF activity and birth outcomes and potential for methane leakage from natural gas infrastructure. The cooperative agreement extends to 2017.

EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources

Begun in 2011, the purpose of the study is to assess the potential impacts of hydraulic fracturing on drinking water resources, if any, and to identify the driving factors that may affect the severity and frequency of such impacts. The research approach includes: analyses of existing data, scenario evaluations, laboratory studies, toxicity studies, and case studies. US EPA released a progress report on December 21, 2012 and stated that preliminary results of the study are expected to be released as a draft for public and

peer review as soon as the end of 2014, although the full study is not expected to be completed before 2016.

Pennsylvania Department of Environmental Protection (PA DEP) Comprehensive Oil and Gas Development Radiation Study

Started in early 2013, PA DEP is analyzing the radioactivity levels in produced and flowback waters, wastewater recycling, treatment sludges, and drill cuttings, as well as issues with transportation, storage, and disposal of drilling wastes, the levels of radon in natural gas, and potential exposures to workers and the public. According to a July 2014 update from the PA DEP, publication of a report could occur as soon as the end of 2014.

University of Pennsylvania Study

A proposed study of HVHF health impacts was announced several months ago. The study is led by researchers from the University of Pennsylvania in collaboration with scientists from Columbia University, Johns Hopkins University, and the University of North Carolina.

Pennsylvania Department of Environmental Protection

Recently proposed community air monitoring will determine concentrations of fine and coarse (silica-sized) particles near a transfer facility that handles hydraulic fracturing silica sand.

These major study initiatives may eventually reduce uncertainties regarding health impacts of HVHF and could contribute to a much more complete knowledge base for

managing HVHF risks. However, it will be years before most of these major initiatives are completed.

Other governmental and research institutes have also recently conducted health impact assessments of HVHF (Institute of Medicine, 2014). These include: the European Commission; University of Michigan, Graham Sustainability Institute; Research Triangle Environmental Health Collaborative; Nova Scotia Independent Panel on Hydraulic Fracturing; Inter-Environmental Health Sciences Core Center Working Group on Unconventional Natural Gas Drilling Operations funded by the National Institute of Environmental Health Sciences; and the Maryland Institute for Applied Environmental Health, School of Public Health, University of Maryland. While these assessments identify many of the same potential environmental impacts mentioned above, more importantly, they reiterate that significant gaps exist in the knowledge of potential public health impacts from HVHF and of the effectiveness of some mitigation measures.

Conclusions

HVHF is a complex activity that could affect many communities in New York State. The number of well pads and associated HVHF activities could be vast and spread out over wide geographic areas where environmental conditions and populations vary. The dispersed nature of the activity magnifies the possibility of process and equipment failures, leading to the potential for cumulative risks for exposures and associated adverse health outcomes. Additionally, the relationships between HVHF environmental impacts and public health are complex and not fully understood. Comprehensive, long-term studies, and in particular longitudinal studies, that could contribute to the understanding of those relationships are either not yet completed or have yet to be initiated. In this instance, however, the overall weight of the evidence from the

cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health.

While a guarantee of absolute safety is not possible, an assessment of the risk to public health must be supported by adequate scientific information to determine with confidence that the overall risk is sufficiently low to justify proceeding with HVHF in New York. The current scientific information is insufficient. Furthermore, it is clear from the existing literature and experience that HVHF activity has resulted in environmental impacts that are potentially adverse to public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF and whether the risks can be adequately managed, HVHF should not proceed in New York State.

| Background

In 1992, the NYS Department of Environmental Conservation (DEC) finalized the Generic Environmental Impact Statement (1992 GEIS) on the Oil, Gas and Solution Mining Regulatory Program.[1,2] Conventional natural gas development in NYS – including the use of low-volume hydraulic fracturing – has been permitted by DEC under the GEIS since that time. High-volume hydraulic fracturing (HVHF), which is often used in conjunction with horizontal drilling and multi-well pad development, is an approach to extracting natural gas that raises new, potentially significant, adverse impacts that were not studied in the 1992 GEIS. Therefore, in 2008 DEC began the process of developing a supplement to the GEIS (hereafter the draft SGEIS) specifically addressing natural gas development using HVHF and directional drilling in unconventional formations such as the Marcellus and Utica Shales (collectively referred to here as HVHF shale-gas development).

In 2012, DEC requested that the New York State Department of Health (DOH) review and assess DEC's analysis of potential health impacts contained in DEC's draft supplemental generic environmental impact statement (draft SGEIS[3]) for HVHF. In response to the original request from DEC, DOH initiated an HVHF Public Health Review process. DOH has a long history of working closely with DEC on all DEC programs that have public health components. DOH has extensive expertise in environmental health, including protecting drinking water supplies, environmental radiation protection, toxicology, environmental exposure assessment, occupational health, and environmental epidemiology. DOH also collects, manages, and analyzes extensive public health surveillance data for all of New York State.

DOH is charged with defending the public health of New Yorkers. In order to meet this charge with respect to HVHF, DOH reviewed and evaluated relevant emerging scientific literature that investigated the environmental health and community health dimensions of HVHF. The literature was assessed in terms of the adequacy of the current science to inform questions regarding public health impacts of HVHF. As part of this review, DOH also sought input from three outside public health expert consultants, engaged in discussions and field visits with health and environmental authorities in states with HVHF activity, and held numerous meetings with local, state, federal, international, academic, environmental, and public health stakeholders. The evaluation considered the available information on all potential pathways that connect HVHF activities and environmental impacts to human exposure and the risk for adverse public health impacts.

HVHF shale-gas development is a large-scale, complex issue that potentially could affect a significant portion of New York State. In order to make an informed assessment of the potential public health consequences of HVHF in New York, the totality of available information from relevant sources has to be evaluated collectively. A single study or isolated piece of information will not provide a complete public health picture for such a complex activity. In assessing whether public health would be adequately protected when allowing a complex activity such as HVHF to go forward, a guarantee of absolute safety is not required, but there must be sufficient information to understand what the likely public health risks will be. Ultimately, in conducting this Public Health Review, DOH evaluated the relevant lines of available evidence collectively, and made a judgment on whether the scientific information was adequate to determine the level of public health risk.

Scope of the Review

DOH evaluated whether the available scientific and technical information provides an adequate basis to understand the likelihood and magnitude of risks for adverse public health impacts from HVHF activities in New York State. The evaluation reviewed how HVHF activities could result in human exposure to: (i) contaminants in air or water; (ii) naturally occurring radioactive materials that result from HVHF activities; and (iii) the effects of HVHF operations such as truck traffic, noise, and social changes on communities. The evaluation also reviewed whether those exposures may result in adverse public health outcomes.

Public Health Review Process

The initial component of the Public Health Review focused on understanding how public health concerns were addressed in the draft SGEIS. Three nationally recognized experts also participated as consultants to the initial phase of the review process. The expert consultants reviewed elements of the draft SGEIS and documentation developed by DOH, and provided extensive input through multiple rounds of communication.

As a result of this input, as well as broader consideration, it became clear that DOH's Public Health Review needed to extend beyond this initial assessment to consider, more broadly, the current state of science regarding HVHF and public health risks. This required an evaluation of the emerging scientific information on environmental public health and community health effects. This also required an analysis of whether such information was sufficient to determine the extent of potential public health impact of HVHF activities in NYS and whether existing mitigation measures implemented in other states are effectively reducing the risk for adverse public health impacts.

One major component of the Public Health Review was an objective evaluation of the emerging scientific information on environmental impacts and public health effects of HVHF activity. Scientific studies reporting relationships between HVHF and public health outcomes were the main focus of this evaluation, but relevant literature that was only focused on HVHF and effects on environmental media was also reviewed. Additional literature was reviewed and considered supplemental to the main Public Health Review (see Appendix 1). More than 20 DOH senior Research Scientists, Public Health Specialists, and Radiological Health Specialists contributed to the review under the direction of former Commissioner Shah and Acting Commissioner Zucker. The entire Public Health Review process involved more than 4500 hours of combined effort.

In addition to evaluating published scientific literature, former Commissioner Shah, Acting Commissioner Zucker, and DOH staff held multiple discussions and meetings with public health and environmental authorities in several states to understand their experience with HVHF. Former Commissioner Shah, Acting Commissioner Zucker, and DOH staff, also engaged in a number of discussions and meetings with researchers from academic institutions and government agencies to learn more about planned and ongoing studies and assessments of the public health implications of HVHF.

| Results

Evaluation of Scientific Literature Relevant to the Objectives of the Public Health Review

In order to evaluate the analysis of health impacts in the draft SGEIS in a broader environmental and public health context, DOH reviewed and evaluated relevant emerging scientific literature investigating the environmental health and community health dimensions of HVHF. This was not intended to be a comprehensive review of all the published scientific literature on HVHF. Rather, the emerging literature was surveyed, and studies with direct environmental health relevance were reviewed to better understand the adequacy of the current science to inform questions regarding public health impacts of HVHF.

Two major types of peer-reviewed scientific studies were the focus of the literature review process – studies of impacts to environmental media and studies of health outcomes. As is very often true in environmental health science, both types of studies have limitations that make it difficult to draw firm conclusions about environmental causation of disease from any one study or small group of studies. Strong conclusions about disease causation in environmental health derive from a collective assessment of the weight of evidence from a large body of research that often takes many years to conduct.[4]

Studies of environmental impacts investigate the effects of HVHF activities on environmental media such as air, water and soil. Contamination of environmental media

has the potential to contribute to human health impacts if people experience exposures to those contaminants (for example, through breathing contaminated air or drinking contaminated water) that are large enough to cause a biological effect. However, studies of environmental impacts often do not attempt to directly demonstrate whether contamination of environmental media has resulted in significant human exposure or whether a health effect occurs as a result of an exposure. Other studies report on observed human health outcomes potentially associated with HVHF activity (i.e., environmental epidemiology studies). Health outcome studies related to HVHF activity focus on health effects reported among people living near HVHF drilling sites. Most health outcome studies can only suggest a potential statistical relationship between a source of environmental contamination and the observed health outcomes. These studies are limited in their ability to demonstrate that an actual exposure to the source has occurred or that exposure to an environmental source causes a health outcome. Health outcome studies vary in the complexity of their design and how rapidly they can be carried out. Some health outcome study designs that are relatively simple and quick to conduct are often also limited in their ability to account for other unrelated factors (usually referred to as bias and confounding) that might contribute to the observed health effects. Longitudinal prospective cohort studies are among the strongest study designs, but are very expensive and take years to conduct.

HVHF Health Outcome Studies

The public health science surrounding HVHF shale-gas development is currently limited and studies are largely exploratory in nature. Peer-reviewed epidemiologic studies were not found that employ robust study designs addressing possible associations between HVHF activities and adverse health outcomes while providing adequate control for confounding and bias. Scientific studies that contain relevant information investigating

human health outcomes potentially associated with HVHF activities are briefly summarized below.

Birth Outcomes

An unpublished 2013 revision to a 2012 working paper by Hill reports results of a study using data on 2,459 natural gas wells completed in Pennsylvania between 2006 and 2010, along with vital records for the years 2003 through 2010. The study compared birth outcomes for infants born to mothers living within selected fixed distances from spudded Marcellus Shale wells (the "existing well" infant group) with outcomes for infants born to mothers living within the same distances from future wells (the "future well" infant group). The outcomes considered were birth weight, gestation, five-minute APGAR (Appearance, Pulse, Grimace, Activity, Respiration) score (a health indicator assessed immediately following birth), small-for-gestational-age (yes/no), premature (yes/no), congenital anomalies (yes/no) and infant death (yes/no). The investigator reported that after specifying a fixed distance of 2.5 km from an existing or future well, and after controlling for multiple risk factors (e.g., maternal age, race, education, WIC status, marital status, insurance status and smoking), the "existing well" infant group had statistically significantly lower averages for birth weight and 5-minute APGAR score, as well as statistically significantly higher prevalence of low birth weight and small-for-gestational age, compared with the "future wells" infant group. No statistically significant differences were observed for prematurity, congenital anomalies or infant death.

Hill's conclusion that a "causal" relationship between natural gas development and birth outcomes was established may overstate the findings of this single study. The statistical approach used by the investigator, the differences-in-differences method, had in the past been employed primarily by social scientists but is increasingly used in public health studies. In the context of this study, this statistical approach assumed that, in the

absence of drilling, average outcomes for the “existing wells” and “future wells” infant groups would have followed parallel paths over time. Because differences may have existed between the two study groups with regard to potential risk factors not incorporated into the statistical analyses (e.g., prenatal care adequacy, maternal lifestyles, pre-existing chronic diseases, perinatal complications) it is possible that this "parallel paths" assumption may not have been appropriate. However, the author was able to demonstrate that, at least with regard to measured characteristics, there were no indications that this key assumption was not met.

A similar study by McKenzie et al. (2014) evaluated potential associations between maternal residence near natural gas wells and birth outcomes in a retrospective cohort study of 124,842 births between 1996 and 2009 in rural Colorado. Specifically, the authors investigated associations between natural gas well density and prevalence of congenital heart defects, neural tube defects, oral clefts, preterm birth, and term low birth weight. The least exposed (reference) group had no natural gas wells within a 10-mile radius. After adjustments for maternal and infant covariates, prevalence of congenital heart defects was significantly positively associated with increased exposure to natural gas development, with an increase of 30% (95% CI: 20% to 50%) for the highest exposure tertile when compared with the reference group. Prevalence of neural tube defects was significantly positively associated with exposure to natural gas development for the highest tertile of exposure, with an increase of 100% (95% CI: 0 to 390%) for the most exposed group when compared with the reference group. Exposure was associated with lower odds of preterm birth and lower odds of low birth weight (i.e., the high exposure groups were less likely to be preterm or low birth weight). No association was found between exposure and oral clefts.

It is notable that these two birth-outcome studies used similar study designs and observed associations between birth-outcome measures and maternal proximity to HVHF well pads. However, there is a lack of coherence between the observed associations in the two studies. Hill reported associations with low birth weight and APGAR score, but no associations with congenital defects. Conversely, McKenzie et al. reported associations between proximity to well pads and some congenital defects, but the highest exposure group had lower odds of preterm birth or low birth weight than the reference group. Taken together, the relationship between maternal proximity to HVHF well pads during pregnancy and birth outcomes, if any, is unclear.

Both birth-outcome studies used proximity to a drilling site as an exposure surrogate, rather than actual environmental contaminant measurements. This was a reasonable approach for an initial exploratory investigation, as it would be difficult and expensive to characterize indoor and outdoor exposures to all potentially relevant environmental agents (e.g., noise, air pollutants, groundwater pollutants, nighttime lighting) at numerous homes and workplaces. However, studies that employ vicinity as a surrogate for exposure cannot identify specific risk factors associated with the observed adverse outcomes or establish how, if at all, these risk factors were related to HVHF. For example, these studies cannot exclude the possibility that another factor unrelated to HVHF also varied by residence proximity to drill pads and contributed to the observed pattern of birth outcomes. The lack of coherent associations between this exposure surrogate and comparable outcomes may reflect weaknesses in the use of this exposure surrogate. The authors noted that greater specificity in exposure estimates would be required to further explore the reported associations.

Case Series and Symptom Reports

Bamberger and Oswald published a study in 2012, which documents case reports of animal and human health effects potentially resulting from nearby natural gas drilling operations. The summary of reported human health effects lacks specificity, but mentions a variety of symptoms such as upper respiratory, burning eyes, headache, gastrointestinal, dermatological, and neurological. The authors acknowledge the lack of complete testing of water, air, soil, and animal tissues that hampered more thorough analysis of the connection between gas drilling and health. They suggest further investigation is needed, ideally with policy changes that could assist in the collection of more complete data sets. Bamberger and Oswald were also guest editors for a 2013 special issue on shale gas development in the same journal (*New Solutions*). The articles in that special issue largely expand on potential health concerns raised in the original Bamberger and Oswald paper, although Bamberger and Oswald (2013) note in their introduction to the special issue that firm conclusions about potential health concerns cannot be established given the lack of relevant data.

Findings from an investigation done by the Earthworks' Oil & Gas Accountability Project were published in a non-peer-reviewed report (Steinzor, 2012). The report summarizes the extent and types of health symptoms experienced by 108 people from 55 households from 14 Pennsylvania counties where HVHF is occurring. It also has results of air sampling near 34 of the households and water sampling from nine of the households. It is difficult to interpret the results of this assessment. Participants report experiencing a number of symptoms, and the results suggest that those living closer than ~½ mile from a gas drilling facility may report symptoms in larger proportions than those living farther than ~½ mile. However, the sample is self-selected, and there was no systematic assessment of baseline health status or comparison with a similar population (the report does mention a five person control group that tended to

experience fewer symptoms) unaffected by HVHF. The results also do not adequately account for potential confounders (except smoking).

An unpublished presentation of findings from the Southwest Pennsylvania Environmental Health Project (SWPA-EHP) was made available on the organization's web site. A formal report of these findings was not available; the findings are summarized in a slide presentation.[5] Self-reported symptoms were summarized for patients from one county in southwestern Pennsylvania who sought medical care at the SWPA-EHP clinic. Self-reported symptom categories occurring in 21 – 48 percent of individuals seeking medical care included: skin rash or irritation, nausea or vomiting, abdominal pain, breathing difficulties or cough, and nosebleeds. Other complaints mentioned in the presentation include anxiety/stress, headache, dizziness, eye irritation, and throat irritation. The presentation attributes up to 27 cases[6] of symptom complaints as plausibly associated with a source of exposure in either air or water. However, there is no environmental exposure assessment presented in support of the claimed associations. No air or water monitoring data are presented. The symptoms reported are common in the general population and can have many causes. As with the Earthworks analysis, the sample is self-selected, and there was no systematic assessment of baseline health status or comparison with a similar non-HVHF population. There is no information presented indicating that the analysis attempted to account for potential confounders or other existing exposure sources.

Rabinowitz et al. (2014) conducted a preliminary (hypothesis-generating) study in the same county in southwestern Pennsylvania as the SWPA-EHP report described above. The study found some evidence that residential proximity of natural gas wells may be associated with the prevalence of certain health symptoms, largely acute or self-limiting dermal and upper-respiratory conditions. As the authors noted, follow-up investigations

would be required before drawing any conclusions with regard to actual disease incidence or possible causal relationships.

Results from a series of patient evaluations or symptom reports as presented above can only be considered hypothesis generating; that is, they can suggest possible relationships between an environmental exposure and health effects that could be investigated systematically in epidemiology studies designed to control for bias, confounding, temporality and chance findings. These types of clinical reports do not allow conclusions to be drawn about causal associations between HVHF exposures and health risks. However, while many of the reported symptoms are common in the general population, these reports indicate current information is not adequate to exclude the possibility that HVHF is contributing to public health impacts.

Local Community Impacts

There is a broad agreement in the public health community that social factors such as income, education, housing, and access to health care influence health status (i.e., so-called social determinants of health).[7] Many historical examples exist of rapid and concentrated increases in extractive resource development (e.g., energy, precious metals) resulting in local community impacts such as interfering with quality-of-life (e.g., noise, odors), overburdened transportation and health infrastructure, and disproportionate increases in social problems, particularly in small isolated rural communities where local governments and infrastructure tend to be unprepared for rapid changes.[8] These impacts could indirectly result in increased stress, which, in turn, can be associated with increased prevalence of some health problems (for example, WHO, 2009). Similar concerns have been raised in some communities where HVHF activity has increased rapidly (Texas DSHS, 2010).

For example, in some areas of HVHF well pad development nearly all water used for hydraulic fracturing is hauled to the pad by truck. One horizontal well is estimated to require about 1500 to 2000 truck trips over the entire life of the well (NTC Consultants, 2011).

A recent study from Pennsylvania reports that automobile and truck accident rates in 2010 - 2012 from counties with heavy HVHF activity were between 15% and 65% higher than accident rates in counties without HVHF. Rates of traffic fatalities and major injuries were higher in heavy drilling counties in southwestern Pennsylvania compared to non-drilling counties in 2012 (Graham, 2015). Major potential adverse impacts from increased truck traffic include increased traffic congestion and accidents; more damage to roads, bridges and other infrastructure; and spills of hazardous materials during transportation.[9]

Cancer Incidence

Fryzek et al. (2013) conducted a retrospective assessment of the potential for an association between childhood cancer incidence and HVHF in Pennsylvania, and reported no increase in childhood cancers after HVHF commenced. Study limitations included the insensitivity of the methods employed, the rarity of childhood cancers, and the absence of adequate lag time between most HVHF activities and most of the study's childhood cancer diagnoses. These raise some uncertainty about the strength of the study conclusions.

Non-peer-reviewed Information

In addition to investigating information in the peer-reviewed scientific literature, DOH has maintained an ongoing effort to follow news reports and other non-peer-reviewed sources for emerging information related to HVHF and potential public health impacts.[10] Many findings reported through such non-peer-reviewed sources are from informal or anecdotal health evaluations that have significant limitations such as self-selected symptoms reports, non-specific symptoms, lack of exposure data, lack of baseline health information, lack of unexposed comparison groups, and lack of controls for bias and confounding. Reports of this sort cannot be used to draw conclusions about associations between reported health symptoms or complaints and any specific potential environmental exposure source such as HVHF shale-gas development. However, these types of reports suggest hypotheses for associations between health outcomes and shale-gas activities that could be tested with proper environmental epidemiology methods.

HVHF Environmental Studies

Studies investigating HVHF impacts on environmental media such as air or water were included in the review if they provided information about the potential for human exposures from HVHF activity.

Air Quality Impacts

Maintaining good air quality is obviously vital for promoting public health; poor air quality can affect large populations of people, and therefore can contribute to significant morbidity and mortality. DOH programs promote clean outdoor air quality by developing health comparison values for use by DEC and by investigating and helping to correct conditions that contribute to poor indoor air quality. NYS was the first state in the

country to establish indoor smoking prohibitions in public spaces under the NYS Clean Indoor Air Act.

The National Institute for Occupational Safety and Health (NIOSH) has assessed potential risks to workers associated with chemical exposure at natural gas drilling sites (NIOSH, 2012). In field studies conducted at 11 sites, respirable crystalline silica and diesel particulates were measured at levels with the potential to pose health hazards. NIOSH has proposed several controls and recommended proper use of personal protective equipment to minimize exposures. NIOSH has also reported that the occupational fatality rate among oil and gas industry workers is seven times higher than the average rate for all US industries (Retzer, 2011). On August 23, 2013, the federal Occupational Safety and Health Administration (OSHA) announced that it intended to propose a revised standard (called a permissible exposure limit) to protect workers from exposure to respirable crystalline silica.[11] OSHA's Notice of Proposed Rulemaking for Occupational Exposure to Respirable Crystalline Silica was published in the Federal Register on September 12, 2013.[12] If enacted, the new regulation would reduce the permissible exposure limit for crystalline silica and would establish certain other requirements related to measuring levels of silica in workplace air, controlling dust, providing respiratory protection, training of workers, and offering medical exams. While the NIOSH assessment focused on worksite air quality, this report is suggestive that uncontrolled silica emissions could affect the air quality of residences or businesses near well pads.

In 2010, the Texas Department of State Health Services collected blood and urine samples from 28 people, living in and near the town of Dish, to determine whether people there had higher levels of volatile organic compounds (VOCs) in their blood than 95% of the general United States (U.S.) population. Community residents had raised

concerns that they were experiencing exposure to air contaminants from nearby gas wells and compressor stations. Measuring the presence of chemicals in biological fluids (i.e., biomonitoring) is a technique that can demonstrate that exposure occurred to those chemicals, but does not necessarily identify the source of the exposure, or when exposure occurred. Based on the pattern of VOC values found in the samples, the information obtained from this investigation did not provide evidence that community-wide exposures from gas wells or compressor stations were occurring in the sample population. Other sources of exposure such as cigarette smoking, disinfectant byproducts in drinking water and consumer or occupational/hobby related products could explain many of the findings.

In 2010, the Colorado Department of Public Health and Environment released a public health consultation evaluating the potential public health hazards of ambient air pollution in areas of Garfield County in close proximity to oil and natural gas development activities. This report summarized results from enhanced air quality monitoring implemented following a 2008 public health consultation[13] which found air concentrations near the upper end of EPA's acceptable range for benzene-associated cancer risk at one monitoring site. In this study, air monitoring was used to measure concentrations of chemical contaminants in the air near HVHF activities, and then those measured levels were compared to health-based comparison values for the chemicals. Health comparison values are a risk-assessment tool and are set at levels to be protective of public health. If comparison values are exceeded, it does not imply that adverse health impacts will occur, but it indicates that further investigation of potential exposures is warranted.

In the 2010 report, the investigators concluded that it could not be determined if breathing ambient air in those areas of Garfield County that were monitored could harm

people's health. This conclusion was reached because the cancer risks and noncancer hazards for 65 out of 86 contaminants could not be quantitatively estimated due to the unavailability of chronic inhalation toxicity values. Although the evaluation suggests that exposures are not likely to result in significant cancer and noncancer effects (the levels measured are much lower than those known to cause health effects), cumulative health effects from synergistic interactions are unknown. Where quantitative evaluations were possible, increased risks of cancer, long-term (chronic) noncancer hazards and short-term (acute) noncancer hazards (where data were available) were low, although for the latter there is uncertainty because insufficient data are available to evaluate intermittent short-term peak exposures.

A similar risk-assessment study of air-quality monitoring in the Barnett Shale region of Texas was published in 2014 by Bunch et al. (2014). The study summarized air-monitoring data for volatile organic chemicals collected at six fixed monitoring locations in Wise, Denton and Tarrant counties in north-central Texas including areas in and around the city of Fort Worth. The monitoring network is operated by the Texas Commission on Environmental Quality (CEQ) and is described in the report as the most extensive air monitoring network in place in any U.S. shale play. The network includes both real-time monitors and 24-hour average samples analyzed in the laboratory, covers regions of the Barnett shale producing both dry and wet gas, and spans areas of urban and suburban development where the potential for community exposure to any shale-gas air emissions could be significant. The analysis of these data included assessing potential health risks of short-term and long-term exposure to all chemicals measured by the monitoring network using existing health comparison values (for example, Texas CEQ air monitoring comparison values or US EPA reference concentrations). Many of the chemicals measured by the existing network are unrelated to shale-gas development. Therefore, the authors also conducted more refined

quantitative risk assessments for a subset of volatile organic chemicals thought to be most likely to be associated with shale gas production.

The Bunch et al. study summarized the results of over 4.6 million data points collected over more than 10 years for up to 105 different volatile organic chemicals per monitor. Only one observed short-term value exceeded an applicable odor-based comparison value.[14] None of the measured short-term (one hour or 24-hour average) air levels for the entire panel of chemicals exceeded an applicable short-term health-based comparison value. Only one chemical (1,2-dibromoethane) had any annual average concentrations that exceeded its applicable long-term health comparison value.[15] The authors noted that the analytical detection limit for 1,2-dibromoethane is substantially higher than its chronic comparison value and about 90% of the 1,2-dibromoethane results that contributed to the exceedances were non-detects. This suggests the true annual average concentrations could have been substantially lower than the reported estimates. The authors also did not consider 1,2-dibromoethane to be a chemical reasonably expected to be associated with shale-gas production. According to the authors, it is used as a lead-scavenger in aviation fuel. The two monitoring locations where the 1,2-dibromoethane 2011 annual averages exceeded applicable comparison values are located near airports. More refined deterministic and probabilistic quantitative risk assessments for annual average concentrations found that estimates of cumulative noncancer and cancer health risks were below levels of concern at all monitoring locations. The authors concluded that their analysis demonstrated that shale gas operations in the monitored region of the Barnett play have not resulted in community-wide exposures to the measured volatile organic chemicals at levels that would pose a health concern.

Macey et al. (2014) analyzed data from grab and passive air samples that were collected in Arkansas, Colorado, Ohio, Pennsylvania and Wyoming by trained volunteers at locations identified through systematic observation of industrial operations and air impacts over the course of residents' daily routines. The investigators reported that concentrations of eight volatile chemicals exceeded risk-based comparison values under several operational circumstances. Benzene, formaldehyde, and hydrogen sulfide were the most common compounds to exceed acute and other risk-based values. However, it was not always clear that the authors employed appropriate risk-based comparison values given the nature of the samples that were collected. For example, the use of comparison values based on lifetime (long-term) cancer risk levels may have substantially overstated cancer risks associated with exposures to short-term levels of air pollutants that were measured. Moreover, retrospective source apportionment efforts are not possible based on study data because the investigators did not collect the necessary control samples, such as upwind air samples, or wind direction data. This complicates evaluation of the study data because, at least in some urban and industrial settings, it is not unusual for atmospheric concentrations of benzene and formaldehyde to exceed some of the comparison values that were employed by the authors (Weisel, 2010).

The Pennsylvania Department of Environmental Protection (PA DEP) conducted short-term, screening-level air quality sampling initiatives in various parts of the Commonwealth where a majority of the Marcellus Shale operations have been undertaken.[16] Sampling windows often captured pollutant concentrations during the early morning hours and late evening hours, to reflect the predominate times when complaints related to Marcellus gas exploration activities are received by the DEP. Following the completion of a comparative analysis, which will consider data from

separate surveys conducted in four Pennsylvania regions, the DEP will determine whether additional, longer-term sampling is warranted.

Data from the northeastern and northcentral regions of Pennsylvania are most relevant to New York State, since the Marcellus in those regions produces predominantly natural gas, rather than oil. The PA DEP did not find an immediate health risk to the general public. Certain compounds were detected at levels that produce odors. For example, methyl mercaptan was often detected at levels that generally produce odors. Methyl mercaptan is a naturally occurring compound present in some shale gas formations as well as in crude oil. Methyl mercaptan has a strong unpleasant smell that can be detected by the human nose at very low levels. Olfactory fatigue, or the loss over time of the ability to smell methyl mercaptan, occurs after prolonged exposure. The PA DEP determined that the methyl mercaptan levels detected could cause violations of PA DEP odor emission provisions in 25 Pa. Code Section 123.31 if they persisted off the property and the Department determined that the odors were “malodors” as defined in 25 Pa. Code Section 121. The PA DEP indicated that prolonged or repeated exposures to strong odors may produce odor-related health effects such as headaches and nausea.

Sampling for carbon monoxide, nitrogen dioxide, sulfur dioxide, and ozone in northeastern Pennsylvania did not detect concentrations above National Ambient Air Quality Standards at any of the sampling sites. With regard to benzene, only one two-minute benzene concentration of 400 parts per billion (ppb), reported in northcentral Pennsylvania, produced a hazard quotient[17] close to 1.0 when compared to the most conservative of the three health-based reference concentrations used in by PA DEP. Because of where the monitoring device was located (i.e., next to a parking lot and road), this one benzene reading was considered most likely due to a mobile source. The

three canister samples collected during the week, which were sited away from the parking lot, did not detect elevated levels of benzene. Considering that this single high benzene value was measured at the background site, the PA DEP has determined that benzene should not be considered a pollutant of concern near Pennsylvania Marcellus Shale operations.

The PA DEP reported that the use of an infrared camera was an effective tool in showing emissions from drilling operations that may have impacted sampling results. At one well site, the camera documented leaks of what is most likely methane. Although the ambient methane concentrations detected in the air were not considered unacceptable in terms of adverse inhalation health effects, the methane emissions represented a waste of resources and a fractional contribution to greenhouse gas levels. The DEP therefore determined that the camera will continue to be deployed during its future investigative and/or sampling efforts.

Reports from other states using HVHF suggest it is common for trucks to form lines when awaiting access to gas well pads (Gold, 2013). If a line of idling trucks forms near a home, this could potentially increase residents' exposures to diesel exhaust for the duration of operations requiring idling. A recent West Virginia study determined that vehicle traffic and engine exhaust were the likely sources of intermittently high dust and benzene concentrations sometimes observed at distances of 625 feet[18] and farther from the center of well pads (McCawley, 2013).

Shonkoff et al. (2014) reviewed the scientific literature related to air pollution from shale and tight gas development, and noted differences in results obtained by different surveys. For example, McKenzie et al. (2012) reported relatively substantial exposures

to certain volatile organic compounds (e.g., trimethylbenzenes, xylenes, and aliphatic hydrocarbons) among residents living ≤ 0.5 mile from oil and gas wells compared with residents living > 0.5 mile from wells. In contrast, Bunch et al. (2014) reported that shale gas production activities in the Barnett Shale Play, Texas, did not result in community-wide exposures to concentrations of volatile organic compounds above federal and state health-based air comparison values. Shonkoff et al. noted that differences between the two studies could have been due to the different sampling methods employed. For example, McKenzie et al., but not Bunch et al., considered data from samples collected at the local (community level) in close proximity to gas development.

Pétron et al. (2012) analyzed data collected at the National Oceanic and Atmospheric Administration Boulder Atmospheric Observatory and reported an alkane and benzene signature when winds blew from the direction of the Denver-Julesburg Basin, an area of considerable oil and gas development. Additional studies have documented substantial greenhouse gas releases and elevated atmospheric ozone concentrations from extensive exploitation of oil and gas deposits by various methods, including HVHF (Kemball-Cook, 2010).

Natural gas can also contain radon, a potential indoor air contaminant. A screening analysis by DOH (see Appendix 2) suggests that radon exposure levels from Marcellus natural gas could contribute a small fraction to the overall indoor radon levels. However, there is substantial uncertainty regarding radon levels in shale gas from various geographic locations and geologic formations because of limited monitoring data, especially from the Appalachian Basin (Rowan and Kramer, 2012), which includes the Marcellus shale.

Water Quality Impacts

Water quantity and quality have obvious importance for public health in terms of having reliable sources of water for public and private drinking-water supplies at all times. Surface waters provide additional indirect public health benefits related to fish resources (both recreation and for food), recreational use (swimming and boating) and flood control in the case of wetland areas. Maintaining adequate surface water quantity and quality helps promote these health benefits. Under the federal Safe Drinking Water Act (SDWA), the US Environmental Protection Agency (US EPA) established the public water system supervision program. In New York State, the DOH has the primary responsibility for implementing and enforcing the drinking water regulations of the SDWA for all public water systems.[19] This also includes oversight and implementation of US EPA's Surface Water Treatment Rule.

With the promulgation of the Surface Water Treatment Rule in the late 1980s, all drinking water taken from surface water sources must be filtered to reduce the risk of waterborne disease. However a waiver, or Filtration Avoidance Determination (FAD), may be granted to a water supplier if it is able to demonstrate ongoing compliance with strict water quality criteria and if it has a plan for the long-term control and management of its watershed.

In New York State, both the City of Syracuse and the City of New York have been issued a FAD. The FAD for the Syracuse public water supply system encompasses Skaneateles Lake and its 59 square mile watershed and for New York City, the FAD encompasses the Catskill and Delaware (Cat/Del) water supplies and its 1600 square mile watershed in the Catskills.

While watershed management is important for any surface water supply, it is critical and required for an unfiltered FAD system. Therefore, both the NYC Cat/Del and Skaneateles Lake watersheds are unique natural and hydrological sources of importance within the State. The importance of these resources is highlighted, in particular, by the 1997 NYC Watershed Memorandum of Agreement (MOA). The MOA is a landmark agreement that recognizes both the importance of preserving high-quality drinking water and the economic health and vitality of communities located within the watershed. It is a legally binding 145 page contract, with 1500 pages of attachments, between NYC, the State, US EPA, nearly 80 local governments in the watershed and environmental groups.

The literature investigating water-related impacts of HVHF activity is relatively extensive compared to literature on other environmental impacts, although most studies do not directly assess the potential for human exposure or public health impacts from water contamination. Osborne et al. (2011) first highlighted the potential for sub-surface methane migration from HVHF activity to affect drinking water wells in Pennsylvania, and subsequent reports from the same group of researchers have continued to investigate this potential source of groundwater contamination. The following summarizes a few of the most recent water-quality investigations of HVHF that could be most germane to understanding the potential for HVHF to contribute to human exposure through drinking water.

Some recent publications have shed light on the potential for and causes of occasional water pollution incidents around oil and gas wells (for example, see: Satterfield, 2011; Sharma, 2014; Warner, 2014; Zhang, 2014). Darrah et al. (2014) identified groundwater contamination clusters that they determined were due to gas leakage from intermediate-depth strata through failures of annulus cement, faulty production casings, and

underground gas well failure. Vengosh et al. (2014) identified published data revealing evidence for stray gas contamination, surface water impacts, and the accumulation of radium isotopes in some disposal and spill sites. Some preliminary data suggest inadequate HVHF wastewater treatment could contribute to formation of disinfection byproducts in treated surface waters (e.g., Chang, 2001; Parker, 2014). These and other reports indicate that there remain data gaps and uncertainties regarding the effectiveness of some common mitigation measures related to both well construction and wastewater management, at least as these have been implemented in other states.

An investigation was reported by Kassotis et al. (2014) using in vitro (i.e., cell culture) assays to assess the estrogen- and androgen-receptor activity of HVHF chemical additives and environmental water samples. Twelve chemicals were chosen that were considered to be known or suspected endocrine-disrupting chemicals and were chemical additives used in natural gas operations in Colorado.[20] Groundwater and surface water samples were collected in Garfield County Colorado from areas considered “drilling dense” near locations where natural gas “incidents” had occurred. Reference groundwater and surface samples were collected in areas of Garfield County considered “drilling sparse” and from the nearby Colorado River and a non-drilling reference location in Missouri. Assay results showed the twelve chosen chemicals showed varying degrees of anti-estrogenic and anti-androgenic activity compared to positive control activities (17β -estradiol and testosterone, respectively). Groundwater and surface water samples concentrated 4-times or 40-times from their levels in the environment had varying degrees of estrogenic, anti-estrogenic or anti-androgenic activity in the test assays, generally with higher activities seen from samples collected from the drilling dense sites, although differences from reference samples were not always statistically significant.

Kassotis et al. concluded that, based on *in vitro* assay results of the selected chemicals and water samples from drilling dense vs. reference locations, natural gas drilling operations may result in elevated endocrine disrupting activity in groundwater and surface water. There are a number of study limitations that suggest a strong conclusion attributing the observed assay responses to natural gas drilling is questionable. For instance, there were no chemical analyses presented of the drilling-dense water samples that would allow an evaluation of whether the observed assay results were due to drilling-related chemicals present in the water or to other unrelated chemicals that could have been present from other sources. Similarly, drilling-dense samples and reference samples were not always matched for other potentially influential factors aside from drilling proximity such as the type (drinking water vs. monitoring) and depth of groundwater wells, stream ecology or land use differences adjacent to sampling locations.

Drilling-dense sampling sites were described by Kassotis et al. as being associated with "natural gas incidents" including equipment leaks, spills or natural gas upwelling. However, these incidents took place at varying times from several months to several years prior to sampling and could have involved very different mixtures of materials (such as bulk chemical additives during a spill or formation brine from an equipment leak). The investigators did not provide details concerning the specific nature of any water contamination that might have resulted from these incidents or what environmental remedial activities may have taken place prior to collecting water samples. This information would have been helpful in evaluating the likelihood that water contamination from the incidents had occurred and persisted in the sampled water sources. This information is especially important because the study report provided no analyte concentration data for the study water samples. The proximity of water sample collection locations to drilling activity alone does not conclusively indicate

that natural gas drilling operations result in endocrine disrupting activity in the water. Even if further detailed research supported drilling-related contaminants as the source of increased endocrine disrupting activity in the *in vitro* assays used in this study, the relevance of the study methods to actual human exposure and human physiological responses are unknown. Therefore, these results do not allow any assessment of the potential risk to human health posed by such contamination.

A critical review of water resource issues associated with HVHF (Vengosh, 2014) noted that treatment and disposal of HVHF solid waste and wastewater is a significant challenge. Gas wells can bring naturally occurring radioactive materials (NORM) to the surface in the cuttings, flowback water and production brine. NORM consists of uranium and thorium and their decay products. Some of those decay products, namely radium and radon, can be a public health concern if exposure occurs at sufficiently-high levels. Rocks and soil contain NORM at various levels, and certain types of rock tend to have higher concentration of NORM.

NORM in flowback and production brine can plate out and concentrate on internal surfaces of pipes and tanks (scale). NORM in pipe scale contains predominantly radium. This can cause an external radiation exposure risk to workers who work with this equipment.

Induced Earthquakes

Although it has long been known that some forms of underground fluid injection can increase the risk of earthquakes,[21] the long-term impacts of extensive hydraulic fracturing upon the risk of earthquakes in the Northeastern U.S. remains poorly

understood. In contrast, some information regarding short-term risks above the Marcellus and Utica shale plays has become available.

Holland (2014) described one of the first observed cases in Oklahoma of earthquakes triggered by the hydraulic fracturing phase (rather than underground wastewater injection). The earthquakes were large enough to be felt by local residents.

In Maxwell's (2013) description of an approach to evaluating HVHF-related seismic events, criteria for confirming events, and existing injection and HVHF seismicity protocols, the author described several seismic events ranging from low to moderate energy. According to the author, during April and May of 2011 hydraulic fracturing near Preese Hall, UK, resulted in an event with magnitude ML=2.3 (local magnitude scale) and later another ML=1.5. The author added that, between 2009 and 2011, 38 earthquakes including a ML=3.8 resulted from hydraulic fracturing in the Horn River Basin shale gas reservoir in north-east British Columbia, Canada.

In 2014, the Ohio Department of Natural Resources (ODNR) announced new, stronger permit conditions for drilling near faults or areas of past seismic activity.[22] The new policies were developed in response to seismic events in Poland Township (Mahoning County) that the ODNR determined were probably connected to hydraulic fracturing near a previously unknown "microfault." Under the new rules, permits issued by ODNR for horizontal drilling within three miles of a known fault or area of seismic activity greater than a 2.0 magnitude require companies to install sensitive seismic monitors. If those monitors detect a seismic event in excess of 1.0 magnitude, activities must pause while the cause is investigated. If the investigation reveals a probable connection to the hydraulic fracturing process, all well completion operations must be suspended. ODNR

says that it will develop new criteria and permit conditions for new applications in light of this change in policy. The department will also review previously issued permits for wells that have not been drilled.

Conclusions – Health and Environmental Literature

The science surrounding HVHF shale-gas development and public health risks is only just beginning to emerge. Many of the published reports investigating environmental and health implications of HVHF activities are preliminary or exploratory in nature. As a result, the available science on HVHF currently is limited and largely suggests hypotheses about potential impacts that need further evaluation. Health impacts that have been reported to be potentially associated with exposure to HVHF activities include a variety of acute or self-limiting signs and symptoms such as skin rash or irritation, nausea or vomiting, abdominal pain, breathing difficulties or cough, nosebleeds, anxiety/stress, headache, dizziness, eye irritation, and throat irritation. Other outcomes that have been reported as potentially associated with HVHF exposure include low birth weight and some congenital defects. Studies of environmental impacts have documented sub-surface methane migration from well casings to groundwater and methane leakage to the atmosphere from HVHF infrastructure. Other environmental impacts including noise and dust from well pads and truck traffic, increased traffic accident rates, inadequate wastewater treatment, and induced earthquakes have been observed. The actual degree and extent of these environmental impacts, as well as the extent to which they might contribute to adverse public health impacts are largely unknown. Nevertheless, the existing studies raise substantial questions about whether the public health risks of HVHF activities are sufficiently understood so that they can be adequately managed.

| Results

Information Gathered from Outside Authoritative Organizations, Public Health Experts, and Formal Health Impact Assessments

Other information sources were sought to provide additional background information on public health risk of HVHF for the Public Health Review. Former Commissioner Shah, Acting Commissioner Zucker, and DOH staff held multiple discussions and meetings with public health and environmental authorities in several states to understand their experience with HVHF. Former Commissioner Shah, Acting Commissioner Zucker, and DOH staff also engaged in a number of discussions and meetings with researchers from academic institutions and government agencies to learn more about planned and ongoing studies and assessments of the public health implications of HVHF. Input was sought from three public health expert consultants regarding the potential public health risk posed by HVHF activities. And, health impact assessments conducted by other state, provincial and international governments were reviewed for any additional insights regarding HVHF public health concerns.

Health Impact Assessments

A health impact assessment (HIA) is a decision tool that uses a structured assessment approach to identify impacts of an activity or policy decision and recommend ways to lessen or prevent adverse public health impacts under alternate decision options. The results of these assessments tend to be based on qualitative judgments when decision alternatives being considered involve large-scale, complex issues such as HVHF. HIAs that examined public health risks of HVHF have recently been conducted by

governments or academic institutions in Maryland (University of Maryland, 2014), Michigan (University of Michigan, 2013), North Carolina (Research Triangle Environmental Health Collaborative, 2013), Nova Scotia (Wheeler, 2014), the National Institute of Environmental Health Sciences (NIEHS; Penning et al, 2014), the Institute of Medicine (IOM, 2014), and the European Commission (Broomfield, 2012).

The European Commission, which is the executive body of the European Union, published a report (Broomfield, 2012) on the results of a preliminary screening of potential public health and environmental risks related to HVHF in Europe, along with risk management recommendations. For each risk identified by the Commission, the preliminary risk screening approach combined a subjective adverse event probability classification ("rare" to "frequent/long-term definite") with a subjective hazard classification ("slight" to "catastrophic") to develop a risk classification ("low" to "very high"). Using this approach, the Commission determined that HVHF in Europe will entail "high" cumulative risks of groundwater contamination, surface water contamination, depletion of water resources, releases to air, increased noise, and increased traffic.

A 2011 Executive Order Issued by Maryland Governor Martin O'Malley established the Maryland Marcellus Shale Safe Drilling Initiative.[23] The Initiative is jointly administered by the Maryland Department of the Environment and the Maryland Department of Natural Resources. The Executive Order also established a Marcellus Shale Safe Drilling Initiative Advisory Commission composed of a variety of governmental, community, environmental and industry stakeholders. According to the Executive Order, the purpose of the Initiative is to:

"… assist State policymakers and regulators in determining whether and how gas production from the Marcellus shale in Maryland can be accomplished without unacceptable risks of adverse impacts to public health, safety, the environment and natural resources."

As part of the Maryland Initiative, the Maryland Department of Health and Mental Hygiene (MDHMH) announced in September, 2013, two public meetings to receive public input on a study of potential public health impacts associated with possible development of the Marcellus Shale in Western Maryland.[24] MDHMH then oversaw the study, which was performed by the University of Maryland School of Public Health's Maryland Institute for Applied Environmental Health. The final study report, entitled "Potential Public Health Impacts of Natural Gas Development and Production in the Marcellus Shale in Western Maryland," was published in July 2014.[25] The report identifies largely the same types of potential health impacts of HVHF activity as those identified in other HIAs. The report presents a hazard evaluation summary of eight potential adverse impacts, rating four (air quality, healthcare infrastructure, occupational health, and social determinants of health) as having a high likelihood of negative public health impact. Three potential impacts (cumulative exposures/risks, flowback and production water-related, and noise) were rated as moderately high, and one (earthquakes) was rated as low.

In 2013 the University of Michigan's Graham Sustainability Institute released several technical reports on HVHF in the State of Michigan that were intended to provide information for decision makers and stakeholders, as well as to help inform the Institute's "Hydraulic Fracturing in Michigan Integrated Assessment," which will evaluate policy options.[26] Faculty-led and student-staffed teams provided reports on the following topics: Technology, Geology/Hydrogeology, Environment/Ecology, Human Health,

Policy/Law, Economics, and Public Perceptions. The Institute noted that its technical reports should not be characterized as final products of the integrated assessment, and that the reports do not provide a scientific risk assessment for aspects of HVHF.

In its Public Health technical report, the Institute preliminarily identified 18 possible public health issues related to HVHF, with "plausibility scores" reflecting qualitative assessments of the evidence suggesting that each issue could be considered a potential public health hazard.[27] Of the 18 issues enumerated, eight were given the highest plausibility score, reflecting the Institute's determination that "scientific evidence exists and is strong (e.g., many studies, good design, causality)." These eight issues were silica exposure, intentional-use chemicals, by-product chemicals, transportation, air quality, water quality, habitat and wildlife (impacts on recreational opportunities, cultural/spiritual practices), and public perceptions (causing, e.g., increased anxiety, family quarrels, depression).

The Institute discussed several "challenges and opportunities" with regard to HVHF in Michigan, beginning with Michigan's lack of a public health tracking system. The Institute also called for complete disclosure of chemicals injected during HVHF, noting that disclosure has thus far been minimal in Michigan, with only a few facilities reporting upon a small number of drilling events out of more than 12,000 wells that have undergone HVHF. The Institute additionally recommended more public health outreach and education in Michigan, particularly in potentially-impacted communities, similar to recommendations in our review. Finally, the Institute indicated that a health economist should be enlisted to help describe risks and benefits of HVHF compared with alternative energy sources.

In response to state legislation allowing the use of horizontal drilling and hydraulic fracturing in North Carolina, a summit meeting was convened in October, 2012, by the Research Triangle Environmental Health Cooperative (EHC). A report presenting recommendations from the summit was released in 2013.[28] According to the report, summit participants represented diverse stakeholder groups including industry, nonprofits, governmental organizations and academia. The report stated that:

> *"The EHC summit aimed to create a neutral space in which to share ideas and experiences to identify gaps in the current knowledge of, and preparations for, the potential impacts of hydraulic fracturing on public health in North Carolina. The summit recommended actions and potential policies to safeguard the health of North Carolinas citizens and environment if hydraulic fracturing occurs in the state."*

Three working groups were formed as part of the summit – exposure pathways, health impacts, and social impacts – and each working group made relevant recommendations for developing new components or strengthening existing components of the state's oil and gas program. While each working group developed extensive specific recommendations, major themes that were common to the working group recommendations included:

- Collect baseline data prior to oil and gas drilling. This includes data on water quality, hydrogeological information, hydrocarbon characterization, air quality, ecosystem information, and population health statistics.
- Develop a comprehensive water and wastewater management plan that addresses how water is allocated among users and how oil and gas drilling wastewater will be managed through treatment, reuse/recycling and disposal.

- Provide adequate and coordinated funding and administrative oversight for oil and gas development programs. Specifically, the state should develop a bonding and remediation program to provide adequate cleanup, remediation, and maintenance funds. Drilling companies should pay into a “premediation” fund financed by a permit fee to drill an oil or gas well. Additional funding is needed to adequately address the potential environmental and social costs of hydraulic fracturing, including collection of comprehensive environmental and health data before, during and after the drilling process. Local, state, and regional agencies should coordinate the administration and oversight of hydraulic fracturing and should avoid duplication of effort.
- Develop and promote a list of best management practices (BMPs) for drilling and hydraulic fracturing. These BMPs should focus on: preventing contaminants from entering the environment; containing contaminants if they do accidentally enter the environment; and monitoring for contaminants to quickly detect releases if they occur, stop them, and begin remediation. Effective regulations require enforcement if violations occur. Regulations must also keep pace with the rapid technological developments in the shale gas industry.

Another assessment was conducted in 2014 by the Nova Scotia Independent Panel on Hydraulic Fracturing, which determined that although HVHF would provide major economic and employment benefits to the province, Nova Scotia does not have the necessary information required to make a final decision on whether to allow HVHF in the province (Wheeler, 2014).[29] Among other things, the review found that: many questions about fracking remain outstanding; municipalities, citizens, Aboriginal governments, and communities should be involved in the risk-assessment and decision-making process; and the report should be used as a basis for informed debate on the issue of HVHF in Nova Scotia. The report recommends that stakeholders “spend

whatever time is necessary learning about these issues, keeping an open mind of future developments …" The report also provides 32 recommendations "to safeguard community health, local economies, ecosystem health, and the environment," in the event that the province moves forward with HVHF.

An assessment was published in 2014 by a working group formed by Environmental Health Sciences Core Centers that are funded by the National Institute of Environmental Health Sciences (Penning, 2014). The Inter-Environmental Health Sciences Core Center Working Group on Unconventional Natural Gas Drilling Operations concluded that there are data gaps and uncertainties regarding impacts and the effectiveness of HVHF mitigation measures. The group further concluded that a potential for water and air pollution exists which might endanger public health, and that the social fabric of communities could be impacted by the rapid emergence of drilling operations. The working group recommended research to inform how potential risks could be mitigated. The assessment did not identify novel information or issues, but it lends support to some of the conclusions made in this Public Health Review with regard to data gaps and uncertainties regarding HVHF-related public health impacts.

In 2012, a workshop convened by the Institute of Medicine (IOM) Roundtable on Environmental Health Sciences, Research, and Medicine discussed the human health impact of shale gas extraction through the lens of a health impact assessment. The workshop examined the state of the science regarding shale gas extraction, the direct and indirect environmental health impacts of shale gas extraction, and the use of health impact assessment as a tool that can help decision makers identify the public health consequences of shale gas extraction (IOM, 2014).

The review of HIAs for this Public Health Review focused on identifying any public health risks different from those identified through the scientific literature review. The review found that the public health risks and information gaps identified in the published HIAs were qualitatively similar to those discussed in the literature review section above. In some cases, specific public health risks were emphasized in these assessments:

- The European Commission HIA determined that HVHF in Europe will entail "high" cumulative risks of groundwater contamination, surface water contamination, depletion of water resources, releases to air, increased noise, and increased traffic.
- The University of Michigan assessment identified priority issues including silica exposure, intentional-use chemicals, by-product chemicals, transportation, air quality, water quality, habitat and wildlife (impacts on recreational opportunities, cultural/spiritual practices), and public perceptions (causing, e.g., increased anxiety, family quarrels, depression).
- The North Carolina HIA emphasized planning and monitoring including: collecting baseline data on water quality, air quality and health statistics; developing a comprehensive water and wastewater management plan; adequately support coordinated enforcement; and, develop and promote best practices.
- Both the NIEHS and IOM assessments emphasized the potential for water and air pollution that could adversely affect public health as well as the potential for social disruption that could result from local community impacts caused by rapid development of HVHF activities.

Meetings with Other State Agencies

Commissioner Shah met with officials of the California Department of Public Health (CDPH) and the California Department of Conservation (CDOC) in July, 2013. In

August, 2013, he held separate meetings with officials in Texas (representing the Texas Department of State Health Services (TDSHS), the Texas Railroad Commission (TRC), and the Texas Commission on Environmental Quality (TCEQ)) and officials in Illinois (representing the Illinois Department of Public Health (IDPH) and the Illinois Department of Natural Resources (IDNR)). The purpose of these meetings was to learn directly from the state agencies about each state's experience with oil and gas development and to evaluate how the oil and gas regulatory programs in those states compare to the regulatory program in New York State. The following summarizes the findings of these meetings at the time they occurred in 2013.

California

Like New York, California has a long history of oil and gas development. As is currently the case in New York, essentially all oil and gas wells in California are vertical wells. Most oil wells in California are stimulated using low-volume hydraulic fracturing. The geology in areas currently being developed in California is very different from the Marcellus Shale formation in New York. Most current activity in California produces oil from tight sand formations. These formations also produce a large quantity of formation water (brine), which is re-used for hydraulic fracturing and for enhanced oil recovery. A small fraction of the produced brine is treated and can be used for agricultural irrigation. The formations currently being drilled in California have very little naturally-occurring radioactive material (NORM). The Monterey Shale in California is a shale formation somewhat analogous to the Marcellus Shale, although the Monterey is expected to produce primarily oil. Exploitation of the Monterey Shale would require horizontal drilling and high-volume hydraulic fracturing, but activity in this formation on a commercial scale has so far not taken place because of technical challenges due to the unusual chemical and physical properties of the formation.

Unlike New York, where low-volume hydraulic fracturing has been specifically regulated under the Generic Environmental Impact Statement since 1992, California does not currently have formal regulations specific to hydraulic fracturing. A discussion draft of proposed hydraulic fracturing regulations was released by CDOC for public review and comment in December, 2012. Public feedback was obtained on the discussion draft in a series of public hearings, and a formal proposed rule is expected to be released soon. The discussion draft indicates that all records submitted under the rules would be considered public records for the purposes of the state's public records law. The discussion draft includes provisions that would require well operators to publicly disclose all information about chemical additives and carrier fluids used in hydraulic fracturing fluids for a well. This requirement would be subject to exceptions for information claimed to be trade secrets.

California does not currently conduct public health surveillance monitoring related specifically to oil and gas development. As is the case in New York State, CDPH monitors water quality for public drinking water supplies as a routine part of its drinking water regulatory program. CDPH has reviewed 250 million individual sampling results from its regulatory water monitoring program. Nine drinking water wells were found to have had detections of chemicals used in hydraulic fracturing. Of those, only two wells had an oil or gas well nearby and further investigation suggested the contaminants were most likely related to other sources.

Texas

Texas also has a long history as a major oil and gas producer in the U.S. In 2011, Texas produced the largest quantities of oil and natural gas of any state. Hydraulic fracturing has been used in the state for about 60 years. Starting in 2004, Texas' Barnett Shale formation was one of the first locations in the United States where high-

volume hydraulic fracturing and directional drilling were used on a commercial scale to develop an unconventional shale formation. The Barnett Shale is a shale formation underlying areas of north Texas including the City of Fort Worth and surrounding suburban and rural counties that is geologically somewhat similar to the Marcellus Shale. Other areas of significant oil and gas development in unconventional shale formations in the state include the Eagle Ford Shale in south Texas and the Haynesville-Bossier shale in east Texas. The Cline Shale in west Texas is now also attracting commercial attention for potential oil production.

Oil and gas development in Texas is regulated by the TRC. Operators are required to comply with all TRC rules, which cover all aspects of well development, such as well construction, casing and cementing, drilling operations and flaring. Operators are required to document their compliance in well completion forms. Well cementers are licensed in Texas, and well operators are required to employ licensed cementers. Unlike New York regulations, the TRC rules do not include specific separation distances from resources such as surface water. Hydraulic fracturing chemical additive information is required to be submitted to fracfocus.org (a publicly-available online database), with the exception of additive information claimed as trade secrets. The TRC can require operators to provide trade secret information to the agency if needed to respond to emergency situations. There are essentially no oil and gas wastewater discharges in Texas. Most oil and gas wastewater is disposed of in Class II underground injection disposal wells. Some wastewater recycling for use in hydraulic fracturing is now being done. The TCEQ issues permits for air pollutant emissions from oil and gas facilities, and also conducts routine air monitoring and enforcement monitoring. TCEQ has a large network of fixed air monitoring stations for volatile organic chemicals, including monitoring sites located near Barnett Shale wells. TCEQ also uses hand-held and aircraft-mounted infra-red cameras for compliance and enforcement monitoring of oil

and gas facilities such as pipelines, tanks, and compressors. The cameras obtain direct evidence of leaks or fugitive emissions of volatile chemicals from equipment and are considered an important enforcement tool by TCEQ staff.

The TDSHS does not have a health surveillance program specific to oil and gas development, but does maintain several general public health surveillance programs similar to those in New York such as infectious-disease reporting, birth defects registry, cancer registry, and trauma registry. TDSHS has noted boomtown problems in some rural parts of the state with rapid increases in oil and gas development. In particular, increased incidence of sexually-transmitted diseases has been observed. Also, acute housing shortages, including shortages of hotel rooms in remote locations, have been observed to result in challenges for regulatory agencies visiting these areas and for social services agencies attempting to place clients in temporary housing. Commonly reported local concerns related to oil and gas development include noise, odors, and impacts from truck traffic.

Illinois

Illinois has a history of oil and gas development similar to New York's. As in New York, conventional vertical wells in Illinois have been stimulated with low-volume hydraulic fracturing for many decades. The New Albany shale formation is an unconventional shale that would require directional drilling and HVHF stimulation for commercial oil and gas development. Illinois convened representatives from statewide environmental organizations and from industry to negotiate legislative language for a program to regulate HVHF activity in the state. The bill was passed into law in 2013 and the IDNR is the agency responsible for implementing the regulatory program.

IDNR staff described several significant elements of the Illinois program that were agreed to in the negotiations. Each well permit application under the Illinois program will be subject to a public hearing process ("contested case" process). Operators in Illinois will be required to conduct water monitoring before and after drilling a well. In Illinois, operators will be subject to a rebuttable presumption of liability, meaning that if water contamination near a HVHF well is discovered, the operator will be assumed to be liable for the contamination unless they can show they did not cause it. A similar law applies to drillers in Pennsylvania, but not in New York. Operators in Illinois will be required to provide complete information on the formula of chemical additives used in each HVHF well to the IDNR. The information will be made available publicly, except for information protected as trade secrets under state law. However, IDNR will be able to share the trade secret information with other state agencies, local emergency responders and physicians when necessary. Operators in Illinois will be required to store HVHF wastewater (including flowback and produced water) in above-ground storage tanks. The draft SGEIS contains the same requirement.

The IDPH does not currently have a health surveillance program specifically targeted at HVHF development. However, the state does maintain similar health surveillance programs to those in New York, including cancer and birth-defect registries and daily chief complaint reporting from emergency departments (i.e., syndromic surveillance). As IDNR works to draft administrative rules to implement the new HVHF law, an inter-agency workgroup in Illinois has been formed that includes relevant state agencies including IDPH. One issue being considered by the workgroup is the roles and responsibilities of each agency in the implementation of the program. Enhanced public health surveillance activities to be conducted by the IDPH is one area being considered by this workgroup. IDPH staff on the call also suggested that health surveillance activities focused on unconventional oil and gas development (which includes HVHF

and other technology such as directional drilling) might ideally be coordinated at a national level by the federal Centers for Disease Control and Prevention. However, such a national surveillance program does not currently exist.

As is the case in New York, IDPH works as a consulting agency to address public health issues that are raised by the environmental and natural-resources agencies in the course of monitoring studies or complaint investigations. IDPH is also considering providing relevant training for HVHF-related emergency events to local physicians and emergency responders. IDPH has been made aware of some significant public health concerns in an area of the New Albany shale located in southwestern Ohio where HVHF development is already active. Quality-of-life impacts were mentioned as particularly notable in that region. Examples included rapid increases in housing costs resulting in some renters being priced out of their homes and significant infrastructure damage in some localities due to increased truck traffic.

Public Health Expert Consultation

As part of this Public Health Review, DOH sought additional input on public health aspects of the draft SGEIS by consulting with three external public health experts. The consultants were provided with DEC and DOH documents to review. Meetings were held with the consultants by conference call and the consultants presented their final comments and recommendations in the form of letters to former Commissioner Shah. The public health expert consultants were given three charge questions to help focus their review. Those charge questions were:

- Are there additional potential public health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS?

- Are additional mitigation measures beyond those identified in the SGEIS needed to address the potential health impacts of HVHF? If so, what additional prevention or mitigation measures are recommended?
- Are existing and proposed environmental and health monitoring and surveillance systems adequate to establish baseline health indicators and to measure potential health impacts? If not, what additional monitoring is recommended?

The following letters from the public health expert consultants report their findings and recommendations to former Commissioner Shah.

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March 3, 2013

Nirav M. Shah, MD, MPH
Commissioner
New York State Department of Health
Albany, NY
Via Email

Dear Dr. Shah:

Thank you for the opportunity to review your Department's "A Public Health Review of the Department of Environmental Conservation's Supplemental Generic Environmental Impact Statement for Shale---Gas Development" (hereafter, PHR). Your November 20, 2012 letter included the draft report and associated materials on health outcome surveillance, existing and planned interactions between state and local agencies under the proposed shale-gas program, the DEC's SGEIS and the response to comments on the SGEIS.

Your charge to reviewers asked us to "focus on whether additional public---health impacts should be considered in the SGEIS and whether additional mitigation measures are needed to address potential public---health impacts." I provided initial comments on the November 20 draft prior to our conference call on Monday December 3, 2012. After discussion with you, your staff, and my fellow peer reviewers, I wrote the first version of this letter and submitted it to you on December 18, 2012. This new version comments on the updated PHR I received in February 2013. My comments are integrated into the earlier text, with some additional points added as an addendum.

My comments in this letter adopt the convention of using "HVHF" or the phrase "shale gas development" to describe the entire process of natural gas well development and production. I do so because hydraulic fracturing is just one step in the natural gas development process and the potential public health impacts are wide ranging and not limited to fracturing. Lastly, since the final decision ultimately rests with New York decision-makers, these comments are designed to address potential impacts and evaluate proposed mitigations in the event the HVHF ban in New York State is lifted.

My responses to the specific charge questions are below, followed by conclusions and final comments.

Are there additional potential public---health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS?

If NY State decides to allow HVHF the DOH has developed a viable approach to addressing the main public health issues associated with shale gas development. The PHR and SGEIS describe a phased start to shale gas development that is coupled with baseline and subsequent monitoring of potential impacts. Although the PHR does not miss any major categories, I have highlighted potential impacts that I believe warrant further attention.

The SGEIS acknowledges that increased traffic accidents are among the expected impacts of HVHF. Given that local government jurisdictions, as opposed to the state, have legal authority to designate and enforce local traffic and road---use laws, it is important that DOH provides communities with tools to address this issue. After our phone call it is my understanding that DOH will recommend that DEC seek ways to strengthen the SGEIS in the area of local road---use agreements, including development of model plans, and will develop approaches for including traffic---related injuries in planned prospective surveillance.

The SGEIS addresses concerns about noise and fugitive dust from pads and traffic, but it is important that DOH clearly define what is included in "visual impairment" and address other nuisance issues that residents may experience. "Light pollution," vibration, and odors can be an issue for residents living near well pads and other production facilities. If gas development occurs in populated areas the impact of odors (as distinct from criteria air pollutants and air toxics) is a likely common complaint. These complaints are often the first signals of air pollution impacts. Details of how DOH plans to work with local health departments to formalize and coordinate systematic data collection on light, vibration, odors, noise, and other nuisance issues should be fleshed out in the PHR and SGEIS. Development of a database for systematic recording of inquiries and citizen complaints can help to identify sentinel events and address community concerns about the potential impacts on health and quality of life.

The SGEIS air analysis looks at both criteria and non---criteria air pollutants and is reasonable to the extent that emission inventories, models, and other key assumptions are reliable. One key uncertainty that should be emphasized in the PHR is the lack of health-based standards for some of the air toxics emitted during well development. Although it is reasonable to use annual and short-term guideline concentrations, EPA provisional risk concentrations, and toxicity values from other authoritative sources, modeling these emissions, as described in the SGEIS, is only the first step in assessing potential air risks. Linking these models to the measurements included in the mitigation plans is important for assessing impacts and evaluating the effectiveness of mitigation.

The term "setback" largely applies to distances to key watersheds in the PHR. I encourage broadening the use of this term in discussions with the public to include distances from air emission sources as well. The PHR summary notes that DEC needs to define more clearly setbacks from NYC watersheds and related infrastructure. The rationale for setbacks for water, air, noise, and other quality of life impacts needs to be clearer throughout the PHR and SGEIS.

The risk from HVHF near plugged or abandoned wells is not directly addressed in the PHR. This potential hazard should also be explored to the extent feasible. Both this hazard and potential well casing failure are scientific uncertainties that may impact on aquifers over time. The SGEIS cites a relatively small probability for well casing failure, but also notes that some parameters that feed into this risk estimate are uncertain. I agree with the DOH's assertion that the value of a highly uncertain probabilistic risk estimate is difficult for decision---makers to evaluate. Nonetheless, the potential for catastrophic failure should be acknowledged given the potential high consequence of a failure.

The overall impact of stress on individual and community health is an important issue that the DOH and DEC need to acknowledge and assess as rigorously as possible. While this concept is implicit in some of the SGEIS text, stress needs to be more fully addressed in the PHR and SGEIS. To help alleviate this concern the DOH and DEC need to encourage active public participation in the permitting process, foster community right---to---know, and make certain monitoring data is publically available. A substantive, ongoing dialogue between State of NY officials and communities will be needed to address this issue long term.

Are additional mitigation measures beyond those identified in the SGEIS needed to address the potential health impacts of HVHF? If so, what additional prevention or mitigation measures are recommended?

As mentioned above, road---use agreements between operators and municipalities are important for reducing potential impacts from truck traffic. While this is appropriate, how this is implemented and enforced at the local level is a key part of mitigation. It is important that DOH work with DEC to develop model agreement language, engage local governments to minimize impacts from trucking operations, and work to ensure this is a "funded" mandate.

The SGEIS includes environmental monitoring as mitigation in cases where the impact of HVHF is uncertain. Continual evaluation of monitoring data is intended to provide assessment of the effectiveness of mitigation requirements and early detection of problems with well construction or operation. It is important that the PHR states the frequency of these evaluations and how this information will be disclosed to the public.

Air monitoring of VOCs for 1 and 24 hrs is mentioned as part of the mitigation strategies outlined in the PHR and SGEIS. It is important to note that even a 1 hr average sample may miss short-term peak pollution levels nearby residents may experience. Though there are no good solutions for real time monitoring for a large number of air toxics, shorter term samples can be collected if done systematically with a strong study design, quality control/assurance, and a clear plan for use of the data. Mitigation approaches should consider using less expensive proxy methods, such as measuring methane plumes, to obtain emission rate estimates. This data may, in turn, be coupled with more rigorous VOC characterization samples to estimate emissions and/or human exposures to air toxics. This VOC characterization is done at the well head in other states. Although the SGEIS states that NY shale is expected to yield mostly "dry" gas, with low petroleum condensate levels, field gas sampling would be informative to help validate existing geochemical data, assess the success of mitigations, and to characterize these potential emission sources. If coupled with radon measurement, this data could be used to address concerns about potential human exposure to radon from this source.

All mitigation assessments sample sizes for baseline air, water, and health indicator measures should be specified to the extent feasible for the proposed "phased" permitting process. While operator groundwater and air monitoring plans proposed in the SGEIS will be reviewed and approved by DEC and DOH, the DEC and DOH should produce guidance on design, implementation and interpretation of monitoring data. This guidance should also define how significant changes from baseline will be determined.

Are existing and proposed environmental and health monitoring and surveillance systems adequate to establish baseline health indicators and to measure potential health impacts? If not, what additional monitoring is recommended?

As a new program there are substantial uncertainties associated with developing the health monitoring and surveillance systems through existing health care systems. Use of "near real time" and longer term tracking and reporting mechanisms is good public health practice, but acceptance of these measures as representative and informative depends on an effective communication platform. I agree that respiratory, asthma, and neurological systems are the place to begin evaluation due to the prevalence of these syndromes and existence of sensitive populations. Where feasible, tracking should focus on expanded data collection in sensitive subpopulations.

It would be useful if DOH would conduct an environmental tracking exercise in as near real time as possible to compare baseline, local regulator, state regulator, and operator collected data. This will require highly specific protocols so that data is collected in ways that provide high quality exposure data that can be explored in tandem with the health outcome data.

Impacts of natural gas development on community character is mentioned in the SGEIS, but formal evaluation metrics are not proposed. While metrics for this issue are likely to be qualitative, it is important that guidance describes how this metric will be measured and/or described prior to the initiation of development. The potential mitigation suggested in the SGEIS, i.e., the DEC policy to abide by local laws or ordinances prohibiting HVHF activity for the first 5 years of the program, may address some community concerns if it is coupled with a substantive communication effort.

Addendum: Additional Comments on the PHR from February 2013 Version Review

Background and Recommendations Section: The lack of substantive research to address many of the main public health concerns is still one of the major limitations facing both public health experts and decision-makers. While this concern is front and center in this draft, the communication plan should be highlighted here as well. This draft also identifies research by the Federal government and others that will address important uncertainties. It is important to highlight some of the data the proposed monitoring and mitigation would collect and how it would address uncertainties that are specific to HVHF in NY.
Given that the final recommendation is about the expert comments, I would also note that it is likely that there will be some unanticipated outcomes – history shows that even the best prepared miss something. The DOH should reserve the option to intervene in cases of unanticipated consequences.

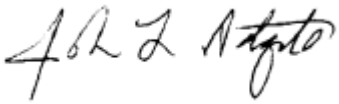
Lastly, the recommendations section should also address more clearly the issue of scale of impacts: if HVHF is allowed in NY State the most public health relevant impacts will be at a local level. The recommendations should be explicit that the mitigations are focused at that level. The section on water, for example, notes that while the total amount of water used at anticipated peak HVHF is small compared to competing demands, there may be "localized or transient impacts that could affect water supplies." The larger issue here is one of scale: both of the industry at peak development, and the local scale where impacts occur. This point is nicely made in the context of water, but this "scale" of impacts point can and should also be made for air, noise, and community quality of life impacts.

Concluding Comments
If shale gas development goes forward in NY the approach outlined in the PHR represents a viable strategy for protecting public health. Prevention of impacts will, however, require a strong partnership between the DOH, DEC, and the local governmental bodies engaged in land use planning, monitoring, and enforcement. It is my belief that mitigation activities will only be perceived as successful if the baseline and follow up monitoring data are high quality, assessment protocols are acceptable to all stakeholders, and the overall process is perceived as unbiased and transparent. This will require an ongoing, substantive dialogue between the public, government, and industry to address stakeholder concerns.

During our conference call you asked the reviewers if a Health Impact Assessment (HIA) should be done for shale gas development in NY and we all said no. As someone who helped develop a HIA in Colorado I know the benefits and shortcomings of HIA for addressing future health impacts from natural gas development. Given the current state of the science I do not think a HIA can project future health effects attributable to shale gas development with reasonable precision. Furthermore, I do not think a state-specific HIA is the best tool for addressing issues that transcend state borders. The impact of methane emissions during well development, for example, is important given the realities of a changing climate. The science assessing the cumulative effects of shale gas development on climate change is, however, still emerging, and the implications of this work for NY-specific regulation unclear. For these reasons I believe New York's proposed prospective monitoring approach that focuses on preventing future exposures, tracking potential health effects, and mitigation is preferable to a HIA at this time.

In closing, thank you for the opportunity to review the DOH's work, and please contact me if you have questions.

Sincerely,



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December 18, 2012

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Via Email

Dear Dr. Shah:

Thank you for the opportunity to review your Department's "A Public Health Review of the Department of Environmental Conservation's Supplemental Generic Environmental Impact Statement for Shale-Gas Development" (hereafter, PHR). Your November 20, 2012 letter included the draft report and associated materials on health outcome surveillance, existing and planned interactions between state and local agencies under the proposed shale-gas program, the DEC's SGEIS and the response to comments on the SGEIS.

Your charge to reviewers asked us to "focus on whether additional public-health impacts should be considered in the SGEIS and whether additional mitigation measures are needed to address potential public-health impacts." I provided initial comments on the November 20 draft prior to our conference call on Monday December 3, 2012. After discussion with you, your staff, and my fellow peer reviewers I have revised my comments after receiving the updated "NY DOH Public Health Review" last week.

My comments in this letter adopt the convention of using "HVHF" or the phrase "shale gas development" to describe the entire process of natural gas well development and production. I do so because hydraulic fracturing is just one step in the natural gas development process. The potential public health impacts can occur either during the relatively intense well development phase or over the much longer production phase.

My responses to the specific charge questions are below, followed by conclusions and final comments.

Are there additional potential public-health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS?

The DOH has developed a strong document that is a viable approach to addressing the main public health issues associated with shale gas development. The PHR and SGEIS describe a phased start to shale gas development that is coupled with baseline and subsequent monitoring of potential impacts. Although the PHR does not miss any major categories, I have highlighted potential impacts that I believe warrant further attention.

The SGEIS acknowledges that increased traffic accidents are among the expected impacts of HVHF. Given that local government jurisdictions, as opposed to the state, have legal authority to designate and enforce local traffic and road-use laws, it is important that DOH provides communities with tools to address this issue. After our phone call it is my understanding that DOH will recommend that DEC seek ways to strengthen the SGEIS in the area of local road-use agreements, including development of model plans, and will develop approaches for including traffic-related injuries in planned prospective surveillance.

The SGEIS addresses concerns about noise and fugitive dust from pads and traffic, but it is important that DOH clearly define what is included in "visual impairment" and address other nuisance issues that residents may experience. "Light pollution," vibration, and odors can be an issue for residents living near well pads and other production facilities. As gas development increasingly occurs in populated areas the impact of odors (as distinct from criteria air pollutants and air toxics) is a common complaint. These complaints are often the first signals of air pollution impacts. Details of how DOH plans to work with local health departments to formalize and coordinate systematic data collection on light, vibration, odors, noise, and other nuisance issues should be fleshed out in the PHR and SGEIS. Development of a database for systematic recording of inquiries and citizen complaints can help to identify sentinel events and address community concerns about the potential impacts on health and quality of life.

The SGEIS air analysis looks at both criteria and non-criteria air pollutants and is reasonable to the extent that emission inventories, models, and other key assumptions are reliable. One key uncertainty that should be emphasized in the PHR is the lack of health-based standards for some of the air toxics emitted during well development. Although it is reasonable to use annual and short-term guideline concentrations, EPA provisional risk concentrations, and toxicity values from other authoritative sources, modeling these emissions, as described in the SGEIS, is only the first step in assessing potential air risks. Linking these models to the measurements included in the mitigation plans is important for assessing impacts and evaluating the effectiveness of mitigation.

The term "setback" largely applies to distances to key watersheds in the PHR. I encourage broadening the use of this term in discussions with the public to include distances from air emission sources as well. The PHR summary notes that DEC needs to define more clearly setbacks from NYC watersheds and related infrastructure. The rationale for setbacks for water, air, and noise impacts needs to be clearer throughout the PHR and SGEIS.

While not formally part of this public health review, potential well casing failure and its impact on aquifers over time is a key scientific uncertainty. The SGEIS cites a relatively small probability, but also notes that some parameters that feed into this risk estimate are inherently uncertain. I agree that for decision-makers the value of a probabilistic risk assessment is problematic when outputs of the analysis are highly uncertain. Nonetheless, the potential for catastrophic failure should be acknowledged given the potential high consequence of some failures.

The overall impact of stress on individual and community health is an important issue that the DOH and DEC need to acknowledge and assess as rigorously as possible. While this concept is implicit in some of the SGEIS text, stress needs to be more fully addressed in the PHR and SGEIS. To help alleviate this concern the DOH and DEC need to encourage active public participation in the permitting process, foster community right-to-know, and make certain monitoring data is publically available. A substantive, ongoing dialogue between State of NY officials and communities will be needed to address this issue long term.

Are additional mitigation measures beyond those identified in the SGEIS needed to address the potential health impacts of HVHF? If so, what additional prevention or mitigation measures are recommended?

As mentioned above, road-use agreements between operators and municipalities are important for reducing potential impacts from truck traffic. While this is appropriate, how this is implemented and enforced at the local level is a key part of mitigation. It is important that DOH work with DEC to develop model agreement language, engage local governments to minimize impacts from trucking operations, and work to ensure this is a "funded" mandate.

The SGEIS includes environmental monitoring as mitigation in cases where the impact of HVHF is uncertain. Continual evaluation of monitoring data is intended to provide assessment of the effectiveness of mitigation requirements and early detection of problems with well construction or operation. It is important that the PHR states the frequency of these evaluations and how this information will be disclosed to the public.

Air monitoring of VOCs for 1 and 24 hrs is mentioned as part of the mitigation strategies outlined in the PHR and SGEIS. It is important to note that even a 1 hr average sample may miss short-term peak pollution levels nearby residents may experience. Though there are

no good solutions for real time monitoring for a large number of air toxics, shorter term samples can be collected if done systematically with a strong study design, quality control/assurance, and a clear plan for use of the data. Mitigation approaches should consider using less expensive proxy methods, such as measuring methane plumes, to obtain emission rate estimates. This data may, in turn, be coupled with more rigorous VOC characterization samples to estimate emissions and/or human exposures to air toxics. This VOC characterization is done at the well head in other states. Although the SGEIS states that NY shale is expected to yield mostly "dry" gas, with low petroleum condensate levels, field gas sampling would be informative to help validate existing geochemical data, assess the success of mitigations, and to characterize these potential emission sources.

All mitigation assessments sample sizes for baseline air, water, and health indicator measures should be specified to the extent feasible for the proposed "phased" permitting process. While operator groundwater and air monitoring plans proposed in the SGEIS will be reviewed and approved by DEC and DOH, the DEC and DOH should produce guidance on design, implementation and interpretation of monitoring data. This guidance should also define how significant changes from baseline will be determined.

Are existing and proposed environmental and health monitoring and surveillance systems adequate to establish baseline health indicators and to measure potential health impacts? If not, what additional monitoring is recommended?

As a new program there are substantial uncertainties associated with developing the health monitoring and surveillance systems through existing health care systems. Use of "near real time" and longer term tracking and reporting mechanisms is good public health practice, but acceptance of these measures as representative and informative depends on an effective communication platform. I agree that respiratory, asthma, and neurological systems are the place to begin evaluation due to the prevalence of these syndromes and existence of sensitive populations. Where feasible, tracking should focus on expanded data collection in sensitive subpopulations.

It would be useful if DOH would conduct a environmental tracking exercise in as near real time as possible to compare baseline, local regulator, state regulator, and operator collected data. This will require highly specific protocols so that data is collected in ways that provide high quality exposure data that can be explored in tandem with the health outcome data.

Impacts of natural gas development on community character is mentioned in the SGEIS, but no formal evaluation metrics are proposed. While metrics for this issue are likely to be qualitative, it is important that guidance describes how this metric will be measured and/or described prior to the initiation of development. The potential mitigation suggested in the SGEIS, i.e., the DEC policy to abide by local laws or ordinances prohibiting HVHF activity for

the first 5 years of the program, may address some community concerns if it is coupled with a substantive communication effort.

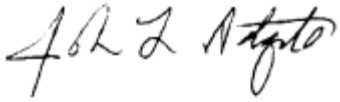
Concluding Comments

If shale gas development goes forward in NY the approach outlined in the PHR represents a reasonable strategy for protecting public health. Prevention of impacts will, however, require a strong partnership between the DOH, DEC, and the local governmental bodies engaged in land use planning, monitoring, and enforcement. It is my belief that mitigation activities will only be perceived as successful if the baseline and follow up monitoring data are high quality, assessment protocols are acceptable to all stakeholders, and the overall process is perceived as unbiased and transparent. This will require an ongoing, substantive dialogue between the public, government, and industry to address stakeholder concerns.

During our conference call you asked the reviewers if a Health Impact Assessment (HIA) should be done for shale gas development in NY and we all said no. As someone who helped develop a HIA in Colorado I know the benefits and shortcomings of HIA for addressing future health impacts from natural gas development. Given the current state of the science I do not think a HIA can project future health effects attributable to shale gas development with reasonable precision. Furthermore, I do not think a state-specific HIA is the best tool for addressing issues that transcend state borders. The impact of methane emissions during well development, for example, is important given the realities of a changing climate. The science assessing the cumulative effects of shale gas development on climate change is, however, still emerging, and the implications of this work for NY-specific regulation unclear. For these reasons I believe New York's proposed prospective monitoring approach that focuses on preventing future exposures, tracking potential health effects, and mitigation is preferable to a HIA at this time.

Thank you for the opportunity to review the DOH's work, and please contact me if you have questions.

Sincerely,



John L. Adgate, PhD, MSPH
Professor and Chair
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March 4,2013

Nirav R. Shah, M.D., M.P.H.
Commissioner, NY State Department of Health
Corning Tower
Empire State Plaza
Albany, NY 12237

Dear Dr. Shah:

I have completed my peer review of the public-health elements of the Department of Environmental Conservation's (DEC) supplemental generic environmental impact statement (SGEIS) for high-volume hydraulic fracturing (HVHF). As requested, this letter summarizes my review of your Department's effort to date.

Overview

The charge was to "focus on whether additional public-health impacts should be considered in the SGEIS and whether additional mitigation measures are needed to address potential public-health impacts. " I also was to "consider whether existing and proposed environmental and health monitoring and surveillance systems are adequate to establish baseline health indicators and to measure potential health impacts." The NY DOH specifically identified several areas of possible concern for public health: contamination of drinking water resources; ambient air pollution; releases of naturally-occurring radioactive materials (NORM); community impacts related to noise and utilization of local services like transportation; healthcare, education, housing and social services; and adequacy of existing and proposed health surveillance and HVHF-related monitoring programs.

Specifically peer reviewers were to address three questions:

1. Are there additional potential public-health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS?

2. Are additional mitigation measures beyond those identified in the SGEIS needed to address the potential health impacts of HVHF? If so, what additional prevention or mitigation measures are recommended?

3. Are existing and proposed environmental, health monitoring, and surveillance systems adequate to establish baseline health indicators and to measure potential health impacts? If not, what additional monitoring is recommended?

In addition to the Health Review Scope and Process, you provided a number of documents for review:

1. "NYSDOH Review of NYSDEC's Supplemental Generic Environmental Impact Statement", dated November 20,2012.

2. "Development of a Health Outcome Surveillance Program for High-Volume Hydraulic Fracturing in New York State" (marked CONFIDENTIAL INTRA-AGENCY DRAFT/FOR DELIBERATION ONLY NOT SUBJECT TO FOIL), dated November 19, 2012.

3. "Description of Anticipated Work and Responsibilities for Center of Environmental Health, Local Health Departments/District Offices, and Department of Environmental Conservation Associated with HVHF Gas Well Drilling" (marked CONFIDENTIAL INTRA-AGENCY DRAFT/FOR DELIBERATION ONLY NOT SUBJECT TO FOIL), dated November 19, 2012.

4. "Advisory Panel on High-Volume Hydraulic Fracturing: State Resource Needs", New York State Department of Health, Center for Environmental Health, dated September 9, 2011.

5. A complete copy of the Interagency Confidential Draft Final SGEIS.

6. A set of health related excerpts from the Draft Final SGEIS prepared by the NY DOH including: (a) a second copy of the Executive Summary from the Draft Final SGEIS; (b) Section 5.4.3.1 of the SGEIS; (c) Section 6.14 of the SGEIS; and (d) a second copy of the Appendix 34, Summary of Health impacts, a document titled "NYSDOH and DEC Summary of Potential Health-Related Impacts and Proposed Mitigation Measures for High-Volume Hydraulic Fracturing".

7. A set of health-related excerpts from the DEC Document: "Response to Comments. Final Supplemental Generic Environmental Impact Statement" including comments excerpted from all areas that might be health related, not just the "Health Impacts" section.

I sent you a first draft of my review on December 2,2012. You held a conference call with John Adgate, Richard Jackson, and I on December 3,2012. On December 7,2012, you emailed me: (1) A revised document titled "A Public Health Review of the Department of Environmental Conservation's Supplemental Generic Environmental Impact Statement for Shale-Gas Development" with changes shown in "track changes", dated December 7, 2012 and (2) a copy of all three of the draft reviewer's comments with annotations (in track changes) from NY DOH staff. On December 17,2012 1 sent you a letter responding to these revised documents. In mid-February you sent me a revised confidential draft: "Public Health Review of the Department of Environmental Conservation's Draft Supplemental Generic Environmental Impact Statement for Shale-Gas Development" and requested review of this draft. Copies of my prior responses to the charge questions with the NY DOH staff comments are attached to this letter as Attachment A. At this time I am responding only to the revised draft public health review.

NY State has done a credible job of thoroughly reviewing potential environmental health impacts of HVHF. It is commendable that such a review has been undertaken prior to issuing permits for such activities. Although this process did not follow the academic model for a Health Impact Assessment I applaud the DOH for having used the DEC SGEIS process to achieve the same end. In some ways this feels like a better process in that it has established the basis for a stronger role for DOH in working with DEC moving forward. As noted previously, I am pleased that NY is committed to reducing methane emissions in the context of HVHF activities. I recommend that New York State continue and expand its efforts to develop cleaner alternative energy sources. New York's renewable energy portfolio standard, Governor Cuomo's NY-Sun initiative and effort to reduce electricity demand 15 percent by 2015, is a good beginning.

As I have noted previously, many of the proposed mitigation measures are a model for other states that

are considering or undertaking these operations. I agree with the notion embedded in the latest review that such mitigation measures would need to be monitored over time. Second I agree with the notion of a phased approach to HVHF gas-development that would allow public health problems to be identified earlier, and reduce problems resulting from overly rapid growth ("boom and bust"). Third, I especially concur with the notion of not allowing HVHF gas-development activity within 4000 feet of the New York City and Syracuse drinking-water supply watersheds.

I am pleased that in this latest draft the NY DOH has addressed a number of issues that I had flagged in my prior reports. The revised document more strongly emphases the numerous data gaps and uncertainties with regard to potential public health impacts of HVHF. I agree with the notion that studies that are underway nationally (the US EPA hydraulic fracturing study) and in Pennsylvania will be helpful in this regard. I am less sanguine about ongoing health studies because I think these are unlikely to capture subclinical health effects as well as effects that occur with longer latency or lag times. I agree with the DOH recommendation to expand its Behavioral Risk Factors Surveillance System to collect critical baseline information in the Marcellus region. I also agree with the decision to explore approaches for including worker and traffic-related injuries, psychosocial stress and noise. Perhaps most important is the new recommendation that the DOH will collaborate with the DEC in assessing new data on HVHF health and environmental impacts as well as the effectiveness of mitigation measures. Some of the most important information will be environmental information because of the problems (noted above) with needing to protect the public from effects that are subclinical or have long latencies and are difficult to detect in real-time using epidemiology.

As noted in prior communications, I think that DOH would require resources for public communications engagement, particularly for those most concerned about health, for example, local health agencies, health providers and members of the public.

Thank you very much for again having had the opportunity to review the "Public Health Review of the Department of Environmental Conservation's Draft Supplemental Generic Environmental Impact Statement for Shale-Gas Development". This document as it currently stands is an excellent review of the relevant public health issues, and attendant uncertainties and data gaps.

Very truly yours,

Lynn R. Goldman, M.D., M.P.H.
Dean, School of Public Health and Health Services
The George Washington University

Attachment: Attachment A

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December 17,2012

Nirav R. Shah, MD., M.P.H.
Commissioner, NY State Department of Health
Corning Tower
Empire State Plaza,
Albany, NY 12237

Dear Dr. Shah:

I have completed my peer review of the public-health elements of the Department of Environmental Conservation's (DEC) supplemental generic environmental impact statement (SGEIS) for high-volume hydraulic fracturing (HVHF). As requested, this letter summarizes my review of your Department's effort to date.

Overview

As I understand the charge, it was to "focus on whether additional public-health impacts should be considered in the SGEIS and whether additional mitigation measures are needed to address potential public-health impacts. " I also was to "consider whether existing and proposed environmental and health monitoring and surveillance systems are adequate to establish baseline health indicators and to measure potential health impacts." The New York Department of Health (NY DOH) specifically identified several areas of possible concern for public health: contamination of drinking water resources; ambient air pollution; releases of naturally-occurring radioactive materials (NORM); community impacts related to noise and utilization of local services like transportation; healthcare, education, housing and social services; and adequacy of existing and proposed health surveillance and HVHF-related monitoring programs.

You charged peer reviewers to address three questions:

"1. Are there additional potential public-health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS?

2. Are additional mitigation measures beyond those identified in the SGEIS needed to address the potential health impacts of HVHF? If so, what additional prevention or mitigation measures are recommended?

3. Are existing and proposed environmental and health monitoring and surveillance systems adequate to establish baseline health indicators and to measure potential health impacts? If not, what additional monitoring is recommended?"

In addition to the Health Review Scope and Process, you provided me with a number of documents for review including:

1. "NYSDOH Review of NYSDEC's Supplemental Generic Environmental Impact Statement", dated November 20, 2012.

2. "Development of a Health Outcome Surveillance Program for High-Volume Hydraulic Fracturing in New York

State" (marked CONFIDENTIAL INTRA-AGENCY DRAFT/FOR DELIBERATION ONLY NOT SUBJECT TO FOIL), dated November 19,2012.

3. "Description of Anticipated Work and Responsibilities for Center of Environmental Health, Local Health Departments/District Offices, and Department of Environmental Conservation Associated with HVHF Gas Well Drilling" (marked CONFIDENTIAL INTRA-AGENCY DRAFT/FOR DELIBERATION ONLY NOT SUBJECT TO FOIL), dated November 19,2012.

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7. A set of health-related excerpts from the DEC Document: "Response to Comments. Final Supplemental Generic Environmental Impact Statement" including comments excerpted from all areas that might be health related, not just the "Health Impacts" section.

I sent you a first draft of my review on December 2,2012. You held a conference call with John Adgate, Richard Jackson and I on December 3,2012, during which we discussed potential local-community impacts; health and environmental monitoring and surveillance programs; potential impacts from contamination of air resources; potential impacts from contamination of drinking water resources; potential impacts from naturally-occurring radioactive material (NORM); and other issues that we reviewers had brought forward either in our draft reviews or in our verbal comments and discussion. On December 7,2012, you emailed me: (1) A revised document titled "A Public Health Review of the Department of Environmental Conservation's Supplemental Generic Environmental Impact Statement for Shale-Gas Development" with changes shown in "track changes", dated December 7,2012 and (2) a copy of all three of the draft reviewer's comments with annotations (in track changes) from NY DOH staff. The copy of my draft responses to the charge questions with the NY DOH staff comments is attached to this letter (Attachment A);

General Comments:

From the review of the documents listed above I conclude that NY State has done a credible job of thoroughly reviewing potential environmental health impacts of HVHF. It is commendable that such a review has been undertaken prior to beginning to issue permits for such activities, and that local communities would be involved in the permitting process. The SGEIS report has been provided to the public for review and the extensive numbers of comments that have been received (as per the *Response to Comments* document) are indicative of a participatory public process. It is also clear that involvement of the NY DOH over the last few years has helped to highlight and address a number of potential public health concerns. In particular the draft *"Description of Anticipated Work and Responsibilities for Center of Environmental Health, Local Health*

Departments/District Offices, and Department of Environmental Conservation Associated with H VHF Gas Well Drilling" indicates a thorough and thoughtful approach to assuring that environmental health threats are addressed collaboratively by New York's state and local health and environmental health agencies. In my experience it often is difficult to bring these various branches of government together in order to assure a tight environmental health safety net. This is among the best of such frameworks that I have reviewed. While it is not a formal Health Impact Assessment the review is, nonetheless, very thorough, and I was able to identify only a few areas that require more review.

Generally speaking, if HVHF gas development is permitted in NYS, there are four additional aspects of the approach taken in the SGEIS that are of critical importance for public health. First is that, the proposed mitigation measures should serve as a model for other states that are considering or undertaking these operations. However, no number of mitigation measures can provide one hundred percent assurance of safety and it is therefore important that the New York DOH would have adequate funding for surveillance activities as well as follow up investigations that would allow for identification of ways that mitigation measures need to be improved as well as potential health impacts. Second it is important that, if NY decides to move forward with HVHF gas-development that, as proposed in the SGEIS, there would be a "phased rollout approach". This not only would allow public health problems to be identified earlier, but also reduce problems resulting from overly rapid growth ("boom and bust"). Third, I agree with the SGEIS proposal that would not allow HVHF gas-development activity within 4000 feet of the New York City and Syracuse drinking water supply watersheds. Finally, it is of utmost importance that New York would allow local input into decision-making about permits.

In addition to specific concerns that are described below, there are some general recommendations that I would like to put forward with regard to provision of public information and involvement of the public moving forward:

1. *Continue the Process of Assessing Health Impacts:* Regardless of when and how NY State moves forward with HVHF activities additional health assessment activities are warranted, I recommend that the NY DOH appoint a panel of experts and citizens to constitute a HVHF health assessment committee. Such a committee could support the DOH as well as the DEC and local health and environmental agencies in review of health related data and other issues. Further assessment of health impacts is needed. While the SGEIS accomplishes many of the goals of an HIA there are still additional issues that need to be addressed. If NY State decides to lift the ban on HVHF the committee can guide the NY DOH in its process of adaptive management as well as reviewing any additional data that may come forward. On the other hand, if HVHF is not permitted but continues to be under consideration, NYS should consider conducting a formal HIA an advisory panel could assist with that process. I appreciate that the revised DOH report recommends exploring options for establishing an advisory panel to advise DOH and DEC on health issues. One caveat is that an advisory process would require resources, and that, if NY State moves forward with HVHF resources also should be made available for possible health investigations or even full-scale studies, possibly with guidance from an advisory panel.

2. *Address Right-To-Know:* The CEH DEC and local agencies are planning to develop a tremendous amount of information with regard to HVHF including, potentially: In my draft comments I listed a number of data sets that would be relevant to HVHF-related health concerns and that should be better shared among agencies, industry and the general public. Rightfully there is a focus on information sharing among agencies but public

transparency also is important. The DOH is recommending that DEC upgrade its existing publicly-available web-based oil and gas drilling information to be a clearinghouse that would provide all interested parties with ready access to the breadth of HVHF information collected under the program (e.g., well locations, monitoring data, and health surveillance findings). This is responsive to my concern about this issue. Additionally, I would hope that there would be strong involvement of DOH to assure that health relevant data are captured, including, as noted by DOH, "near-real time monitoring and surveillance results".

3. Engage the Public: It is not clear how the public would be engaged beyond the GEIS process. Local communities have a tremendous amount of information that is useful for agencies, and that understanding their concerns is useful in guiding the development of education and outreach materials. This issue is of great concern both in those communities and statewide and public engagement activities need adequate resources to assure that the State is reaching out and involving the public proactively. In the response to this concern, the DOH has emphasized the efforts that DEC plans to undertake to meet periodically with industry officials and local government staff; to obtain public comment for applications for well pads; to disclose hydraulic fracturing fluid content for each chemical before drilling and after well completion; to post waste tracking forms on a website for view by the public; and to provide local points of contact for disseminating information. These are good efforts. Additionally DOH itself would require resources for public communications engagement, particularly for those most concerned about health, for example, local health agencies, health providers and members of the public.

4. *Address Greenhouse Gases:* The draft SGEIS correctly identifies greenhouse gases (GHG) as potentially causing public health impacts, especially methane and carbon dioxide. The SGEIS thoroughly assesses the potential for emissions of these gases both in development and production of HVHF wells and in "post production", i.e., transport and use of natural gas, and highlights the requirement to comply with new EPA regulations requiring greenhouse gas mitigation measures and performance standards for new sources in the oil and natural gas industry. However, use of natural gas by utilities and companies to generate electricity in New York will of course emit more GHG's than would result from the development of certain alternative energy sources. Granted, the use of natural gas in New York State will occur regardless of the point of origin of the natural gas. Nonetheless, the draft SGEIS points to credible efforts by New York to promote the transition to cleaner sources of electricity, including the renewable energy portfolio standard, Governor Cuomo's NY-Sun initiative, New York's energy efficiency portfolio standard which seeks to reduce electricity demand 15% by 2015. 1 recommend that this approach be strengthened in the context of cheaper natural gas, and (to date) lack of a mechanism to internalize the costs of carbon dioxide and methane emissions to the atmosphere, nationally or in New York.

Specific Comments and Recommendations:

Question 1: Additional potential public-health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS

Chemicals and Radionuclides: I am pleased that in the December 7 "Public Health Review ..." you noted my concern about the level (and quality) of information about formaldehyde, glycol ethers/ethoxylated alcohols and microbiocides (Attachment A), and have stated your intention to request that DEC "DEC, in collaboration with DOH, must revise the SGEIS to reflect additional available" about these chemicals. I also raised a concern with the possibility that flow-back and produced waters could become contaminated by various naturally-

occurring metals like arsenic, cadmium, lead, manganese, and mercury, depending on what is present naturally. NY DOH points to language in the SGEIS indicating that a number of required mitigation measures would be used. I would agree that proper measures need to be taken to assure that such waters are properly handled, treated and disposed of. However, I continue to think that such an approach requires information about levels and toxicity of contaminants, including metals.

As to the more general issue of potential public health impacts of HVHF-related chemicals, one of the recommendations in the DOH report is that DEC must continue to engage DOH to evaluate potential health concerns related to any new fracturing additive chemicals that are proposed for use as HVHF development proceeds and to develop protocols that are to be followed for conducting alternatives assessments for HVHF chemical additive products. I strongly agree with this recommendation.

Potential Human Health Impacts:

Drinking Water: *I support DOH plans to evaluate levels of drinking water pollutants and provide a public health interpretation of these data. DOH would require resources for this.*

Air pollution: I reviewed the air pollution models and found them to be quite complex and very dependent on conditions that could be site-specific which as stack heights, placement of engines and presence of H2S or "sour" gas in sites. The model for PM2.5 suggests that additional mitigation measures may be needed to prevent short-range impacts. Similarly the model predicts the need for additional controls of benzene and formaldehyde emissions. The SGEIS also provides preliminary models for ozone formation that suggest the need to address ozone projections over time. Although local communities may not be interested in precise quantification of emissions, permit decisions may at least in part depend on anticipated air releases related to these operations. I appreciate that the DOH would review and interpret air monitoring data including assessing potential health impacts.

Water availability: I appreciate that in response to my draft comments the DOH report has been revised to refer to potential health impacts related to other water-quality issues, including loss of fish resources (recreationally and as a source of healthy food), water recreational opportunities, and flood control. Also in response to my draft comments, DOH has informed me that the DEC has promulgated water withdrawal regulations **(**http://www.dec.nv.nov/regulations/78258.html**)** and that the DOH will reference these regulations in their report. Such regulatory requirements are important, as well as carrying out monitoring activities to make sure that the cumulative sum of water withdrawals related to HVHF does not harm downstream aquatic environments.

Socioeconomic impacts: While job creation is expected to occur, new jobs would be distributed unevenly around the state. Some areas could experience short term labor shortages and therefore increased wages, possible negative impacts on existing industries, and in-migration of new specialized workers and their families. Employment in impacted regions is expected to peak in 20 years; income from operations in 30 years. If the additional jobs employ people in these communities who currently are unemployed or underemployed this could increase income to households and reduce service demands on public health. On the other hand, if prices increase rapidly this could have a negative effect on families and increase demands for public health services.

Population impacts: The SGEIS found that while population impacts would be minor statewide there could be more significant impacts in particular areas, perhaps offsetting population declines that are occurring in some of these rural areas. The SGEIS notes that in construction phases there would be many workers who live locally in temporary housing. Local health authorities would experience increased demand for public health services from such temporary residents as well as issues related to safety of food, drinking water and housing. In areas where populations increase quickly there could be impacts on access to medical care and adequacy of emergency medical services.

Traffic: The SGEIS has considered the potential for increased traffic impacts and there likely to would be significant impacts in many areas. In addition to noise and air pollution impacts there are potential impacts due to traffic related injuries. NIOSH has reported that workers in the oil and gas injury have high rates of traffic related injuries and mortality; presumably residential vehicles and pedestrians could be at risk as well.

Healthcare and public health services: *I recommend consideration of potential impact on public health systems and healthcare services from rapid population changes.* I understand, from responses to my draft comments, that DOH thinks that DEC's proposed phased roll out of HVHF permitting would be expected to mitigate the possible effect of rapid population growth and the associated increased demand for services. DOH stated that ongoing interaction with and monitoring of healthcare facilities would keep the agency appraised of impacts on such facilities. Likewise DOH expects that its routine interactions with the local health departments that provide local public health would keep them informed of potential impacts on local public health programs, and resource needs of these programs. While the phased rollout is likely to be helpful on a statewide basis there could be relatively large changes impacting health and public health services in local communities. I would recommend a more proactive approach that would attempt to anticipate potential impacts on healthcare and public health systems before there are any impacts on health in communities. Finally, DOH has noted in response to my draft comments that, "If HVHF permitting is authorized in NYS, additional resources would be made available to local health departments." I would agree with that approach.

Injury control: In response to another one of my recommendations in the earlier draft, the DOH states that it would address additional injury prevention and surveillance activities by exploring mechanisms to include worker and traffic-related injuries/deaths in health surveillance activities, and to enhance injury prevention activities. I would agree with that approach.

Noise: My draft comments noted that noise impacts of HVHF are greater than conventional gas wells during the period of time when horizontal drilling is underway, that HVHF is associated with more noise from diesel truck traffic, and that the SGEIS did not discuss noise impacts on health. *I recommend that if HVHF activities proceed, noise levels near operations should be monitored to determine appropriate mitigation efforts to protect human health.* In its response the DOH states that it "will provide DEC with additional information for the SGEIS on the potential human health effects (i.e., beyond simply annoyance) of noise". As they note, the impact analysis discussion and the mitigation measures are targeted at human receptors. However, I think that an understanding of potential health hazards is relevant to decision making including recommendations for local noise monitoring.

Local emergency planning: The draft SGEIS lays out a set of mitigations that include a requirement for operators of sites to respond in emergency situations (Section 7.13). *I recommend consideration of potential impacts to local first responder systems.* As noted above, the phased rollout would be helpful on a statewide

basis there could be relatively large changes in demand for emergency services impacting local communities.

Psychosocial stress: I am pleased that in response to my draft comments the DOH has indicated that their report will specifically identify stress as a public health issue. DOH has indicated that they "will explore approaches/metrics for evaluating stress (e.g., tracking prescription drug use)" and/or via modifications to the BRFSS.

Question 2: Additional mitigation measures beyond those identified in the SGElS needed to address the potential health impacts of HVHF

Generally NY State has proposed a set of mitigation measures that, if successful would do much to address the potential impacts of HVHF. As noted in my general comments (above) I have broad concerns about the engagement and participation of the public in decision making going forward, as well as how the public's rightto-know can be addressed via making information available in real-time. In terms of more specific recommendations, and the DOH response to these recommendations:

1. Permitting decisions need to be informed by information about local impacts especially in areas that are difficult to model in the general case, for example in estimation and control of PM2.5 emissions, which can have serious local impacts.

2. Regional impacts on ozone formation also would need to be addressed over time. DOH indicates that it agrees with this point and that the issue is mentioned in the SGEIS.

3. As noted above, DOH indicates that noise will be recognized as a health hazard, measured, and mitigated to control health risks.

4. DOH has indicted that stress and stress-related health effects also will be identified as potential health hazards.

5. DOH indicates that it will address local traffic impacts as causing potential hazards, specifically, air emissions, increased noise, possibly increased stress and increased risk of unintentional injury.

6. I continue to think that specific communities could see local impacts on local public health and healthcare services as well as emergency medical services and first responders, and that this needs to be addressed proactively.

Question 3: Adequacy of existing and proposed environmental and health monitoring and surveillance systems to establish baseline health indicators and to measure potential health impacts

Generally, NY State has a strong public health surveillance system and the kind of expertise in this area that provides a strong foundation for a special surveillance effort such as the one outlined in the draft document: "Development of a Health Outcome Surveillance Program for High-Volume Hydraulic Fracturing in New York State". The basic elements of the system --near real-time surveillance, longer-term surveillance, and a public reporting mechanism -form a sound framework for such a program.

ESSS: The proposed use of the existing Electronic Syndromic Surveillance System (ESSS) seems appropriate. Covering hospital emergency department visits in most of the state, it would pick up unusual upticks in a number of health conditions and I would agree that the selection of respiratory, asthma and neurological

outcomes is a reasonable target for HVHF-related outcomes. I also think that it is reasonable for NY to incorporate new "flags" related to HVHF for detection of unusual numbers of Emergency Room (ER) visits. Additionally the plans for follow-up investigations also are reasonable.

I recommend that NY consider developing and articulating more explicit criteria for when additional actions will be taken in order to fully explicate statements like l'ifunusual patterns or possible links are found". In response to this recommendation DOH indicates that if HVHF permitting is authorized in NYS then they would, *a priori,* more specifically define what is meant by "unusual patterns" or "possible links". In that case I also recommend that NY DOH obtain input both from scientific peer reviewer and stakeholders to increase the credibility and transparency of the effort.

Longer Term Tracking: The proposed longer term tracking effort is appropriate and builds on New York's existing surveillance capacity. I agree that this longer-term effort should be carried out in the absence of findings from the ESSS system since many health issues would not manifest themselves via time-related clusters of ER visits.

I recommended (and NY DOH indicates that they agree) an initial focus on outcomes with short latency periods, which would include birth outcomes (low birth weight, preterm birth, and birth defects) and hospital admissions for myocardial infarction and respiratory diseases. Cancer surveillance also is important but is a longer term effort. **I** *also recommend monitoring changes in other risk factors for these outcomes, for example, downward trends in air pollution and smoking. As noted above ideally the NY DOH would have resources for follow-up studies.*

Additional Surveillance: In addition to the above there are some additional steps that could be taken to enhance public health surveillance. First, ER surveillance could miss episodes where events are more spread out over time and/or where people either do not seek emergency room care. Second, NY DOH should be able to take advantage of existing routine environmental monitoring, especially of air and water pollutants.

I also recommended (and NY DOH agreed) systematic collection of physician and citizen reports of possible adverse health problems associated with HVHF. They also agreed with my recommendation to link traffic injury and mortality data as well as occupational injury data to GIS data on HVHF activities to spot opportunities to mitigate motor vehicle injury risks in association with HVHF activities. Finally, NY DOH indicates that they have intended that they would conduct analyses of air and drinking water data collected by other state and local agencies and provide surveillance summaries of levels and trends of pollutants associated with HVHF activities.

In closing, I recognize the truly impressive quantity and quality of work that has been performed to date by the NY DOH. I also realize that the above recommendations cannot be accomplished without the application of sufficient resources at multiple levels, from communities through the staff at the NY DOH. Thank you very much for the opportunity to peer review the draft SGEIS and the State DOH plans.

Very truly yours,

Lynn R. Goldman, M.D., M.P.H.
Dean

Enclosure

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Dr Nirav Shah
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Dear Doctor Shah:

Thank you for your request that I and two other independent health advisors review the materials that were provided to us on High-Volume Hydraulic Fracturing (HVHF) in New York State (NYS).

NYS has taken on a very difficult and important challenge. You and your colleagues have devoted considerable resources and hard work in confronting the health issues related to HVHF. These efforts are truly commendable and for this reason I agreed to perform my review on voluntary non-paid basis for NYS, and my comments are my own and are not those of my employer.

As noted in my Curriculum Vitae, I am a physician, a member of the U.S. Institute of Medicine, and have more than thirty years' experience in environmental public health leadership at the federal and state levels.
Given the importance of energy availability and reduction of petroleum imports, and the pervasiveness of the proponents' advertising campaigns and political power, HVHF is likely to continue in the United States and worldwide. At the same time, HVHF is confounded by serious concerns about environmental degradation and worker and community health impacts. With such important and complex issues regarding HVHF, we are all burdened by inadequate federal health leadership and the paucity of useful federal health research in this area. HVHF is at a scale and impact that the need for a national Health Impact Assessment (HIA) has urgency.

All means of energy production have impacts on health, and these impacts can be substantial at the global, community, and personal levels and include risks to workers, consumers, and residential populations. This is true for the more conventional means of energy production—hydro, coal, petroleum, solar, natural gas. It is also true for HVHP operations.

The public is deeply concerned about HVHF as evidenced by the 80,000 public comments received during the preparation of the NYS SGEIS. The comments enumerated specific health concerns as well as profound worry about the community stress from these operations and impacts to the landscape and beauty of upstate New York. These "quality of life" issues were mentioned but to a lesser extent than quantified toxic exposures in the SGEIS

report. Yet such community impacts perdure; they can be multigenerational and small impacts multiplied by centuries become large.

Because of the unknown risks, NYS is appropriately cautious in the decision about HVHF. The following issues are to me the most important health questions about HVHF:

- Have all negative health impacts that can be reasonably anticipated been identified?
- Are public engagement and communication in the decision process adequate?
- Is there a commitment to HVHF process modifications based on experience in and outside NYS?
- Will effects of HVHF be recorded in real time and in ways that are publically accessible?
- Does NYS DoH possess the necessary authority to monitor HVHF?
- Are there qualified individuals and funding for the health accountability and advisory roles for HVHF?
- If NYS makes a decision to proceed with HVHF, will this occur in a careful phased-in rollout with aggressive health oversight?

The following are my observations and recommendations on issues related to health impacts and risk mitigation of HVHF:

Air Contamination: Physical threats to the environment and human health must be appropriately measured and communicated. Placement of real time analyzers at drilling sites is an effective way to monitor airborne threats such as hydrocarbon and greenhouse gas (GHG) emissions and release of pollutants, carcinogens, and neurotoxins into the air and water. At a minimum, testing for contamination of air as well as water must occur with appropriate frequency along with timely and real time notification of DoH and the public.

Water Contamination: On the issue of potential water contamination, the DoH's responsibility for drinking water protection and the prohibition of certain drilling locations are appropriate. It does appear that the DoH will be notified of all permits. This information should be made available in a master information clearinghouse so all impacted parties will be notified as information is being developed.

Noise Impacts: Noise measurement and abatement are also necessary. In the SGEIS it appears that intermittent noise exposures are dismissed because they are transient; yet from a health standpoint noise poses a significant risk. For example, engine-brake noise from large trucks passing a school or health facility will be intermittent but disruptive and potentially harmful. It appears there are provisions to mitigate these exposures during the rollout period, and noise abatement measures must be continued.

Radiation Exposure: On the issue of radiation exposures, it appears that short term risks above background are not particularly evident. I cannot speak to long term risks and defer to Health Physicists. My experience as Director of CDC's National Center for Environmental Health and in California as the State Health Officer is that Health Physicists are in short supply. I suspect that DoH could need additional health physicist staffing although I defer to DoH on this.

Cumulative Risk: It appears that acute health impacts of HVHF are well covered in the documents. The questions about chronic disease threats are more challenging and the answers more incomplete. It seems to me that appropriate worker and other human health protections are necessary and prudent given the uncertainty

about long term effects. The active monitoring of health impacts of HVHF appears to be proposed in the documents and is essential. There must be an ongoing and transparent "learn as we go" Health Impact Assessment.

Notification of Risk: The notification process related to environmental monitoring is important. While drilling firms and property owners will be notified of measured levels, some of the documents indicate cases where the DoH and Emergency Authorities "may" be notified or "should" be notified. From a public health perspective, DoH notification should not be optional or permissive. DoH will need to be involved at some point, and the sooner notification occurs the greater the ability to protect health and mitigate impacts. My experience in other settings such as refineries is that "real time" notification is essential. Delays in or failure to notify health authorities and the public should merit aggressive and increasing penalties.

Worker Safety: Workers are the persons most likely to be more exposed. If a site operator contracts or sub-contracts out work, as is often the case for some of the most dangerous work, the operator must still bear the responsibility to protect and train the workers and bear the liability when there are failures. I understand that enforcement authority in New York resides in federal programs; nevertheless worker protection is of great urgency. It is essential that DoH, the National Institute of Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), and other workplace health and safety personnel are able to carry out unannounced inspections and to issue stop-work orders in the presence of imminent hazard. Examples of imminent hazards include violations of the silica respiratory standard, standards for other hydrocarbons, and for noise.

Community Health: Health is more than the absence of disease as DoH staff knows well, and environmental health is more than the absence of toxic exposures. The walkability of communities is a legitimate health priority as is the protection of natural, scenic, and other environmental assets that promote physical activity by community residents. Rates of obesity and diabetes have lethally doubled in the last generation in the United States including New York State, and any development that reduces physical activity or encourages inactivity and unhealthy eating is a health threat. Factors that can discourage walking and biking and other outdoor activity, such as noise, odors, and heavy truck traffic that may be present with HVHF, present a real measurable health threat.

Protection of Sensitive Populations: On the issue of public protection, the DoH's HIA now contains more explicit discussion of risks to sensitive populations, especially children and the elderly.

Tracking documented illness: In cases of human exposure, there must be prompt and professional medical evaluation and good recordkeeping of workers and others with documented illness. However, registries that track general and undocumented environmental exposures in my own experience are rarely a good investment of limited public health resources. These efforts quickly become financially and administratively untenable.

Health Communication: In earlier documents, there is reflected a misunderstanding of "health communication." A fundamental tenet of health communication is that it is a two-way process involving listening as well as speaking. Yet in the SGEIS the term communication is misused to mean merely dispersing public information. This misunderstanding is not present in the DoH HIA. In addition, more clarification is needed about

how communication will occur and within what timelines. Notification should not be permissive but required. This discussion exemplifies the need for a central clearinghouse for collected data, including planned permits, site locations, drilling dates, discharges, exceedances, and human exposures or illnesses. The public has a "right to know" with appropriate confidentiality of personal protected information.

Health Advisory Committee: The report indicates that an external Health Advisory Committee is to be considered. I urge this most strongly. My experience is that elected officials view Advisory Committees with skepticism, however well-balanced committees of knowledgeable and respected persons of good will and courtesy work well in highly contended situations. Advisory Committees do require clear mission and task statements, as well as appropriate staffing and timelines, bylaws, membership rotation, and sunset dates.

Full Accounting of Impacts: It is important to fully consider potential impacts to local, county and state levels on both the positive and negative sides. "Boomtowns" have inherent social and public health threats, and these negative effects must be mitigated. HVHF needs to create more health benefits than health negatives. This goes back to my original observation that all means of energy production (particularly old coal-fired power plants) are associated with negative health impacts. Ongoing data to better evaluate benefits are needed.

Sufficient Funding: I believe the resource impacts of HVHF on DoH and local health jurisdictions will be substantial. In similar situations of great public concern at CDC we were obliged to assign individuals to regional offices to track concerns. Resources may include health educators, information managers, toxicologists, chemists competent in biomonitoring, industrial hygienists, GIS specialists, occupational health experts, syndromic and sentinel events surveillance, local assignees and clerical staff. My experience is that elected officials often publically promise funding and staffing for roles while the actual funding does not occur or is quietly redirected to other areas.

Phased Rollout with Health Impact Assessment (HIA): The 2011 report on HIA by the National Academy of Sciences Committee that I chaired took a team of experts 18 months to develop. Our Committee asserted that traditional Environmental Impact Assessments (EIAs) are often focused on non-human impacts within an engineering and regulatory framework and too often give little attention to personal or population health. In general, the Committee found that large scale projects and programs with a strong likelihood of human health impacts should be subject to rigorous HIA that is consonant with the National Environmental Policy Act (NEPA). HVHF is precisely the kind of activity to which HIA should be applied. I believe the current DoH HIA (Dec 7, 2012 version) enumerates the issues and concerns well. If the policy decision in NYS is to proceed with HVHF, the need for an HIA is not moot, rather what is needed is an aggressive "learn as you go" HIA during a carefully phased rollout.

In conclusion: With the increasing pressure for HVHF in NYS, if it is approved, it creates a need to assure long term health benefits. The history of extraction industries with their boom and bust cycles can be dealt with wisely if the good of the public overall is the goal and there is strong regulation. These comments are not an endorsement of HVHF; they reflect my belief that the NYS DoH Public Health Review that was updated and sent to me on December 7, 2012, reflects substantial "due diligence."

Thank you for the chance to review such an important health issue.

Respectfully submitted,

Richard J. Jackson, MD, MPH, FAAP
Professor and Chair of Environmental Health Sciences

Some common themes run through the information obtained from consultation with other state agencies, outside authorities, and the public health expert consultants. Common concerns include air quality impacts, truck traffic impacts, noise, challenges with wastewater management, social disruption associated with rapidly-escalating industrialization in communities, and the cumulative effect of HVHF activities on stress. The public health expert consultants particularly emphasized that data gaps exist regarding the degree and extent to which HVHF contributes indirectly to human health impacts due to stressors including off-site nuisance odors and visual impacts such as nuisance light pollution (i.e., beyond simply annoyance). All of these factors can influence stress and quality of life perceptions that can adversely impact health. Another data gap highlighted by the expert consultants was the need for evaluation of uncertainties regarding the potential indirect public health impacts that could be associated with degradation of surface waters and wetlands through impacts on fish resources (recreationally and as a source of healthy food), other healthy recreational opportunities (e.g., swimming, boating) and flood control.

Most of the recently-published HIAs acknowledge that there are significant gaps in our knowledge of potential public health impacts from HVHF and of the effectiveness to date of some mitigation measures. Other common themes include the need for robust and constantly evolving regulatory framework, for strong enforcement of rules designed to ensure best practices, and for community involvement.

| Overall Conclusions

The DOH Public Health Review finds that information gaps still exist regarding various aspects of HVHF activities. Well-designed, prospective, longitudinal studies are lacking that evaluate the overall effect of HVHF shale-gas development on public health outcomes. The existing science investigating associations between HVHF activities and observable adverse health outcomes is very sparse and the studies that have been published have significant scientific limitations. Nevertheless, studies are suggestive of potential public health risks related to HVHF activity that warrant further careful evaluation. Additional population-based research and surveillance, and more studies involving field investigations in locations with active HVHF shale-gas development, would be valuable.

Systematic investigations studying the effects of HVHF activity on groundwater resources, local-community air quality, radon exposure, noise exposure, wastewater treatment, induced seismicity, traffic, psychosocial stress, and injuries would help reduce scientific uncertainties. While some of the on-going or proposed major study initiatives may help close those existing data gaps, each of these alone would not adequately address the array of complex concerns. For example:

Marcellus Shale Initiative Study.

Geisinger Health System, the lead organization in the collaborative Marcellus Shale Initiative, cares for many patients in areas where shale gas is being developed in Pennsylvania. They began pilot studies in 2013 using well and infrastructure data to estimate exposures to all aspects of Marcellus shale development in Pennsylvania. According to the a National Institutes of Health abstract, Geisinger will use these

exposure estimates to evaluate whether asthma control and pregnancy outcomes are affected by Marcellus shale development by studying 30,000 asthma patients and 22,000 pregnancies in the Geisinger Health System from 2006-13. Results from this study are not expected to be available for several years.

University of Colorado at Boulder, Sustainability Research Network.

A five-year cooperative agreement funded by the National Science Foundation (NSF) under NSF's Sustainability Research Network competition, this program involves a multi-disciplinary team of investigators and is intended to address:

> *"the conflict between natural gas extraction and water and air resources protection with the development of a social-ecological system framework with which to assess the conflict and to identify needs for scientific information. Scientific investigations will be conducted to assess and mitigate the problems. Outreach and education efforts will focus on citizen science, public involvement, and awareness of the science and policy issues."*[30]

Published research has been produced from this program investigating associations between HVHF activity and birth outcomes and potential for methane leakage from natural gas infrastructure. The cooperative agreement extends to 2017.

EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources.

Begun in 2011, the purpose of the study is to assess the potential impacts of hydraulic fracturing on drinking water resources, if any, and to identify the driving factors that may affect the severity and frequency of such impacts. The research approach includes:

analyses of existing data, scenario evaluations, laboratory studies, toxicity studies, and case studies. US EPA released a progress report on December 21, 2012 and stated that preliminary results of the study are expected to be released as a draft for public and peer review as soon as the end of 2014, although the full study is not expected to be completed before 2016.

Pennsylvania Department of Environmental Protection (PA DEP) Comprehensive Oil and Gas Development Radiation Study.

Started in early 2013, PA DEP is analyzing the radioactivity levels in produced and flowback waters, wastewater recycling, treatment sludges, and drill cuttings, as well as issues with transportation, storage, and disposal of drilling wastes, the levels of radon in natural gas, and potential exposures to workers and the public. According to a July 2014 update from the PA DEP, publication of a report could occur as soon as the end of 2014.

University of Pennsylvania Study.

A proposed study of HVHF health impacts was announced several months ago. The study is led by researchers from the University of Pennsylvania in collaboration with scientists from Columbia University, Johns Hopkins University, and the University of North Carolina.

These major study initiatives may eventually reduce uncertainties regarding health impacts of HVHF and could contribute to a much more complete knowledge base for managing HVHF risks. However, it will be years before most of these major initiatives are completed.

HVHF is a complex activity that could affect many communities. The number of well pads and associated HVHF activities could be vast and spread out over wide geographic areas where environmental conditions and populations vary. The dispersed nature of the activity magnifies the possibility of process and equipment failures, leading to the potential for cumulative risks for exposures and associated adverse health outcomes. Additionally, the relationships between HVHF environmental impacts and public health are complex and not fully understood. Comprehensive, long-term studies, and in particular longitudinal studies, that could contribute to the understanding of those relationships are either not yet completed or have yet to be initiated. In this instance, however, the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health.

While a guarantee of absolute safety is not possible, an assessment of the risk to public health must be supported by adequate scientific information to determine with confidence that the overall risk is sufficiently low to justify proceeding with HVHF in New York. The current scientific information is insufficient. Furthermore, it is clear from the existing literature and experience that HVHF activity has resulted in environmental impacts that are potentially adverse to public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF and whether the risks can be adequately managed, HVHF should not proceed in New York State.

| Endnotes

[1] The Generic Environmental Impact Statement (1992 GEIS) on the Oil, Gas and Solution Mining Regulatory Program is posted on DEC's website at http://www.dec.ny.gov/energy/45912.html. The 1992 GEIS includes an analysis of impacts from gas drilling and low-volume hydraulic fracturing. Since 1992 the Department has used the 1992 GEIS as the basis of its State Environmental Quality Review Act (SEQRA) review for permit applications for gas drilling in New York State.

[2] All internet addresses cited in this report were confirmed to be active as of November 20, 2014.

[3] The revision of the SGEIS reviewed by DOH and the DOH expert consultants was a newly revised draft-final SGEIS provided by DEC to DOH on October 22, 2012 that incorporated changes by DEC in response to public comments received on the 2009 draft SGEIS and the 2011 revised draft SGEIS.

[4] For example, the broad public health consensus that a causal relationship exists between levels of fine particulate matter in outdoor air and many respiratory and cardiovascular health outcomes, including premature mortality, is based on weight-of-evidence evaluations of several thousand studies published over decades. (See U.S. Environmental Protection Agency, (2009), Integrated Science Assessment for Particulate Matter (Final Report)).

[5] As of December, 2014, the slide presentation is no longer available on the SWPA-EHP web site. This report appears to be similar to, and possibly a preliminary version of, the subsequent peer-reviewed study by Rabinowitz et al. (2014)

[6] The total number of cases categorized by symptom type sums up to 27, but it is not clear whether some individuals might have been counted in more than one symptom category.

[7] For example, see: http://www.cdc.gov/socialdeterminants/.

[8] For a recent example, see: http://headwaterseconomics.org/energy/western-counties-fossil-fuel-development.

[9] Truck traffic also contributes to airborne emissions of fugitive dust and truck exhaust from the well pad. See Air Quality Impacts discussion above.

[10] For example, the Earthworks and Southwest Pennsylvania Environmental Health Project reports described previously.

[11] https://www.osha.gov/silica/.

[12] The NPRM is available from the Federal Register in print (Document number: 2013-20997) or online at https://federalregister.gov/a/2013-20997.

[13] http://www.atsdr.cdc.gov/HAC/pha/Garfield_County_HC_3-13-08/Garfield_County_HC_3-13-08.pdf.

[14] The maximum 1-hour toluene concentration at one monitoring location in 2007 was 653 micrograms/m^3 vs. a short-term odor comparison value of 640 micrograms/m^3.

[15] Annual average concentrations of 1,2-dibromoethane for 2011 were 0.42 micrograms/m^3 and 0.33 micrograms/m^3 at the Denton Airport South canister and the Fort Worth Northwest canister, respectively vs. the chronic health-based comparison value of 0.0167 micrograms/m^3.

[16] http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_related_topics/20349/air/986695.

[17] A hazard quotient is a comparison of an exposure level in the environment to a risk-based comparison value. A hazard quotient at or below 1.0 generally indicates that exposures are unlikely to have significant health risk.

[18] WV's occupied dwelling structure setback is 625 ft from the well-pad center.

[19] US EPA delegated primary SDWA implementation and enforcement authority (known as primacy) to NYS DOH.

[20] Six of the twelve chemicals tested in Kassotis et al. are not listed among the HVHF chemical additives submitted to DEC by drillers and well service companies as potential additives to be used in New York State. These include diethanolamine, diethyl glycol methyl ether, N,N-dimethylformamide, styrene, bisphenol A, and sodium tetraborade (sic) decahydrate. Sodium tetraborate decahydrate is listed in the draft SGEIS as a potential HVHF chemical additive in NYS.

[21] See, for example, U.S. Geological Survey. 2014. Record Number of Oklahoma Tremors Raises Possibility of Damaging Earthquakes. Updated USGS-Oklahoma Geological Survey Joint Statement on Oklahoma Earthquakes http://earthquake.usgs.gov/regional/ceus/products/newsrelease_05022014.php. Also see US EPA's Underground Injection Control web pages: http://yosemite.epa.gov/r10/water.nsf/476d8e2e8829cf19882565d400706530/51bbc02148429af1882568730082f6fa!opendocument.

[22] http://ohiodnr.gov/news/post/ohio-announces-tougher-permit-conditions-for-drilling-activities-near-faults-and-areas-of-seismic-activity.

[23] http://www.governor.maryland.gov/executiveorders/01.01.2011.11.pdf.

[24] http://dhmh.maryland.gov/newsroom1/Pages/Comments-Requested-on-the-Marcellus-Shale-Project.aspx.

[25] http://www.mde.state.md.us/programs/Land/mining/marcellus/Pages/Health_Study.aspx; http://www.marcellushealth.org/final-report.html.

[26] http://graham.umich.edu/knowledge/pubs.

[27] http://graham.umich.edu/media/files/HF-05-Public-Health.pdf.

[28] http://environmentalhealthcollaborative.org/images/2012SummitWorkProduct.pdf.

[29] http://www.novascotia.ca/nse/pollutionprevention/consultation.hydraulic.fracturing.asp (Website includes multiple related publications.)

[30] Routes to Sustainability for Natural Gas Development and Water and Air Resources in the Rocky Mountain Region. National Science Foundation Award Abstract #1240584. http://www.nsf.gov/news/news_summ.jsp?cntn_id=125599; Shonkoff, S.B., et al. (2014). Environmental Public Health Dimensions of shale and Tight Gas Development. *Environmental Health Perspectives*, 122(8):787-95.; http://dx.doi.org/10.1289/ehp.1307866.

[31] For example, a vast literature exists on HVHF engineering, shale-gas geology, geophysics and petrology that is outside of the scope of the Public Health Review and outside of DOH expertise.

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| Appendix 1

Supplemental Literature Considered for the Public Health Review

The focused literature review presented above presents and analyzes the peer-reviewed scientific literature judged to be most relevant to assessing the potential for adverse public health risks from HVHF activities. The focused literature review was not intended to encompass the entirety of published literature on HVHF.[31] However, DOH reviewed a broader range of peer-reviewed studies in addition to those discussed in the main report that investigate various aspects of HVHF, but were judged to provide supplemental background information for the Public Health Review. This supplemental peer-reviewed literature provided additional support for the main conclusions of the Public Health Review. An extended bibliographic list of these peer-reviewed studies is presented below, including the study abstracts from each of the peer-reviewed references.

Allen, D.T., Torres, V.M., Thomas, J., Sullivan, D.W., Harrison, M., Hendler, A., Herndon, S.C., Kolb, C.E., Fraser, M.P., Hill, A.D., Lamb, B.K., Miskimins, J., Sawyer, R.F., Seinfeld, J.H. Measurements of Methane Emissions at Natural Gas Production Sites in the United States. Proc Natl Acad Sci U S A. 2013 Oct 29;110(44):17768-73. doi: 10.1073/pnas.1304880110. Epub 2013 Sep 16. Erratum in: Proc Natl Acad Sci U S A. 2013 Oct 29;110(44):18023.

Abstract

Engineering estimates of methane emissions from natural gas production have led to varied projections of national emissions. This work reports direct measurements

of methane emissions at 190 onshore natural gas sites in the United States (150 production sites, 27 well completion flowbacks, 9 well unloadings, and 4 workovers). For well completion flowbacks, which clear fractured wells of liquid to allow gas production, methane emissions ranged from 0.01 Mg to 17 Mg (mean = 1.7 Mg; 95% confidence bounds of 0.67-3.3 Mg), compared with an average of 81 Mg per event in the 2011 EPA national emission inventory from April 2013. Emission factors for pneumatic pumps and controllers as well as equipment leaks were both comparable to and higher than estimates in the national inventory. Overall, if emission factors from this work for completion flowbacks, equipment leaks, and pneumatic pumps and controllers are assumed to be representative of national populations and are used to estimate national emissions, total annual emissions from these source categories are calculated to be 957 Gg of methane (with sampling and measurement uncertainties estimated at ± 200 Gg). The estimate for comparable source categories in the EPA national inventory is ~1,200 Gg. Additional measurements of unloadings and workovers are needed to produce national emission estimates for these source categories. The 957 Gg in emissions for completion flowbacks, pneumatics, and equipment leaks, coupled with EPA national inventory estimates for other categories, leads to an estimated 2,300 Gg of methane emissions from natural gas production (0.42% of gross gas production).

Allen, D.T. Atmospheric Emissions and Air Quality Impacts from Natural Gas Production and Use. Annu Rev Chem Biomol Eng. 2014;5:55-75. doi: 10.1146/annurev-chembioeng-060713-035938. Epub 2014 Feb 5. Review.

Abstract

The US Energy Information Administration projects that hydraulic fracturing of shale formations will become a dominant source of domestic natural gas supply over the

next several decades, transforming the energy landscape in the United States. However, the environmental impacts associated with fracking for shale gas have made it controversial. This review examines emissions and impacts of air pollutants associated with shale gas production and use. Emissions and impacts of greenhouse gases, photochemically active air pollutants, and toxic air pollutants are described. In addition to the direct atmospheric impacts of expanded natural gas production, indirect effects are also described. Widespread availability of shale gas can drive down natural gas prices, which, in turn, can impact the use patterns for natural gas. Natural gas production and use in electricity generation are used as a case study for examining these indirect consequences of expanded natural gas availability.

Aukema, K.G., Kasinkas, L., Aksan, A., Wackett, L.P. Use of Silica-Encapsulated Pseudomonas Sp. Strain NCIB 9816-4 in Biodegradation of Novel Hydrocarbon Ring Structures Found in Hydraulic Fracturing Waters. Appl Environ Microbiol. 2014 Aug;80(16):4968-76. doi: 10.1128/AEM.01100-14. Epub 2014 Jun 6.

Abstract

The most problematic hydrocarbons in hydraulic fracturing (fracking) wastewaters consist of fused, isolated, bridged, and spiro ring systems, and ring systems have been poorly studied with respect to biodegradation, prompting the testing here of six major ring structural subclasses using a well-characterized bacterium and a silica encapsulation system previously shown to enhance biodegradation. The direct biological oxygenation of spiro ring compounds was demonstrated here. These and other hydrocarbon ring compounds have previously been shown to be present in flow-back waters and waters produced from hydraulic fracturing operations. Pseudomonas sp. strain NCIB 9816-4, containing naphthalene dioxygenase, was

selected for its broad substrate specificity, and it was demonstrated here to oxidize fundamental ring structures that are common in shale-derived waters but not previously investigated with this or related enzymes. Pseudomonas sp. NCIB 9816-4 was tested here in the presence of a silica encasement, a protocol that has previously been shown to protect bacteria against the extremes of salinity present in fracking wastewaters. These studies demonstrate the degradation of highly hydrophobic compounds by a silica-encapsulated model bacterium, demonstrate what it may not degrade, and contribute to knowledge of the full range of hydrocarbon ring compounds that can be oxidized using Pseudomonas sp. NCIB 9816-4.

Bamberger, M., Oswald, R. The Shale Gas Revolution from the Viewpoint of a Former Industry Insider. New Solutions 2014 Jul 29:1-16. [Epub ahead of print].

Abstract

This is an interview conducted with an oil and gas worker who was employed in the industry from 1993 to 2012. He requested that his name not be used. From 2008 to 2012, he drilled wells for a major operator in Bradford County, Pennsylvania. Bradford County is the center of the Marcellus shale gas boom in Northeastern Pennsylvania. In 2012, he formed a consulting business to assist clients who need information on the details of gas and oil drilling operations. In this interview, the worker describes the benefits and difficulties of the hard work involved in drilling unconventional gas wells in Pennsylvania. In particular, he outlines the safety procedures that were in place and how they sometimes failed, leading to workplace injuries. He provides a compelling view of the trade-offs between the economic opportunities of working on a rig and the dangers and stresses of working long hours under hazardous conditions.

Bamberger, M., Oswald, R.E. Unconventional Oil and Gas Extraction and Animal Health. Environ Sci Process Impacts. 2014 Aug;16(8):1860-5.

Abstract

The extraction of hydrocarbons from shale formations using horizontal drilling with high volume hydraulic fracturing (unconventional shale gas and tight oil extraction), while derived from methods that have been used for decades, is a relatively new innovation that was introduced first in the United States and has more recently spread worldwide. Although this has led to the availability of new sources of fossil fuels for domestic consumption and export, important issues have been raised concerning the safety of the process relative to public health, animal health, and our food supply. Because of the multiple toxicants used and generated, and because of the complexity of the drilling, hydraulic fracturing, and completion processes including associated infrastructure such as pipelines, compressor stations and processing plants, impacts on the health of humans and animals are difficult to assess definitively. We discuss here findings concerning the safety of unconventional oil and gas extraction from the perspectives of public health, veterinary medicine, and food safety.

Caulton, D.R., Shepson, P.B., Santoro, R.L., Sparks, J.P., Howarth, R.W., Ingraffea, A.R., Cambaliza, M.O., Sweeney, C., Karion, A., Davis, K.J., Stirm, B.H., Montzka, S.A., Miller, B.R. Toward a Better Understanding and Quantification of Methane Emissions from Shale Gas Development. Proc Natl Acad Sci U S A. 2014 Apr 29;111(17):6237-42. doi: 10.1073/pnas.1316546111. Epub 2014 Apr 14.

Abstract

The identification and quantification of methane emissions from natural gas production has become increasingly important owing to the increase in the natural gas component of the energy sector. An instrumented aircraft platform was used to identify large sources of methane and quantify emission rates in southwestern PA in June 2012. A large regional flux, 2.0-14 g CH4 s(-1) km(-2), was quantified for a ~ 2,800-km(2) area, which did not differ statistically from a bottom-up inventory, 2.3-4.6 g CH4 s(-1) km(-2). Large emissions averaging 34 g CH4/s per well were observed from seven well pads determined to be in the drilling phase, 2 to 3 orders of magnitude greater than US Environmental Protection Agency estimates for this operational phase. The emissions from these well pads, representing ~ 1% of the total number of wells, account for 4-30% of the observed regional flux. More work is needed to determine all of the sources of methane emissions from natural gas production, to ascertain why these emissions occur and to evaluate their climate and atmospheric chemistry impacts.

Chen, J., Al-Wadei, M.H., Kennedy, R.C., Terry, P.D. Hydraulic Fracturing: Paving the Way for a Sustainable Future? J Environ Public Health. 2014;2014:656824. doi: 10.1155/2014/656824. Epub 2014 Mar 25. PubMed PMID: 24790614; PubMed Central PMCID: PMC3984842.

Abstract

With the introduction of hydraulic fracturing technology, the United States has become the largest natural gas producer in the world with a substantial portion of the production coming from shale plays. In this review, we examined current hydraulic fracturing literature including associated wastewater management on quantity and quality of groundwater. We conclude that proper documentation/reporting systems for wastewater discharge and spills need to be enforced at the federal, state, and industrial level. Furthermore, Underground Injection Control (UIC) requirements under SDWA should be extended to hydraulic fracturing operations regardless if diesel fuel is used as a fracturing fluid or not. One of the biggest barriers that hinder the advancement of our knowledge on the hydraulic fracturing process is the lack of transparency of chemicals used in the practice. Federal laws mandating hydraulic companies to disclose fracturing fluid composition and concentration not only to federal and state regulatory agencies but also to health care professionals would encourage this practice. The full disclosure of fracturing chemicals will allow future research to fill knowledge gaps for a better understanding of the impacts of hydraulic fracturing on human health and the environment.

Cluff, M.A., Hartsock, A., MacRae, J.D., Carter, K., Mouser, P.J. Temporal Changes in Microbial Ecology and Geochemistry in Produced Water from Hydraulically Fractured Marcellus Shale Gas Wells. Environ Sci Technol. 2014 Jun 3;48(11):6508-17. doi: 10.1021/es501173p. Epub 2014 May 20.

Abstract

Microorganisms play several important roles in unconventional gas recovery, from biodegradation of hydrocarbons to souring of wells and corrosion of equipment. During and after the hydraulic fracturing process, microorganisms are subjected to harsh physicochemical conditions within the kilometer-deep hydrocarbon-bearing shale, including high pressures, elevated temperatures, exposure to chemical additives and biocides, and brine-level salinities. A portion of the injected fluid returns to the surface and may be reused in other fracturing operations, a process that can enrich for certain taxa. This study tracked microbial community dynamics using pyrotag sequencing of 16S rRNA genes in water samples from three hydraulically fractured Marcellus shale wells in Pennsylvania, USA over a 328-day period. There was a reduction in microbial richness and diversity after fracturing, with the lowest diversity at 49 days. Thirty-one taxa dominated injected, flowback, and produced water communities, which took on distinct signatures as injected carbon and electron acceptors were attenuated within the shale. The majority (>90%) of the community in flowback and produced fluids was related to halotolerant bacteria associated with fermentation, hydrocarbon oxidation, and sulfur-cycling metabolisms, including heterotrophic genera Halolactibacillus, Vibrio, Marinobacter, Halanaerobium, and Halomonas, and autotrophs belonging to Arcobacter. Sequences related to halotolerant methanogenic genera Methanohalophilus and Methanolobus were detected at low abundance (<2%) in produced waters several months after hydraulic fracturing. Five taxa were strong indicators of later produced fluids. These results provide insight into the temporal trajectory of subsurface

microbial communities after "fracking" and have important implications for the enrichment of microbes potentially detrimental to well infrastructure and natural gas fouling during this process.

Coram, A., Moss, J., Blashki, G. Harms Unknown: Health Uncertainties Cast Doubt on the Role of Unconventional Gas in Australia's Energy Future. Med J Aust. 2014 Mar 3;200(4):210-3.

Abstract

There is a push to increase production of unconventional gas in Australia, which would intensify the use of the controversial technique of hydraulic fracturing. The uncertainties surrounding the health implications of unconventional gas, when considered together with doubts surrounding its greenhouse gas profile and cost, weigh heavily against proceeding with proposed future developments. The health and environmental impacts of hydraulic fracturing have been the source of widespread public concern. A review of available literature shows a considerable degree of uncertainty, but an emerging consensus about the main risks. Gas is often claimed to be a less climate-damaging alternative to coal; however, this is called into question by the fugitive emissions produced by unconventional gas extraction and the consequences of its export. While the health effects associated with fracturing chemicals have attracted considerable public attention, risks posed by wastewater, community disruption and the interaction between exposures are of also of concern. The health burdens of unconventional gas are likely to fall disproportionately on rural communities, the young and the elderly. While the health and environmental risks and benefits must be compared with other energy choices, coal provides a poor benchmark.

Edwards, P.M., Brown, S.S., Roberts, J.M., Ahmadov, R., Banta, R.M., deGouw, J.A., Dubé, W.P., Field, R.A., Flynn, J.H., Gilman, J.B., Graus, M., Helmig, D., Koss, A., Langford, A.O., Lefer, B.L., Lerner, B.M., Li, R., Li, S.M., McKeen, S.A., Murphy, S.M., Parrish, D.D., Senff, C.J., Soltis, J., Stutz, J., Sweeney, C., Thompson, C.R., Trainer, M.K., Tsai, C., Veres, P.R., Washenfelder, R.A., Warneke, C., Wild, R.J., Young, C.J., Yuan, B., Zamora, R. High Winter Ozone Pollution from Carbonyl Photolysis in an Oil and Gas Basin. Nature. 2014 Oct 16;514(7522):351-4. doi: 10.1038/nature13767. Epub 2014 Oct 1.

Abstract

The United States is now experiencing the most rapid expansion in oil and gas production in four decades, owing in large part to implementation of new extraction technologies such as horizontal drilling combined with hydraulic fracturing. The environmental impacts of this development, from its effect on water quality to the influence of increased methane leakage on climate, have been a matter of intense debate. Air quality impacts are associated with emissions of nitrogen oxides (NOx = NO + NO2) and volatile organic compounds (VOCs), whose photochemistry leads to production of ozone, a secondary pollutant with negative health effects. Recent observations in oil- and gas-producing basins in the western United States have identified ozone mixing ratios well in excess of present air quality standards, but only during winter. Understanding winter ozone production in these regions is scientifically challenging. It occurs during cold periods of snow cover when meteorological inversions concentrate air pollutants from oil and gas activities, but when solar irradiance and absolute humidity, which are both required to initiate conventional photochemistry essential for ozone production, are at a minimum. Here, using data from a remote location in the oil and gas basin of northeastern Utah and a box model, we provide a quantitative assessment of the photochemistry that leads to these extreme winter ozone pollution events, and identify key factors that

control ozone production in this unique environment. We find that ozone production occurs at lower NOx and much larger VOC concentrations than does its summertime urban counterpart, leading to carbonyl (oxygenated VOCs with a C = O moiety) photolysis as a dominant oxidant source. Extreme VOC concentrations optimize the ozone production efficiency of NOx. There is considerable potential for global growth in oil and gas extraction from shale. This analysis could help inform strategies to monitor and mitigate air quality impacts and provide broader insight into the response of winter ozone to primary pollutants.

Ellsworth, W.L. Injection-Induced Earthquakes. Science. 2013 Jul 12;341(6142):1225942. doi: 10.1126/science.1225942.

Abstract

Earthquakes in unusual locations have become an important topic of discussion in both North America and Europe, owing to the concern that industrial activity could cause damaging earthquakes. It has long been understood that earthquakes can be induced by impoundment of reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface, and injection of fluids into underground formations. Injection-induced earthquakes have, in particular, become a focus of discussion as the application of hydraulic fracturing to tight shale formations is enabling the production of oil and gas from previously unproductive formations. Earthquakes can be induced as part of the process to stimulate the production from tight shale formations, or by disposal of wastewater associated with stimulation and production. Here, I review recent seismic activity that may be associated with industrial activity, with a focus on the disposal of wastewater by injection in deep wells; assess the scientific understanding of induced earthquakes; and discuss the key scientific challenges to be met for assessing this hazard.

Field, R.A., Soltis, J., Murphy, S. Air Quality Concerns of Unconventional Oil and Natural Gas Production. Environ Sci Process Impacts. 2014 May;16(5):954-69. doi: 10.1039/c4em00081a.

Abstract

Increased use of hydraulic fracturing ("fracking") in unconventional oil and natural gas (O & NG) development from coal, sandstone, and shale deposits in the United States (US) has created environmental concerns over water and air quality impacts. In this perspective we focus on how the production of unconventional O & NG affects air quality. We pay particular attention to shale gas as this type of development has transformed natural gas production in the US and is set to become important in the rest of the world. A variety of potential emission sources can be spread over tens of thousands of acres of a production area and this complicates assessment of local and regional air quality impacts. We outline upstream activities including drilling, completion and production. After contrasting the context for development activities in the US and Europe we explore the use of inventories for determining air emissions. Location and scale of analysis is important, as O & NG production emissions in some US basins account for nearly 100% of the pollution burden, whereas in other basins these activities make up less than 10% of total air emissions. While emission inventories are beneficial to quantifying air emissions from a particular source category, they do have limitations when determining air quality impacts from a large area. Air monitoring is essential, not only to validate inventories, but also to measure impacts. We describe the use of measurements, including ground-based mobile monitoring, network stations, airborne, and satellite platforms for measuring air quality impacts. We identify nitrogen oxides, volatile organic compounds (VOC), ozone, hazardous air pollutants (HAP), and methane as pollutants of concern related to O & NG activities. These pollutants can contribute to air quality concerns and they may be regulated in ambient air, due to human health

or climate forcing concerns. Close to well pads, emissions are concentrated and exposure to a wide range of pollutants is possible. Public health protection is improved when emissions are controlled and facilities are located away from where people live. Based on lessons learned in the US we outline an approach for future unconventional O & NG development that includes regulation, assessment and monitoring.

Finkel, M.L., Hays, J. The Implications of Unconventional Drilling for Natural Gas: A Global Public Health Concern. Public Health. 2013 Oct;127(10):889-93. doi: 10.1016/j.puhe.2013.07.005. Epub 2013 Oct 9. Review.

Abstract

Unconventional drilling for natural gas by means of high volume horizontal hydraulic fracturing (fracking) is an important global public health issue. Given that no sound epidemiologic study has been done to assess the extent of exposure-related adverse health effects among populations living in areas where natural gas extraction is going on, it is imperative that research be conducted to quantify the potential risks to the environment and to human health not just in the short-term, but over a longer time period since many diseases (i.e., cancers) appear years after exposure. It should not be concluded that an absence of data implies that no harm is being done.

Flewelling, S.A., Sharma, M. Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine. Groundwater. 2014 Jan-Feb;52(1):9-19. doi: 10.1111/gwat.12095. Epub 2013 Jul 29.

Abstract

Recent increases in the use of hydraulic fracturing (HF) to aid extraction of oil and gas from black shales have raised concerns regarding potential environmental effects associated with predictions of upward migration of HF fluid and brine. Some recent studies have suggested that such upward migration can be large and that timescales for migration can be as short as a few years. In this article, we discuss the physical constraints on upward fluid migration from black shales (e.g., the Marcellus, Bakken, and Eagle Ford) to shallow aquifers, taking into account the potential changes to the subsurface brought about by HF. Our review of the literature indicates that HF affects a very limited portion of the entire thickness of the overlying bedrock and therefore, is unable to create direct hydraulic communication between black shales and shallow aquifers via induced fractures. As a result, upward migration of HF fluid and brine is controlled by preexisting hydraulic gradients and bedrock permeability. We show that in cases where there is an upward gradient, permeability is low, upward flow rates are low, and mean travel times are long (often $>10^6$ years). Consequently, the recently proposed rapid upward migration of brine and HF fluid, predicted to occur as a result of increased HF activity, does not appear to be physically plausible. Unrealistically high estimates of upward flow are the result of invalid assumptions about HF and the hydrogeology of sedimentary basins.

Goldstein, B.D., Malone, S. Obfuscation does not Provide Comfort: Response to the Article by Fryzek et al on Hydraulic Fracturing and Childhood Cancer. J Occup Environ Med. 2013 Nov;55(11):1376-8.

No summary is available.

Goldstein, B.D., Brooks, B.W., Cohen, S.D., Gates, A.E., Honeycutt, M.E., Morris, J.B., Orme-Zavaleta, J., Penning, T.M., Snawder, J. The Role of Toxicological Science in Meeting the Challenges and Opportunities of Hydraulic Fracturing. Toxicol Sci. 2014 Jun;139(2):271-83. doi: 10.1093/toxsci/kfu061. Epub 2014 Apr 4.

Abstract

We briefly describe how toxicology can inform the discussion and debate of the merits of hydraulic fracturing by providing information on the potential toxicity of the chemical and physical agents associated with this process, individually and in combination. We consider upstream activities related to bringing chemical and physical agents to the site, on-site activities including drilling of wells and containment of agents injected into or produced from the well, and downstream activities including the flow/removal of hydrocarbon products and of produced water from the site. A broad variety of chemical and physical agents are involved. As the industry expands this has raised concern about the potential for toxicological effects on ecosystems, workers, and the general public. Response to these concerns requires a concerted and collaborative toxicological assessment. This assessment should take into account the different geology in areas newly subjected to hydraulic fracturing as well as evolving industrial practices that can alter the chemical and physical agents of toxicological interest. The potential for ecosystem or human exposure to mixtures of these agents presents a particular toxicological and public

health challenge. These data are essential for developing a reliable assessment of the potential risks to the environment and to human health of the rapidly increasing use of hydraulic fracturing and deep underground horizontal drilling techniques for tightly bound shale gas and other fossil fuels. Input from toxicologists will be most effective when employed early in the process, before there are unwanted consequences to the environment and human health, or economic losses due to the need to abandon or rework costly initiatives.

Holland, A.A. Imaging Time Dependent Crustal Deformation Using GPS Geodesy and Induced Seismicity, Stress and Optimal Fault Orientations in the North American Mid-Continent. Graduate Thesis. The University of Arizona. 2014. http://arizona.openrepository.com/arizona/handle/10150/332903.

Abstract

Transient deformation has been observed in a number of different types of tectonic environments. These transient deformation signals are often observed using continuous GPS (CGPS) position time-series observations. Examining transient deformation using CGPS time-series is problematic due to the, often, low signal-to-noise ratios and variability in duration of transient motions observed. A technique to estimate a continuous velocity function from noisy CGPS coordinate time-series of is examined. The resolution of this technique is dependent on the signal-to-noise ratio and the duration or frequency content of the transient signal being modeled. Short period signals require greater signal-to-noise ratios for effective resolution of the actual transient signal. The technique presented here is similar to a low-pass filter but with a number of advantages when working with CGPS data. Data gaps do not adversely impact the technique but limit resolution near the gap epochs, if there is some a priori knowledge of the noise contained within the time-series this

information can be included in the model, and model parameter uncertainties provide information on the uncertainty of instantaneous velocity through time.

A large transient has been observed in the North-American stable continental interior as a significant increase in the number and moment release of earthquakes through time. This increase in the number of earthquakes has been suggested to be largely related changes in oil and gas production activities within the region as triggered or induced seismicity, primarily from fluid injection. One of the first observed cases of triggered earthquakes from hydraulic fracturing where the earthquakes were large enough to be felt by local residents is documented. The multiple strong temporal and spatial correlations between these earthquakes indicate that hydraulic fracturing in a nearby well likely triggered the earthquake sequence. The largest magnitude earthquake in this sequence was a magnitude 2.9 with 16 earthquakes greater than magnitude 2. The earthquakes in this sequence occurred within 2.5 km of the hydraulic fracturing operation and focal depths are similar to the depths of hydraulic fracturing treatment depths. In addition to the documentation of a transient earthquake signal associated with hydraulic fracturing, the observed focal mechanisms throughout Oklahoma are documented. These focal mechanisms were used to examine the maximum horizontal stress orientations and active fault orientations associated with the increased rates of seismicity observed in the region. Generally, active-fault orientations and the stresses are consistent through broad portions of Oklahoma with one exception, the onging Jones earthquake sequence in central Oklahoma that started in 2009. In the Jones earthquake sequence a bi-modal distribution of focal mechanisms are observed. One orientation of active faults observed in the Jones earthquake sequence would not be expected to be active in the observed regional stress field. This unfavorably oriented set of faults appear to be pre-existing structures and activity on these structures may suggest that pore-pressure increases in the sub-surface due to fluid injection in the area make it

possible for faults that are not optimally oriented within the regional stress-field to reactivate.

Jackson, R.E., Gorody, A.W., Mayer, B., Roy, J.W., Ryan, M.C., Van Stempvoort, D.R. Groundwater Protection and Unconventional Gas Extraction: The Critical Need for Field-Based Hydrogeological Research. Groundwater. 2013 Jul-Aug;51(4):488-510. doi: 10.1111/gwat.12074. Epub 2013 Jun 7.

Abstract

Unconventional natural gas extraction from tight sandstones, shales, and some coal-beds is typically accomplished by horizontal drilling and hydraulic fracturing that is necessary for economic development of these new hydrocarbon resources. Concerns have been raised regarding the potential for contamination of shallow groundwater by stray gases, formation waters, and fracturing chemicals associated with unconventional gas exploration. A lack of sound scientific hydrogeological field observations and a scarcity of published peer-reviewed articles on the effects of both conventional and unconventional oil and gas activities on shallow groundwater make it difficult to address these issues. Here, we discuss several case studies related to both conventional and unconventional oil and gas activities illustrating how under some circumstances stray or fugitive gas from deep gas-rich formations has migrated from the subsurface into shallow aquifers and how it has affected groundwater quality. Examples include impacts of uncemented well annuli in areas of historic drilling operations, effects related to poor cement bonding in both new and old hydrocarbon wells, and ineffective cementing practices. We also summarize studies describing how structural features influence the role of natural and induced fractures as contaminant fluid migration pathways. On the basis of these studies, we identify two areas where field-focused research is urgently needed to fill current

science gaps related to unconventional gas extraction: (1) baseline geochemical mapping (with time series sampling from a sufficient network of groundwater monitoring wells) and (2) field testing of potential mechanisms and pathways by which hydrocarbon gases, reservoir fluids, and fracturing chemicals might potentially invade and contaminate useable groundwater.

Jackson, R.B., Vengosh, A., Darrah, T.H., Warner, N.R., Down, A., Poreda, R.J., Osborn, S.G., Zhao, K., Karr, J.D. Increased Stray Gas Abundance in a Subset of Drinking Water Wells Near Marcellus Shale Gas Extraction. Proc Natl Acad Sci U S A. 2013 Jul 9;110(28):11250-5. doi: 0.1073/pnas.1221635110. Epub 2013 Jun 24.

Abstract

Horizontal drilling and hydraulic fracturing are transforming energy production, but their potential environmental effects remain controversial. We analyzed 141 drinking water wells across the Appalachian Plateaus physiographic province of northeastern Pennsylvania, examining natural gas concentrations and isotopic signatures with proximity to shale gas wells. Methane was detected in 82% of drinking water samples, with average concentrations six times higher for homes <1 km from natural gas wells (P = 0.0006). Ethane was 23 times higher in homes <1 km from gas wells (P = 0.0013); propane was detected in 10 water wells, all within approximately 1 km distance (P = 0.01). Of three factors previously proposed to influence gas concentrations in shallow groundwater (distances to gas wells, valley bottoms, and the Appalachian Structural Front, a proxy for tectonic deformation), distance to gas wells was highly significant for methane concentrations (P = 0.007; multiple regression), whereas distances to valley bottoms and the Appalachian Structural Front were not significant (P = 0.27 and P = 0.11, respectively). Distance to gas wells was also the most significant factor for Pearson and Spearman correlation

analyses (P < 0.01). For ethane concentrations, distance to gas wells was the only statistically significant factor (P < 0.005). Isotopic signatures (δ(13)C-CH4, δ(13)C-C2H6, and δ(2)H-CH4), hydrocarbon ratios (methane to ethane and propane), and the ratio of the noble gas (4)He to CH4 in groundwater were characteristic of a thermally postmature Marcellus-like source in some cases. Overall, our data suggest that some homeowners living <1 km from gas wells have drinking water contaminated with stray gases.

Jiang, M., Hendrickson, C.T., VanBriesen, J.M. Life Cycle Water Consumption and Wastewater Generation Impacts of a Marcellus Shale Gas Well. Environ Sci Technol. 2014 Feb 4;48(3):1911-20. doi: 10.1021/es4047654. Epub 2014 Jan 10.

Abstract

This study estimates the life cycle water consumption and wastewater generation impacts of a Marcellus shale gas well from its construction to end of life. Direct water consumption at the well site was assessed by analysis of data from approximately 500 individual well completion reports collected in 2010 by the Pennsylvania Department of Conservation and Natural Resources. Indirect water consumption for supply chain production at each life cycle stage of the well was estimated using the economic input-output life cycle assessment (EIO-LCA) method. Life cycle direct and indirect water quality pollution impacts were assessed and compared using the tool for the reduction and assessment of chemical and other environmental impacts (TRACI). Wastewater treatment cost was proposed as an additional indicator for water quality pollution impacts from shale gas well wastewater. Four water management scenarios for Marcellus shale well wastewater were assessed: current conditions in Pennsylvania; complete discharge; direct reuse and desalination; and complete desalination. The results show that under the current conditions, an

average Marcellus shale gas well consumes 20,000 m(3) (with a range from 6700 to 33,000 m(3)) of freshwater per well over its life cycle excluding final gas utilization, with 65% direct water consumption at the well site and 35% indirect water consumption across the supply chain production. If all flowback and produced water is released into the environment without treatment, direct wastewater from a Marcellus shale gas well is estimated to have 300-3000 kg N-eq eutrophication potential, 900-23,000 kg 2,4D-eq freshwater ecotoxicity potential, 0-370 kg benzene-eq carcinogenic potential, and 2800-71,000 MT toluene-eq noncarcinogenic potential. The potential toxicity of the chemicals in the wastewater from the well site exceeds those associated with supply chain production, except for carcinogenic effects. If all the Marcellus shale well wastewater is treated to surface discharge standards by desalination, $59,000-270,000 per well would be required. The life cycle study results indicate that when gas end use is not considered hydraulic fracturing is the largest contributor to the life cycle water impacts of a Marcellus shale gas well.

Kohl, C.A., Capo, R.C., Stewart, B.W., Wall, A.J., Schroeder, K.T., Hammack, R.W., Guthrie, G.D. Strontium Isotopes Test Long-Term Zonal Isolation of Injected and Marcellus Formation Water After Hydraulic Fracturing. Environ Sci Technol. 2014 Aug 19;48(16):9867-73. doi: 10.1021/es501099k. Epub 2014 Jul 28.

Abstract

One concern regarding unconventional hydrocarbon production from organic-rich shale is that hydraulic fracture stimulation could create pathways that allow injected fluids and deep brines from the target formation or adjacent units to migrate upward into shallow drinking water aquifers. This study presents Sr isotope and geochemical data from a well-constrained site in Greene County, Pennsylvania, in which samples were collected before and after hydraulic fracturing of the Middle Devonian

Marcellus Shale. Results spanning a 15-month period indicated no significant migration of Marcellus-derived fluids into Upper Devonian/Lower Mississippian units located 900-1200 m above the lateral Marcellus boreholes or into groundwater sampled at a spring near the site. Monitoring the Sr isotope ratio of water from legacy oil and gas wells or drinking water wells can provide a sensitive early warning of upward brine migration for many years after well stimulation.

Kondash, A.J., Warner, N.R., Lahav, O., Vengosh, A. Radium and Barium Removal through Blending Hydraulic Fracturing Fluids with Acid Mine Drainage. Environ Sci Technol. 2014 Jan 21;48(2):1334-42. doi: 10.1021/es403852h. Epub 2013 Dec 24.

Abstract

Wastewaters generated during hydraulic fracturing of the Marcellus Shale typically contain high concentrations of salts, naturally occurring radioactive material (NORM), and metals, such as barium, that pose environmental and public health risks upon inadequate treatment and disposal. In addition, fresh water scarcity in dry regions or during periods of drought could limit shale gas development. This paper explores the possibility of using alternative water sources and their impact on NORM levels through blending acid mine drainage (AMD) effluent with recycled hydraulic fracturing flowback fluids (HFFFs). We conducted a series of laboratory experiments in which the chemistry and NORM of different mix proportions of AMD and HFFF were examined after reacting for 48 h. The experimental data combined with geochemical modeling and X-ray diffraction analysis suggest that several ions, including sulfate, iron, barium, strontium, and a large portion of radium (60-100%), precipitated into newly formed solids composed mainly of Sr barite within the first ~ 10 h of mixing. The results imply that blending AMD and HFFF could be an effective management practice for both remediation of the high NORM in the Marcellus HFFF

wastewater and beneficial utilization of AMD that is currently contaminating waterways in northeastern U.S.A.

Lautz, L.K., Hoke, G.D., Lu, Z., Siegel, D.I., Christian, K., Kessler, J.D., Teale, N.G. Using Discriminant Analysis to Determine Sources of Salinity in Shallow Groundwater Prior to Hydraulic Fracturing. Environ Sci Technol. 2014 Aug 19;48(16):9061-9. doi: 10.1021/es502244v. Epub 2014 Aug 1.

Abstract

High-volume hydraulic fracturing (HVHF) gas-drilling operations in the Marcellus Play have raised environmental concerns, including the risk of groundwater contamination. Fingerprinting water impacted by gas-drilling operations is not trivial given other potential sources of contamination. We present a multivariate statistical modeling framework for developing a quantitative, geochemical fingerprinting tool to distinguish sources of high salinity in shallow groundwater. The model was developed using new geochemical data for 204 wells in New York State (NYS), which has a HVHF moratorium and published data for additional wells in NYS and several salinity sources (Appalachian Basin brines, road salt, septic effluent, and animal waste). The model incorporates a stochastic simulation to predict the geochemistry of high salinity (>20 mg/L Cl) groundwater impacted by different salinity sources and then employs linear discriminant analysis to classify samples from different populations. Model results indicate Appalachian Basin brines are the primary source of salinity in 35% of sampled NYS groundwater wells with >20 mg/L Cl. The model provides an effective means for differentiating groundwater impacted by basin brines versus other contaminants. Using this framework, similar discriminatory tools can be derived for other regions from background water quality data.

Mackie, P., Johnman, C., Sim, F. Hydraulic Fracturing: A New Public Health Problem 138 Years in the Making? Public Health. 2013 Oct;127(10):887-8. doi:10.1016/j.puhe.2013.09.009. Epub 2013 Oct 19. PubMed PMID: 24148802.

Summary

It is clear that hydraulic fracturing IS a public health issue, just as fuel poverty and carbon reduction are public health issues. It is also clear that it is a complex issue: there will never be all the necessary information to make risk free choices, so governments will, as usual, have to seek to balance the known – and suspected – risks to health on the basis of what evidence there is, until such time as the evidence is stronger. To do that, it is imperative to ensure a public health approach is included when planning and decision making on this issue takes place: that cannot be too soon.

Maguire-Boyle, S.J., Garner, D.J., Heimann, J.E., Gao, L., Orbaek, A.W., Barron, A.R. Automated Method for Determining the Flow of Surface Functionalized Nanoparticles through a Hydraulically Fractured Mineral Formation Using Plasmonic Silver Nanoparticles. Environ Sci Process Impacts. 2014 Feb;16(2):220-31. doi: 10.1039/c3em00718a.

Abstract

Quantifying nanoparticle (NP) transport within porous geological media is imperative in the design of tracers and sensors to monitor the environmental impact of hydraulic fracturing that has seen increasing concern over recent years, in particular the potential pollution and contamination of aquifers. The surface chemistry of a NP defining many of its solubility and transport properties means that there is a wide range of functionality that it is desirable to screen for optimum transport. Most prior transport methods are limited in determining if significant adsorption occurs of a NP over a limited column distance, however, translating this to effects over large

distances is difficult. Herein we report an automated method that allows for the simulation of adsorption effects of a dilute nanoparticle solution over large distances under a range of solution parameters. Using plasmonic silver NPs and UV-visible spectroscopic detection allows for low concentrations to be used while offering greater consistency in peak absorbance leading to a higher degree of data reliability and statistics. As an example, breakthrough curves were determined for mercaptosuccinic acid (MSA) and cysteamine (CYS) functionalized Ag NPs passing through Ottawa sand (typical proppant material) immobile phase (C) or bypassing the immobile phase (C0). Automation allows for multiple sequences such that the absorption plateau after each breakthrough and the rate of breakthrough can be compared for multiple runs to provide statistical analysis. The mobility of the NPs as a function of pH is readily determined. The stickiness (α) of the NP to the immobile phase calculated from the C/C0 ratio shows that MSA-Ag NPs show good mobility, with a slight decrease around neutral pH, while CYS-Ag NPs shows an almost sinusoidal variation. The automated process described herein allows for rapid screening of NP functionality, as a function of immobile phase (proppant versus reservoir material), hydraulic fracturing fluid additives (guar, surfactant) and conditions (pH, temperature).

Maguire-Boyle, S.J., Barron, A.R. Organic Compounds in Produced Waters from Shale Gas Wells. Environ Sci Process Impacts. 2014 Sep 24;16(10):2237-48. doi: 10.1039/c4em00376d.

Abstract

A detailed analysis is reported of the organic composition of produced water samples from typical shale gas wells in the Marcellus (PA), Eagle Ford (TX), and Barnett (NM) formations. The quality of shale gas produced (and frac flowback)

waters is a current environmental concern and disposal problem for producers. Re-use of produced water for hydraulic fracturing is being encouraged; however, knowledge of the organic impurities is important in determining the method of treatment. The metal content was determined by inductively coupled plasma optical emission spectrometry (ICP-OES). Mineral elements are expected depending on the reservoir geology and salts used in hydraulic fracturing; however, significant levels of other transition metals and heavier main group elements are observed. The presence of scaling elements (Ca and Ba) is related to the pH of the water rather than total dissolved solids (TDS). Using gas chromatography mass spectrometry (GC/MS) analysis of the chloroform extracts of the produced water samples, a plethora of organic compounds were identified. In each water sample, the majority of organics are saturated (aliphatic), and only a small fraction comes under aromatic, resin, and asphaltene categories. Unlike coalbed methane produced water it appears that shale oil/gas produced water does not contain significant quantities of polyaromatic hydrocarbons reducing the potential health hazard. Marcellus and Barnett produced waters contain predominantly C6-C16 hydrocarbons, while the Eagle Ford produced water shows the highest concentration in the C17-C30 range. The structures of the saturated hydrocarbons identified generally follows the trend of linear > branched > cyclic. Heterocyclic compounds are identified with the largest fraction being fatty alcohols, esters, and ethers. However, the presence of various fatty acid phthalate esters in the Barnett and Marcellus produced waters can be related to their use in drilling fluids and breaker additives rather than their presence in connate fluids. Halogen containing compounds are found in each of the water samples, and although the fluorocarbon compounds identified are used as tracers, the presence of chlorocarbons and organobromides formed as a consequence of using chlorine containing oxidants (to remove bacteria from source water), suggests

that industry should concentrate on non-chemical treatments of frac and produced waters.

Manda, A.K., Heath, J.L., Klein, W.A., Griffin, M.T., Montz, B.E. Evolution of Multi-Well Pad Development and Influence of Well Pads on Environmental Violations and Wastewater Volumes in the Marcellus Shale (USA). J Environ Manage. 2014 Sep 1;142:36-45. doi: 0.1016/j.jenvman.2014.04.011. Epub 2014 May 8.

Abstract

A majority of well pads for unconventional gas wells that are drilled into the Marcellus shale (northeastern USA) consist of multiple wells (in some cases as many as 12 wells per pad), yet the influence of the evolution of well pad development on the extent of environmental violations and wastewater production is unknown. Although the development of multi-well pads (MWP) at the expense of single well pads (SWP) has been mostly driven by economic factors, the concentrated nature of drilling activities from hydraulic fracturing and horizontal drilling operations on MWP suggests that MWP may create less surface disturbance, produce more volumes of wastewater, and generate more environmental violations than SWP. To explore these hypotheses, we use geospatial techniques and statistical analyses (i.e., regression and Mann-Whitney tests) to assess development of unconventional shale gas wells, and quantify environmental violations and wastewater volumes on SWP and MWP in Pennsylvania. The analyses include assessments of the influence of different types of well pads on potential, minor and major environmental events. Results reveal that (a) in recent years, a majority of pads on which new wells for unconventional gas were drilled are MWP, (b) on average, MWP have about five wells located on each pad and thus, had the transition to MWP not occurred, between two and four times as much land surface

disturbance would have occurred per year if drilling was relegated to SWP, (c) there were more environmental violations on MWP than SWP, but when the number of wells were taken into account, fewer environmental violations per well were observed on MWP than on SWP, (d) there were more wastewater and recycled wastewater volumes per pad and per well produced on MWP than on SWP, and (e) the proportion of wastewater that was recycled was higher on MWP than SWP. This study sheds light on how the evolution from SWP to MWP has influenced environmental violations and wastewater production in a field that has undergone rapid development in recent years.

Mash, R., Minnaar, J., Mash, B. Health and Fracking: Should the Medical Profession be Concerned? S Afr Med J. 2014 Feb 26;104(5):332-5. doi: 10.7196/samj.7860.

Abstract

The use of natural gas that is obtained from high-volume hydraulic fracturing (fracking) may reduce carbon emissions relative to the use of coal and have substantial economic benefits for South Africa. However, concerns have been raised regarding the health and environmental impacts. The drilling and fracking processes use hundreds of chemicals as well as silica sand. Additional elements are either released from or formed in the shale during drilling. These substances can enter the environment in various ways: through failures in the well casing; via alternative underground pathways; as wastewater, spills and leaks on the wellpad; through transportation accidents; and as air pollution. Although many of these chemicals and elements have known adverse health effects, there is little evidence available on the health impacts of fracking. These health concerns have not yet been fully addressed in policy making, and the authors recommend that the voice of health professionals

should be part of the public debate on fracking and that a full health impact assessment be required before companies are given the go-ahead to drill.

Mazur, A. How did the Fracking Controversy Emerge in the Period 2010-2012? Public Underst Sci. 2014 Aug 8. pii: 0963662514545311. [Epub ahead of print]

Abstract

In 2010-2012, the controversy over fracking grew rapidly, first in the United States, and then internationally. An important step was the anti-fracking documentary film Gasland. With help from celebrity sources, the film was produced and won a prize at the Sundance Film Festival by early 2010 and had an Oscar nomination by early 2011, in the meantime popularizing potent images of hazard including tainted aquifers and ignitable water running from kitchen faucets. During this period, major US news organizations paid little attention to the issue. The offshore Deepwater Horizon disaster of April 2010 spurred The New York Times to prolific reporting on potential risks of the new onshore technique for extracting shale gas. With flagship news coverage, the controversy had by 2012 gained wide media attention that evoked public concern and opposition, spreading from the United States to other nations.

McJeon, H., Edmonds, J., Bauer, N., Clarke, L., Fisher, B., Flannery, B.P., Hilaire, J., Krey, V., Marangoni, G., Mi, R., Riahi, K., Rogner, H., Tavoni, M. Limited Impact on Decadal-Scale Climate Change from Increased Use of Natural Gas. Nature. 2014 Oct 23;514(7523):482-5. doi: 10.1038/nature13837. Epub 2014 Oct 15.

Abstract

The most important energy development of the past decade has been the wide deployment of hydraulic fracturing technologies that enable the production of previously uneconomic shale gas resources in North America. If these advanced gas production technologies were to be deployed globally, the energy market could see a large influx of economically competitive unconventional gas resources. The climate implications of such abundant natural gas have been hotly debated. Some researchers have observed that abundant natural gas substituting for coal could reduce carbon dioxide (CO2) emissions. Others have reported that the non-CO2 greenhouse gas emissions associated with shale gas production make its lifecycle emissions higher than those of coal. Assessment of the full impact of abundant gas on climate change requires an integrated approach to the global energy-economy-climate systems, but the literature has been limited in either its geographic scope or its coverage of greenhouse gases. Here we show that market-driven increases in global supplies of unconventional natural gas do not discernibly reduce the trajectory of greenhouse gas emissions or climate forcing. Our results, based on simulations from five state-of-the-art integrated assessment models of energy-economy-climate systems independently forced by an abundant gas scenario, project large additional natural gas consumption of up to +170 per cent by 2050. The impact on CO2 emissions, however, is found to be much smaller (from -2 per cent to +11 per cent), and a majority of the models reported a small increase in climate forcing (from -0.3 per cent to +7 per cent) associated with the increased use of abundant gas. Our results show that although market penetration of globally abundant gas may

substantially change the future energy system, it is not necessarily an effective substitute for climate change mitigation policy.

Mohan, A.M., Bibby, K.J., Lipus, D., Hammack, R.W., Gregory, K.B. The Functional Potential of Microbial Communities in Hydraulic Fracturing Source Water and Produced Water from Natural Gas Extraction Characterized By Metagenomic Sequencing. PLoS One. 2014 Oct 22;9(10):e107682. doi: 10.1371/journal.pone.0107682. eCollection 2014.

Abstract

Microbial activity in produced water from hydraulic fracturing operations can lead to undesired environmental impacts and increase gas production costs. However, the metabolic profile of these microbial communities is not well understood. Here, for the first time, we present results from a shotgun metagenome of microbial communities in both hydraulic fracturing source water and wastewater produced by hydraulic fracturing. Taxonomic analyses showed an increase in anaerobic/facultative anaerobic classes related to Clostridia, Gammaproteobacteria, Bacteroidia and Epsilonproteobacteria in produced water as compared to predominantly aerobic Alphaproteobacteria in the fracturing source water. The metabolic profile revealed a relative increase in genes responsible for carbohydrate metabolism, respiration, sporulation and dormancy, iron acquisition and metabolism, stress response and sulfur metabolism in the produced water samples. These results suggest that microbial communities in produced water have an increased genetic ability to handle stress, which has significant implications for produced water management, such as disinfection.

Murali Mohan, A., Hartsock, A., Hammack, R.W., Vidic, R.D., Gregory, K.B. Microbial Communities In Flowback Water Impoundments from Hydraulic Fracturing for Recovery of Shale Gas. FEMS Microbiol Ecol. 2013 Dec;86(3):567-80. doi: 10.1111/1574-6941.12183. Epub 2013 Aug 13.

Abstract

Hydraulic fracturing for natural gas extraction from shale produces waste brine known as flowback that is impounded at the surface prior to reuse and/or disposal. During impoundment, microbial activity can alter the fate of metals including radionuclides, give rise to odorous compounds, and result in biocorrosion that complicates water and waste management and increases production costs. Here, we describe the microbial ecology at multiple depths of three flowback impoundments from the Marcellus shale that were managed differently. 16S rRNA gene clone libraries revealed that bacterial communities in the untreated and biocide-amended impoundments were depth dependent, diverse, and most similar to species within the taxa γ-proteobacteria, α-proteobacteria, δ-proteobacteria, Clostridia, Synergistetes, Thermotogae, Spirochetes, and Bacteroidetes. The bacterial community in the pretreated and aerated impoundment was uniform with depth, less diverse, and most similar to known iodide-oxidizing bacteria in the α-proteobacteria. Archaea were identified only in the untreated and biocide-amended impoundments and were affiliated to the Methanomicrobia class. This is the first study of microbial communities in flowback water impoundments from hydraulic fracturing. The findings expand our knowledge of microbial diversity of an emergent and unexplored environment and may guide the management of flowback impoundments.

Murali Mohan, A., Hartsock, A., Bibby, K.J., Hammack, R.W., Vidic, R.D., Gregory, K.B. Microbial Community Changes in Hydraulic Fracturing Fluids and Produced Water from Shale Gas Extraction. Environ Sci Technol. 2013 Nov 19;47(22):13141-50. doi: 10.1021/es402928b. Epub 2013 Oct 31.

Abstract

Microbial communities associated with produced water from hydraulic fracturing are not well understood, and their deleterious activity can lead to significant increases in production costs and adverse environmental impacts. In this study, we compared the microbial ecology in prefracturing fluids (fracturing source water and fracturing fluid) and produced water at multiple time points from a natural gas well in southwestern Pennsylvania using 16S rRNA gene-based clone libraries, pyrosequencing, and quantitative PCR. The majority of the bacterial community in prefracturing fluids constituted aerobic species affiliated with the class Alphaproteobacteria. However, their relative abundance decreased in produced water with an increase in halotolerant, anaerobic/facultative anaerobic species affiliated with the classes Clostridia, Bacilli, Gammaproteobacteria, Epsilonproteobacteria, Bacteroidia, and Fusobacteria. Produced water collected at the last time point (day 187) consisted almost entirely of sequences similar to Clostridia and showed a decrease in bacterial abundance by 3 orders of magnitude compared to the prefracturing fluids and produced water samplesfrom earlier time points. Geochemical analysis showed that produced water contained higher concentrations of salts and total radioactivity compared to prefracturing fluids. This study provides evidence of long-term subsurface selection of the microbial community introduced through hydraulic fracturing, which may include significant implications for disinfection as well as reuse of produced water in future fracturing operations.

Rafferty, M.A., Limonik, E. Is Shale Gas Drilling an Energy Solution or Public Health Crisis? Public Health Nurs. 2013 Sep-Oct;30(5):454-62. doi: 10.1111/phn.12036. Epub 2013 Apr 22.

Abstract

High-volume horizontal hydraulic fracturing, a controversial new mining technique used to drill for shale gas, is being implemented worldwide. Chemicals used in the process are known neurotoxins, carcinogens, and endocrine disruptors. People who live near shale gas drilling sites report symptoms that they attribute to contaminated air and water. When they seek help from clinicians, a diagnosis is often elusive because the chemicals to which the patients have been exposed are a closely guarded trade secret. Many nurses have voiced grave concern about shale gas drilling safety. Full disclosure of the chemicals used in the process is necessary in order for nurses and other health professionals to effectively care for patients. The economic exuberance surrounding natural gas has resulted in insufficient scrutiny into the health implications. Nursing research aimed at determining what effect unconventional drilling has on human health could help fill that gap. Public health nurses using the precautionary principle should advocate for a more concerted transition from fossil fuels to sustainable energy. Any initiation or further expansion of unconventional gas drilling must be preceded by a comprehensive Health Impact Assessment (HIA).

Ren, L., Zhao, J., Hu, Y. Hydraulic Fracture Extending into Network in Shale: Reviewing Influence Factors and their Mechanism. ScientificWorldJournal. 2014;2014:847107. doi: 0.1155/2014/847107. Epub 2014 Jun 15.

Abstract

Hydraulic fracture in shale reservoir presents complex network propagation, which has essential difference with traditional plane biwing fracture at forming mechanism.

Based on the research results of experiments, field fracturing practice, theory analysis, and numerical simulation, the influence factors and their mechanism of hydraulic fracture extending into network in shale have been systematically analyzed and discussed. Research results show that the fracture propagation in shale reservoir is influenced by the geological and the engineering factors, which includes rock mineral composition, rock mechanical properties, horizontal stress field, natural fractures, treating net pressure, fracturing fluid viscosity, and fracturing scale. This study has important theoretical value and practical significance to understand fracture network propagation mechanism in shale reservoir and contributes to improving the science and efficiency of shale reservoir fracturing design.

Rich, A.L., Crosby, E.C. Analysis of Reserve Pit Sludge from Unconventional Natural Gas Hydraulic Fracturing and Drilling Operations for the Presence of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM). New Solut. 2013;23(1):117-35.

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 232Thorium decay series (228Ra, 228Th, 208Tl), and 226Radium decay series (214Pb, 214Bi, 210Pb) 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.

Roundtable on Environmental Health Sciences, Research, and Medicine, Board on Population Health and Public Health Practice, Institute of Medicine. Health Impact Assessment of Shale Gas Extraction: Workshop Summary. Washington (DC): National Academies Press (US); 2014 Dec 30.

Excerpt

Natural gas extraction from shale formations, which includes hydraulic fracturing, is increasingly in the news as the use of extraction technologies has expanded, rural communities have been transformed seemingly overnight, public awareness has increased, and regulations have been developed. The governmental public health system, which retains primary responsibility for health, was not an early participant in discussions about shale gas extraction; thus public health is lacking critical information about environmental health impacts of these technologies and is limited in its ability to address concerns raised by regulators at the federal and state levels, communities, and workers employed in the shale gas extraction industry. Health Impact Assessment of Shale Gas Extraction is the summary of a workshop convened in 2012 by the Institute of Medicine (IOM) Roundtable on Environmental Health Sciences, Research, and Medicine to discuss the human health impact of shale gas extraction through the lens of a health impact assessment. Eminent scientists, physicians, public health experts, and representatives from government agencies at federal and state levels, from nongovernment organizations, from the business sector, and from interest groups representing the interests of the citizens

met to exchange ideas and to inform on hydraulic fracturing as a means of extraction of natural gas. This report examines the state of the science regarding shale gas extraction, the direct and indirect environmental health impacts of shale gas extraction, and the use of health impact assessment as a tool that can help decision makers identify the public health consequences of shale gas extraction.

Roy, A.A., Adams, P.J., Robinson, A.L. Air Pollutant Emissions from the Development, Production, and Processing of Marcellus Shale Natural Gas. J Air Waste Manag Assoc. 2014 Jan;64(1):19-37. PubMed PMID: 24620400.

Abstract

The Marcellus Shale is one of the largest natural gas reserves in the United States; it has recently been the focus of intense drilling and leasing activity. This paper describes an air emissions inventory for the development, production, and processing of natural gas in the Marcellus Shale region for 2009 and 2020. It includes estimates of the emissions of oxides of nitrogen (NOx), volatile organic compounds (VOCs), and primary fine particulate matter (< or = 2.5 microm aerodynamic diameter; PM2.5) from major activities such as drilling, hydraulic fracturing, compressor stations, and completion venting. The inventory is constructed using a process-level approach; a Monte Carlo analysis is used to explicitly account for the uncertainty. Emissions were estimated for 2009 and projected to 2020, accounting for the effects of existing and potential additional regulations. In 2020, Marcellus activities are predicted to contribute 6-18% (95% confidence interval) of the NOx emissions in the Marcellus region, with an average contribution of 12% (129 tons/day). In 2020, the predicted contribution of Marcellus activities to the regional anthropogenic VOC emissions ranged between 7% and 28% (95% confidence interval), with an average contribution of 12% (100 tons/day).

These estimates account for the implementation of recently promulgated regulations such as the Tier 4 off-road diesel engine regulation and the US. Environmental Protection Agency's (EPA) Oil and Gas Rule. These regulations significantly reduce the Marcellus VOC and NOx emissions, but there are significant opportunities for further reduction in these emissions using existing technologies.

Implications

The Marcellus Shale is one of the largest natural gas reserves in United States. The development and production of this gas may emit substantial amounts of oxides of nitrogen and volatile organic compounds. These emissions may have special significance because Marcellus development is occurring close to areas that have been designated nonattainment for the ozone standard. Control technologies exist to substantially reduce these impacts. PM2.5 emissions are predicted to be negligible in a regional context, but elemental carbon emissions from diesel powered equipment may be important.

Rozell, D.J. "Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine" by S.A. Flewelling and M. Sharma. Groundwater. 2014 Jul-Aug;52(4):491-2. doi: 10.1111/gwat.12229. Epub 2014 Jun 27.

No summary is available.

Sang, W., Stoof, C.R., Zhang,W., Morales, V.L., Gao, B., Kay, R.W., Liu, L., Zhang, Y., Steenhuis, T.S. Effect of Hydrofracking Fluid on Colloid Transport in the Unsaturated Zone. Environ Sci Technol. 2014 Jul 15;48(14):8266-74. doi: 10.1021/es501441e. Epub 2014 Jun 25.

Abstract

Hydraulic fracturing is expanding rapidly in the US to meet increasing energy demand and requires high volumes of hydrofracking fluid to displace natural gas from shale. Accidental spills and deliberate land application of hydrofracking fluids, which return to the surface during hydrofracking, are common causes of environmental contamination. Since the chemistry of hydrofracking fluids favors transport of colloids and mineral particles through rock cracks, it may also facilitate transport of in situ colloids and associated pollutants in unsaturated soils. We investigated this by subsequently injecting deionized water and flowback fluid at increasing flow rates into unsaturated sand columns containing colloids. Colloid retention and mobilization was measured in the column effluent and visualized in situ with bright field microscopy. While <5% of initial colloids were released by flushing with deionized water, 32-36% were released by flushing with flowback fluid in two distinct breakthrough peaks. These peaks resulted from 1) surface tension reduction and steric repulsion and 2) slow kinetic disaggregation of colloid flocs. Increasing the flow rate of the flowback fluid mobilized an additional 36% of colloids, due to the expansion of water filled pore space. This study suggests that hydrofracking fluid may also indirectly contaminate groundwater by remobilizing existing colloidal pollutants.

Sommariva, R., Blake, R.S., Cuss, R.J., Cordell, R.L., Harrington, J.F., White, I.R., Monks, P.S. Observations of the Release of Non-Methane Hydrocarbons from

Fractured Shale. Environ Sci Technol. 2014 Aug 5;48(15):8891-6. doi: 10.1021/es502508w. Epub 2014 Jul 14.

Abstract

The organic content of shale has become of commercial interest as a source of hydrocarbons, owing to the development of hydraulic fracturing ("fracking"). While the main focus is on the extraction of methane, shale also contains significant amounts of non-methane hydrocarbons (NMHCs). We describe the first real-time observations of the release of NMHCs from a fractured shale. Samples from the Bowland-Hodder formation (England) were analyzed under different conditions using mass spectrometry, with the objective of understanding the dynamic process of gas release upon fracturing of the shale. A wide range of NMHCs (alkanes, cycloalkanes, aromatics, and bicyclic hydrocarbons) are released at parts per million or parts per billion level with temperature- and humidity-dependent release rates, which can be rationalized in terms of the physicochemical characteristics of different hydrocarbon classes. Our results indicate that higher energy inputs (i.e., temperatures) significantly increase the amount of NMHCs released from shale, while humidity tends to suppress it; additionally, a large fraction of the gas is released within the first hour after the shale has been fractured. These findings suggest that other hydrocarbons of commercial interest may be extracted from shale and open the possibility to optimize the "fracking" process, improving gas yields and reducing environmental impacts.

Stephens, D.B. Analysis of the Groundwater Monitoring Controversy at the Pavillion, Wyoming Natural Gas Field. Groundwater. 2014 Sep 17. doi: 10.1111/gwat.12272. [Epub ahead of print].

Abstract

The U.S. Environmental Protection Agency (EPA) was contacted by citizens of Pavillion, Wyoming 6 years ago regarding taste and odor in their water wells in an area where hydraulic fracturing operations were occurring. EPA conducted a field investigation, including drilling two deep monitor wells, and concluded in a draft report that constituents associated with hydraulic fracturing had impacted the drinking water aquifer. Following extensive media coverage, pressure from state and other federal agencies, and extensive technical criticism from industry, EPA stated the draft report would not undergo peer review, that it would not rely on the conclusions, and that it had relinquished its lead role in the investigation to the State of Wyoming for further investigation without resolving the source of the taste and odor problem. Review of the events leading up to EPA's decision suggests that much of the criticism could have been avoided through improved preproject planning with clear objectives. Such planning would have identified the high national significance and potential implications of the proposed work. Expanded stakeholder involvement and technical input could have eliminated some of the difficulties that plagued the investigation. However, collecting baseline groundwater quality data prior to initiating hydraulic fracturing likely would have been an effective way to evaluate potential impacts. The Pavillion groundwater investigation provides an excellent opportunity for improving field methods, report transparency, clarity of communication, and the peer review process in future investigations of the impacts of hydraulic fracturing on groundwater.

Stringfellow, W.T., Domen, J.K., Camarillo, M.K., Sandelin, W.L., Borglin, S. Physical, Chemical, and Biological Characteristics of Compounds Used in Hydraulic Fracturing. J Hazard Mater. 2014 Jun 30;275:37-54. doi: 10.1016/j.jhazmat.2014.04.040. Epub 2014 Apr 25.

Abstract

Hydraulic fracturing (HF), a method to enhance oil and gas production, has become increasingly common throughout the U.S. As such, it is important to characterize the chemicals found in HF fluids to evaluate potential environmental fate, including fate in treatment systems, and human health impacts. Eighty-one common HF chemical additives were identified and categorized according to their functions. Physical and chemical characteristics of these additives were determined using publicly available chemical information databases. Fifty-five of the compounds are organic and twenty-seven of these are considered readily or inherently biodegradable. Seventeen chemicals have high theoretical chemical oxygen demand and are used in concentrations that present potential treatment challenges. Most of the HF chemicals evaluated are non-toxic or of low toxicity and only three are classified as Category 2 oral toxins according to standards in the Globally Harmonized System of Classification and Labeling of Chemicals; however, toxicity information was not located for thirty of the HF chemicals evaluated. Volatilization is not expected to be a significant exposure pathway for most HF chemicals. Gaps in toxicity and other chemical properties suggest deficiencies in the current state of knowledge, highlighting the need for further assessment to understand potential issues associated with HF chemicals in the environment.

Sun, M., Lowry, G.V., Gregory, K.B. Selective Oxidation of Bromide in Wastewater Brines from Hydraulic Fracturing. Water Res. 2013 Jul 1;47(11):3723-31. doi:10.1016/j.watres.2013.04.041. Epub 2013 Apr 30.

Abstract

Brines generated from oil and natural gas production, including flowback water and produced water from hydraulic fracturing of shale gas, may contain elevated concentrations of bromide (~1 g/L). Bromide is a broad concern due to the potential for forming brominated disinfection byproducts (DBPs) during drinking water treatment. Conventional treatment processes for bromide removal is costly and not specific. Selective bromide removal is technically challenging due to the presence of other ions in the brine, especially chloride as high as 30-200 g/L. This study evaluates the ability of solid graphite electrodes to selectively oxidize bromide to bromine in flowback water and produced water from a shale gas operation in Southwestern PA. The bromine can then be outgassed from the solution and recovered, as a process well understood in the bromine industry. This study revealed that bromide may be selectively and rapidly removed from oil and gas brines (~10 h(-1) m(-2) for produced water and ~60 h(-1) m(-2) for flowback water). The electrolysis occurs with a current efficiency between 60 and 90%, and the estimated energy cost is ~6 kJ/g Br. These data are similar to those for the chlor-alkali process that is commonly used for chlorine gas and sodium hydroxide production. The results demonstrate that bromide may be selectively removed from oil and gas brines to create an opportunity for environmental protection and resource recovery.

Thurman, E.M., Ferrer, I., Blotevogel, J., Borch, T. Analysis of Hydraulic Fracturing Flowback and Produced Waters Using Accurate Mass: Identification of Ethoxylated Surfactants. Anal Chem. 2014 Oct 7;86(19):9653-61. doi: 10.1021/ac502163k. Epub 2014 Sep 16.

Abstract

Two series of ethylene oxide (EO) surfactants, polyethylene glycols (PEGs from EO3 to EO33) and linear alkyl ethoxylates (LAEs C-9 to C-15 with EO3-EO28), were identified in hydraulic fracturing flowback and produced water using a new application of the Kendrick mass defect and liquid chromatography/quadrupole-time-of-flight mass spectrometry. The Kendrick mass defect differentiates the proton, ammonium, and sodium adducts in both singly and doubly charged forms. A structural model of adduct formation is presented, and binding constants are calculated, which is based on a spherical cagelike conformation, where the central cation (NH4(+) or Na(+)) is coordinated with ether oxygens. A major purpose of the study was the identification of the ethylene oxide (EO) surfactants and the construction of a database with accurate masses and retention times in order to unravel the mass spectral complexity of surfactant mixtures used in hydraulic fracturing fluids. For example, over 500 accurate mass assignments are made in a few seconds of computer time, which then is used as a fingerprint chromatogram of the water samples. This technique is applied to a series of flowback and produced water samples to illustrate the usefulness of ethoxylate "fingerprinting", in a first application to monitor water quality that results from fluids used in hydraulic fracturing.

Vikram, A., Lipus, D., Bibby, K. Produced Water Exposure Alters Bacterial Response to Biocides. Environ Sci Technol. 2014 Oct 22. [Epub ahead of print].

Abstract

Microbial activity during the holding and reuse of wastewater from hydraulic fracturing operations, termed produced water, may lead to issues with corrosion, sulfide release, and fouling. Biocides are applied to control biological activity, often with limited efficacy, which is typically attributed to chemical interactions with the produced water. However, it is unknown whether there is a biologically driven mechanism to biocide tolerance in produced water. Here, we demonstrate that produced water exposure results in an enhanced tolerance against the typically used biocide glutaraldehyde and increased susceptibility to the oxidative biocide hypochlorite in a native and a model bacteria and that this altered resistance is due to the salinity of the produced water. In addition, we elucidate the genetic response of the model organism Pseudomonas fluorescens to produced water exposure to provide a mechanistic interpretation of the altered biocide resistance. The RNA-seq data demonstrated the induction of genes involved in osmotic stress, energy production and conversion, membrane integrity, and protein transport following produced water exposure, which facilitates bacterial survival and alters biocide tolerance. Efforts to fundamentally understand biocide resistance mechanisms, which enable the optimization of biocide application, hold significant implications for greening of the fracturing process through encouraging produced water recycling. Specifically, these results suggest the necessity of optimizing biocide application at the level of individual shale plays, rather than historical experience, based upon produced water characteristics and salinity.

Webb, E., Bushkin-Bedient, S., et al. 2014. Developmental and Reproductive Effects of Chemicals Associated with Unconventional Oil and Natural Gas Operations. Rev. Environ. Health. 29: 307-318.

Abstract

Abstract Unconventional oil and gas (UOG) operations have the potential to increase air and water pollution in communities located near UOG operations. Every stage of UOG operation from well construction to extraction, operations, transportation, and distribution can lead to air and water contamination. Hundreds of chemicals are associated with the process of unconventional oil and natural gas production. In this work, we review the scientific literature providing evidence that adult and early life exposure to chemicals associated with UOG operations can result in adverse reproductive health and developmental effects in humans. Volatile organic compounds (VOCs) [including benzene, toluene, ethyl benzene, and xylene (BTEX) and formaldehyde] and heavy metals (including arsenic, cadmium and lead) are just a few of the known contributors to reduced air and water quality that pose a threat to human developmental and reproductive health. The developing fetus is particularly sensitive to environmental factors, which include air and water pollution. Research shows that there are critical windows of vulnerability during prenatal and early postnatal development, during which chemical exposures can cause potentially permanent damage to the growing embryo and fetus. Many of the air and water pollutants found near UOG operation sites are recognized as being developmental and reproductive toxicants; therefore there is a compelling need to increase our knowledge of the potential health consequences for adults, infants, and children from these chemicals through rapid and thorough health research investigation.

Weber, B.A., Geigle, J., Barkdull, C. 2014. Rural North Dakota's Oil Boom and its Impact on Social Services. Soc Work. Jan; 59(1):62-72.

Abstract

Over the last five years, North Dakota has experienced an oil boom based on high oil prices and hydraulic fracturing technologies. This has brought economic expansion and population growth to rural communities that had previously experienced decades of depopulation and economic struggle. Although the state has enjoyed many benefits--especially in juxtaposition to a sluggish national economy--the boom has also meant the arrival of economic refugees and dramatic impacts on largely rural social service systems. In the midst of a rapidly changing situation, available information tends to swing between euphoria over economic success and hysteria about rising crime and shifting cultures. In response, the authors used a primary focus group with county social service directors from across the state and a followup focus group with social workers operating on the edge of oil activity. Grounded in resilience theory, qualitative analysis of the primary focus group, and triangulation of data from other sources, this study provides a more objective report of the housing and social challenges, the benefits of the boom, and the challenges to solutions.

Zhang, T., Gregory, K., Hammack, R.W., Vidic, R.D. Co-precipitation of Radium with Barium and Strontium Sulfate and its Impact on the Fate of Radium During Treatment of Produced Water from Unconventional Gas Extraction. Environ Sci Technol. 2014 Apr 15;48(8):4596-603. doi: 10.1021/es405168b. Epub 2014 Apr 7.

Abstract

Radium occurs in flowback and produced waters from hydraulic fracturing for unconventional gas extraction along with high concentrations of barium and strontium and elevated salinity. Radium is often removed from this wastewater by co-precipitation with barium or other alkaline earth metals. The distribution equation for Ra in the precipitate is derived from the equilibrium of the lattice replacement reaction (inclusion) between the Ra(2+) ion and the carrier ions (e.g., Ba(2+) and Sr(2+)) in aqueous and solid phases and is often applied to describe the fate of radium in these systems. Although the theoretical distribution coefficient for Ra-SrSO4 (Kd = 237) is much larger than that for Ra-BaSO4 (Kd = 1.54), previous studies have focused on Ra-BaSO4 equilibrium. This study evaluates the equilibria and kinetics of co-precipitation reactions in Ra-Ba-SO4 and Ra-Sr-SO4 binary systems and the Ra-Ba-Sr-SO4 ternary system under varying ionic strength (IS) conditions that are representative of brines generated during unconventional gas extraction. Results show that radium removal generally follows the theoretical distribution law in binary systems and is enhanced in the Ra-Ba-SO4 system and restrained in the Ra-Sr-SO4 system by high IS. However, the experimental distribution coefficient (Kd') varies widely and cannot be accurately described by the distribution equation, which depends on IS, kinetics of carrier precipitation and does not account for radium removal by adsorption. Radium removal in the ternary system is controlled by the co-precipitation of Ra-Ba-SO4, which is attributed to the rapid BaSO4 nucleation rate and closer ionic radii of Ra(2+) with Ba(2+) than with Sr(2+). Carrier (i.e., barite) recycling during water treatment was shown to be effective in

enhancing radium removal even after co-precipitation was completed. Calculations based on experimental results show that Ra levels in the precipitate generated in centralized waste treatment facilities far exceed regulatory limits for disposal in municipal sanitary landfills and require careful monitoring of allowed source term loading (ASTL) for technically enhanced naturally occurring materials (TENORM) in these landfills. Several alternatives for sustainable management of TENORM are discussed.

Zvala-Araiza, D., Sullivan, D.W., Allen, D.T. 2014. Atmospheric Hydrocarbon Emissions and Concentrations in the Barnett Shale Natural Gas Production Region. EnvSciTech. 48:5314−5321.

Abstract

Hourly ambient hydrocarbon concentration data were collected, in the Barnett Shale Natural Gas Production Region, using automated gas chromatography (auto-GC), for the period from April 2010 to December 2011. Data for three sites were compared: a site in the geographical center of the natural gas production region (Eagle Mountain Lake (EML)); a rural/suburban site at the periphery of the production region (Flower Mound Shiloh), and an urban site (Hinton). The dominant hydrocarbon species observed in the Barnett Shale region were light alkanes. Analyses of daily, monthly, and hourly patterns showed little variation in relative composition. Observed concentrations were compared to concentrations predicted using a dispersion model (AERMOD) and a spatially resolved inventory of volatile organic compounds (VOC) emissions from natural gas production (Barnett Shale Special Emissions Inventory) prepared by the Texas Commission on Environmental Quality (TCEQ), and other emissions information. The predicted concentrations of VOC due to natural gas production were 0-40% lower than background corrected

measurements, after accounting for potential under-estimation of certain emission categories. Hourly and daily variations in observed, background corrected concentrations were primarily explained by variability in meteorology, suggesting that episodic emission events had little impact on hourly averaged concentrations. Total emissions for VOC from natural gas production sources are estimated to be approximately 25,300 tons/yr, when accounting for potential under-estimation of certain emission categories. This region produced, in 2011, approximately 5 bcf/d of natural gas (100 Gg/d) for a VOC to natural gas production ratio (mass basis) of 0.0006.

In addition to studies published in the peer-reviewed scientific literature, there are many documents produced by governmental organizations on all aspects of HVHF activities. The following reports also provided additional background information for the Public Health Review.

Colorado's Air Quality Control Commission. REGULATION NUMBER 3, STATIONARY SOURCE PERMITTING AND AIR POLLUTANT EMISSION NOTICE, REQUIREMENTS 5 CCR 1001-5 http://perma.cc/TEP5-T7TM

Rulemaking Summary
On February 23, 2014, Colorado's Air Quality Control Commission ("Commission") fully adopted EPA's

Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution found in 40 C.F.R. Part 60, Subpart OOOO ("NSPS OOOO") into Regulation Number 6, Part A; adopted corresponding revisions to its emissions reporting and permitting framework in Regulation Number 3, Parts A, B, and C; and adopted complementary oil and gas control measures in Regulation Number 7. This rulemaking was the culmination of the Commission's October 2012, directive to

consider full adoption of EPA's NSPS OOOO. These oil and gas control measures revisions focus on identifying and repairing leaks in the oil and gas sector, but also contain some recordkeeping and reporting requirements. This rulemaking received support from environmental groups and some companies within the oil and gas industry. In addition to extensive VOC reductions, the Regulation Number 7 revisions also regulate methane emissions from the oil and gas industry.

These oil and gas control measures are estimated to reduce VOC emissions by approximately 93,500 tons per year and methane/ethane emissions by approximately 65,000 tons per year, at a cost of approximately $42.5 million per year.

US EPA. 2014. Advance notice of proposed rulemaking under 40 CFR Chapter I [EPA–HQ–OPPT–2011–1019; FRL–9909–13] Hydraulic Fracturing Chemicals and Mixtures.

Summary

In its response to a citizen petition submitted under section 21 of the Toxic Substances Control Act (TSCA), EPA indicated that as a first step, it would convene a stakeholder process to develop an approach to obtain information on chemical substances and mixtures used in hydraulic fracturing. To gather information to inform EPA's proposal, the Agency is issuing this advance notice of proposed rulemaking (ANPR) and initiating a public participation process to seek comment on the information that should be reported or disclosed for hydraulic fracturing chemical substances and mixtures and the mechanism for obtaining this information. This mechanism could be regulatory (under TSCA section 8(a) and/or section 8(d)), voluntary, or a combination of both and could include best management practices, third-party certification and collection, and incentives for disclosure of this

information. In addition, the Agency is seeking comment on ways of minimizing reporting burdens and costs and of avoiding the duplication of state and other federal agency information collections, while at the same time maximizing data available for EPA risk characterization, external transparency, and public understanding. Also, EPA is soliciting comments on incentives and recognition programs that could be used to support the development and use of safer chemicals in hydraulic fracturing.

Dusseault, M. & Jackson, R. Seepage Pathway Assessment for Natural Gas to Shallow Groundwater During Well Stimulation, Production and After Abandonment. GeoMontréal 2013 [66th Canadian Geotechnical Conference and the 11th Joint CGS/IAH-CNC Groundwater Conference].

Abstract

Hydraulic fracture stimulation (HFS) of unconventional oil and gas reservoirs has become the focus of public concern with respect to fugitive gas emissions, fracture height growth, induced seismicity and groundwater pollution. We evaluate the potential pathways of fugitive gas seepage during stimulation and production and conclude that the quality of surface casing and deeper casing installations is a major concern with respect to future gas migration. The pathway outside the casing is of greatest concern, and likely leads to many wells leaking natural gas upwards from intermediate, non-depleted thin gas zones, rather than from the deeper target reservoirs which are depleted during production. We substantiate this argument with isotopic data from the Western Canada Sedimentary Basin. These paths must be understood and the probability of leakage addressed by mitigating methods such as casing perforation and squeeze, expanding packers of long life and controlled leak-off into saline aquifers. With a few exceptions, hydraulic fracture stimulation itself

appears not to be a significant risk. These exceptions include situations involving fluids during the high pressure stage of HFS when (1) old well casings are intersected by fracturing fluids and (2) when these fluids pressurize nearby offset wells that have not been shut in, and particularly offset wells in the same formation that are surrounded by a region of pressure depletion where the horizontal stresses have also been diminished.

Ellsworth, W.l., Hickman, S,H., Lleons, A.l., Mcgarr, A., Michael, A.J., Rubinstein, J.l. 2012. Are Seismicity Rate Changes in the Midcontinent Natural Or Manmade? SSA 2012 Abstract # 12-137.

Summary

A remarkable increase in the rate of M 3 and greater earthquakes is currently in progress in the US midcontinent. The average number of M >= 3 earthquakes/year increased starting in 2001, culminating in a six-fold increase over 20th century levels in 2011. Is this increase natural or manmade? To address this question, we take a regional approach to explore changes in the rate of earthquake occurrence in the midcontinent (defined here as 85° to 108° West, 25° to 50° North) using the USGS Preliminary Determination of Epicenters and National Seismic Hazard Map catalogs. These catalogs appear to be complete for M >= 3 since 1970. From 1970 through 2000, the rate of M >= 3 events averaged 21 +- 7.6/year in the entire region. This rate increased to 29 +- 3.5 from 2001 through 2008. In 2009, 2010 and 2011, 50, 87 and 134 events occurred, respectively. The modest increase that began in 2001 is due to increased seismicity in the coal bed methane field of the Raton Basin along the Colorado-New Mexico border west of Trinidad, CO. The acceleration in activity that began in 2009 appears to involve a combination of source regions of oil and gas production, including the Guy, Arkansas region, and in central and southern

Oklahoma. Horton, et al. (2012) provided strong evidence linking the Guy, AR activity to deep waste water injection wells. In Oklahoma, the rate of M >= 3 events abruptly increased in 2009 from 1.2/year in the previous half-century to over 25/year. This rate increase is exclusive of the November 2011 M 5.6 earthquake and its aftershocks. A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region. While the seismicity rate changes described here are almost certainly manmade, it remains to be determined how they are related to either changes in extraction methodologies or the rate of oil and gas production.

Hammack, R., Harbert, W., Sharma, S., Stewart, B., Capo, R., Wall, A., Wells, A., Diehl, R., Blaushild, D., Sams, J., Veloski, G. 2014. An Evaluation of Fracture Growth and Gas/Fluid Migration as Horizontal Marcellus Shale Gas Wells are Hydraulically Fractured in Greene County, Pennsylvania; NETL-TRS-3-2014; EPAct Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA.

Executive Summary

This field study monitored the induced fracturing of six horizontal Marcellus Shale gas wells in Greene County, Pennsylvania. The study had two research objectives: 1) to determine the maximum height of fractures created by hydraulic fracturing at this location; and 2) to determine if natural gas or fluids from the hydraulically fractured Marcellus Shale had migrated 3,800 ft upward to an overlying Upper Devonian/Lower Mississippian gas field during or after hydraulic fracturing.

The Tully Limestone occurs about 280 ft above the Marcellus Shale at this location and is considered to be a barrier to upward fracture growth when intact.

Microseismic monitoring using vertical geophone arrays located 10,288 microseismic events during hydraulic fracturing; about 40% of the events were above the Tully Limestone, but all events were at least 2,000 ft below producing zones in the overlying Upper Devonian/Lower Mississippian gas field, and more than 5,000 ft below drinking water aquifers.

Monitoring for evidence of fluid and gas migration was performed during and after the hydraulic fracturing of six horizontal Marcellus Shale gas wells. This monitoring program included: 1) gas pressure and production histories of three Upper Devonian/Lower Mississippian wells; 2) chemical and isotopic analysis of the gas produced from seven Upper Devonian/Lower Mississippian wells; 3) chemical and isotopic analysis of water produced from five Upper Devonian/Lower Mississippian wells; and 4) monitoring for perfluorocarbon tracers in gas produced from two Upper Devonian/Lower Mississippian wells.

Gas production and pressure histories from three Upper Devonian/Lower Mississippian gas wells that directly overlie stimulated, horizontal Marcellus Shale gas wells recorded no production or pressure increase in the 12-month period after hydraulic fracturing. An increase would imply communication with the over-pressured Marcellus Formation below. Sampling to detect possible migration of fluid and gas from the underlying hydraulically fractured Marcellus Shale gas wells commenced 2 months prior to hydraulic fracturing to establish background conditions. Analyses have been completed for gas samples collected up to 8 months after hydraulic fracturing and for produced water samples collected up to 5 months after hydraulic fracturing. Samples of gas and produced water continue to be collected monthly (produced water) and bimonthly (gas) from seven Upper Devonian/Lower Mississippian gas wells.

Current findings are: 1) no evidence of gas migration from the Marcellus Shale; and 2) no evidence of brine migration from the Marcellus Shale. Four perfluorocarbon tracers were injected with hydraulic fracturing fluids into 10 stages of a 14-stage, horizontal Marcellus Shale gas well during stimulation. Gas samples collected from two Upper Devonian/Lower Mississippian wells that directly overlie the tracer injection well were analyzed for presence of the tracer. No tracer was found in 17 gas samples taken from each of the two wells during the 2-month period after completion of the hydraulic fracturing.

Pennsylvania DEP. Regional Determination Letters. http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination_Letters/Regional_Determination_Letters.pdf.

Summary

The following list identifies cases where DEP determined that a private water supply was impacted by oil and gas activities. The oil and gas activities referenced in the list below include operations associated with both conventional and unconventional drilling activities that either resulted in a water diminution event or an increase in constituents above background conditions. This list is intended to identify historic water supply impacts and does not necessarily represent ongoing impacts. Many of the water supply complaints listed below have either returned to background conditions, have been mitigated through the installation of water treatment controls or have been addressed through the replacement of the original water supply. This list is dynamic in nature and will be updated to reflect new water supply impacts as they are reported to DEP and a determination is made; however, the list will retain cases of water supply impacts even after the impact has been resolved.

Public Health Association Australia (2014) Submission to Northern Territory Legislative Assembly Inquiry into Hydraulic Fracturing. PHAA NT Branch, ACT, Australia.

No summary is available.

Schumacher B, Griggs J, Askren D, Litman B, Shannon B, Mehrhoff M, Nelson A, Schultz MK. 2014. Development of Rapid Radiochemical Method for Gross Alpha and Gross Beta Activity Concentration in Flowback and Produced Waters from Hydraulic Fracturing Operations (EPA Report).

Summary and Conclusions

Three parts of The Gross Alpha and Gross Beta Method in FPWHFO were tested using a matrix based on the composition of a FPWHFO sample received from the EPA to determine whether they would satisfy method development guidelines outlined in the Method Validation Guide for Qualifying Methods Used by Radiological Laboratories Participating in Incident Response Activities (EPA, 2009). Two of the three parts comprise measurements of alpha emitters in the sample while the third is designed to measure beta emitters.

The MQOs for each of the three parts differed based on the matrix complexity, the instruments used for analyses, and the nuclear constants associated with the principal radionuclides used for the development process, and variation associated with preparation of the test samples. The as-tested MQOs and measured results are presented in Table 3. The final method with flow diagram used in this method development study is presented in Attachment III.

Each of the three parts of the method validated met all of the acceptance criteria for method uncertainty as shown in Tables 6A, 6B, and 6C. A summary of the observed

levels of uncertainty at each of three activity levels is summarized in Tables 7A, 7B, and 7C. Detectable levels of bias were observed across the activity levels for each of the three measurements as summarized in Table 10. The levels of bias, however, were so large that they compromised the determinatoin of method uncertainty. The detection capability for each of the three parts was successfully verified as summarized in 9A, 9B, and 9C.

Although all testing criteria were met as described in this report, the complexity of the matrix prevented development of a single-measurement method for gross alpha and beta in FPWHFO samples that will be simple, economical, and sufficiently rugged in matrices beyond the one used for the testing. Performing this analysis required a level of effort that was much different from previous analytical methods in other water matrices for alpha or beta emitters. Several unique approaches were attempted in order to identify an analytical approach that would accommodate this particularly challenging matrix. Section 11 provides a brief synopsis of development activities and Attachment 1 provides additional detail supporting the method development activities preliminary to final testing.

The final approach for gross alpha requires two measurements. The first measurement involves gross alpha by liquid scintillation counting following chemical separation to isolate thorium, uranium and polonium from the matrix. Method testing in the surrogate matrix indicates that a measureable bias is associated with the technique. Average recovery were 74±11% (k=1) of the known concentration of 230Th. Recoveries ranged from 57–104%. Although all of the testing criteria were met, the observed low bias raises possible questions about the ruggedness of the technique, especially with regard to use of the method for analyzing of FPWHFO of different compositions, from different regions or different times in the hydraulic fracturing life cycle. Possible future work should be done to improve the ruggedness

of the method and to develop estimates of uncertainty and decision criteria that would protect against decision errors using this screening technique.17 See Section 11 for recommendations for possible future work in this area.

The second measurement for alpha activity associated with 226Ra is performed by gamma spectrometry. The gamma spectrometry measurement is used to simultaneously determine the activity of longer-lived members of the thorium and uranium decay chains for calculation of gross beta activity. Although the development process detected bias in the gamma spectrometry measurements at some levels, the magnitude of the bias is lower than that observed for the alpha and there is no need for concern about the ruggedness of the non-destructive measurement technique since there are no variables such chemical separations that will introduce variable levels of bias into the method. Section 11 suggests the possibility of future work to improve the sensitivity of the gamma spectrometry measurement.

Due to the physics of the measurement technologies, radionuclide determinations performed by gamma spectrometry are generally less sensitive and have higher uncertainty that those performed by the liquid scintillation counting. This complicates the reporting process, the determination of uncertainty, and prevents calculation of a single meaningful value for gross alpha detection capability. Section 11 recommends that measurements of gross alpha by LSC and of 226Ra be reported and interpreted separately and suggests the possibility of future work that would improve the sensitivity of the gamma spectrometry measurement thereby minimize the disparity in the sensitivity of the two techniques.

Finally, as mentioned in the introduction in Section 1, all gross alpha and beta measurements are limited by the complexities of radioactive decay and ingrowth in the uranium and thorium decay chains which causes the alpha and beta activity

physically present in the sample to change over time. Thus gross alpha and beta measurements are often not (inter-) comparable from measurement to measurement or laboratory to laboratory. This significantly complicated the interpretation of gross alpha and beta results. Section 11 recommends that future work explore the impact of timing on the performance of the method and the interpretation of results, a project that would benefit gross alpha and beta measurements of natural products in all water matrices.

Stinson, R.J., Townsend, I., Donley, T.L., Chirenje, T., Patrick, D. 2014. Heavy Metal Distribution in Surficial Water: A Possible Link to Hydrocarbon Exploration and Extraction, Middle Susquehanna River Sub-Basin, Pennsylvania. Northeastern Section – Geological Society of America, Northeastern Section, 49th Annual Meeting (23–25 March, 2014), Lancaster, Pennsylvania.

Summary

Several environmental and human health concerns have emerged in the past few years due to the recent boom of hydrocarbon exploration and the new hydraulic fracturing methods involved. Although many different concerns exist, groundwater contamination has continually been the focal point of water issues relating to hydraulic fracturing. Surficial water has a fast residence time in the hydrologic cycle and does not directly impact humans as much as groundwater; therefore, it tends to be overlooked. For a chance to better understand the interaction between surface water and hydraulic fracturing, this project helps to determine if hydraulic fracturing is influencing the local watershed. Water samples were collected from tributaries leading into the Susquehanna River, from Bradford and Wyoming Counties, PA, to measure the concentrations of potential pollutants. Concentrations of heavy metals, such as arsenic, strontium, selenium, barium, nickel, cadmium, lead, copper, and

zinc, were measured by means of atomic absorption spectrophotometry. On-site measurements, comprising of temperature, pH, dissolved oxygen, conductivity, and turbidity, were also measured. A statistical analysis of the collected data was interpreted and graphical representations were produced to portray the results. Results of the analyzed data showing a trend in increased concentration levels of pollutants with distinct distribution patterns could be considered a link to hydraulic fracturing. Effluence in surficial water can be acquired via runoff, which can originate from different phases of the hydraulic fracturing process; specifically, the handling and disposal of all fluids. This project holds the groundwork for additional research to understand the relationship between surficial water and hydraulic fracturing. Further investigation and modeling can be attempted to recognize the following: how the pollutants are deposited and transported, watershed quality and impacts (negative or positive), if the pollutants found are at levels that can endanger human health, and, most importantly, whether hydraulic fracturing can be labeled as a point-source or not.

US EPA. 2014. Advance notice of proposed rulemaking under 40 CFR Chapter I [EPA–HQ–OPPT–2011–1019; FRL–9909–13] Hydraulic Fracturing Chemicals and Mixtures.

Summary

In its response to a citizen petition submitted under section 21 of the Toxic Substances Control Act (TSCA), EPA indicated that as a first step, it would convene a stakeholder process to develop an approach to obtain information on chemical substances and mixtures used in hydraulic fracturing. To gather information to inform EPA's proposal, the Agency is issuing this advance notice of proposed rulemaking (ANPR) and initiating a public participation process to seek comment on the information that should be reported or disclosed for hydraulic fracturing chemical

substances and mixtures and the mechanism for obtaining this information. This mechanism could be regulatory (under TSCA section 8(a) and/or section 8(d)), voluntary, or a combination of both and could include best management practices, third-party certification and collection, and incentives for disclosure of this information. In addition, the Agency is seeking comment on ways of minimizing reporting burdens and costs and of avoiding the duplication of state and other federal agency information collections, while at the same time maximizing data available for EPA risk characterization, external transparency, and public understanding. Also, EPA is soliciting comments on incentives and recognition programs that could be used to support the development and use of safer chemicals in hydraulic fracturing.

USGS. 2014. Record Number of Oklahoma Tremors Raises Possibility of Damaging Earthquakes. Updated USGS-Oklahoma Geological Survey Joint Statement on Oklahoma Earthquakes. Originally Released: 10/22/2013 1:07:59 PM; Updated May 2, 2014. http://earthquake.usgs.gov/regional/ceus/products/newsrelease_05022014.php.

Summary

The rate of earthquakes in Oklahoma has increased by about 50 percent since October 2013, significantly increasing the chance for a damaging quake in central Oklahoma. In a new joint statement by the U.S. Geological Survey and Oklahoma Geological Survey, the agencies reported that 183 earthquakes of magnitude 3.0 or greater occurred in Oklahoma from October 2013 through April 14, 2014. This compares with a long-term average from 1978 to 2008 of only two magnitude 3.0 or larger earthquakes per year. As a result of the increased number of small and moderate shocks, the likelihood of future, damaging earthquakes has increased for central and north-central Oklahoma.

“We hope that this new advisory of increased hazard will become a crucial consideration in earthquake preparedness for residents, schools and businesses in the central Oklahoma area,” said Dr. Bill Leith, USGS Senior Science Advisor for Earthquakes and Geologic Hazards. “Building owners and government officials should have a special concern for older, unreinforced brick structures, which are vulnerable to serious damage during sufficient shaking.”

The joint statement indicates that a likely contributing factor to the increase in earthquakes is wastewater disposal by injection into deep geologic formations. The water injection can increase underground pressures, lubricate faults and cause earthquakes – a process known as injection-induced seismicity. Much of this wastewater is a byproduct of oil and gas production and is routinely disposed of by injection into wells specifically designed and approved for this purpose. The recent earthquake rate changes are not due to typical, random fluctuations in natural seismicity rates.

Oklahoma’s heightened earthquake activity since 2009 includes 20 magnitude 4.0 to 4.8 quakes, plus one of the two largest recorded earthquakes in Oklahoma’s history – a magnitude 5.6 earthquake that occurred near Prague on Nov. 5, 2011, which damaged a number of homes and the historic Benedictine Hall at St. Gregory's University in Shawnee.

As a result of the increased seismicity, the Oklahoma Geological Survey has increased the number of monitoring stations and now operates a seismograph network of 15 permanent stations and 17 temporary stations. Both agencies are actively involved in research to determine the cause of the increased earthquake rate and to quantify the increased hazard in central Oklahoma.

| Appendix 2

Radon Screening Analysis

Radon is a naturally occurring, radioactive gas found in soil and rock. It seeps into homes through cracks in the foundation, walls, and joints. Radon comes from the natural (radioactive) breakdown of uranium in soil, rock and water and gets into the air. The amount of uranium in soil, rock and water varies across New York State. Radon from soil is the primary source of elevated levels in homes. Radon is a potential public health concern because elevated radon levels in the home can increase the risk of lung cancer for residents. This risk is greatly increased among smokers living in homes with elevated radon levels.

The New York State Department of Health has been collecting radon data since 1987. The data come from New York residents who choose to test their homes through the DOH radon program (Figures A and B).The information contained in the database is posted on the DOH website (http://www.health.ny.gov/environmental/radiological/radon/radon.htm) and contains basement radon results for about 70,000 homes. The information is listed by county and town and is updated semi-annually. DOH has a radon outreach and education program that promotes testing and mitigation in high risk radon areas and encourages testing by providing low-cost radon test kits to residents across the state.

Radon from Natural Gas

Natural gas contains radon from the decay of naturally occurring radium. The amount of radon will vary depending on the source of natural gas. Radon undergoes radioactive decay with a 3.8 day half-life. This means that the amount of radon in the natural gas decreases by 50% every 3.8 days. Transport of the natural gas through gathering and distribution lines provides time for radon gas to decay resulting in a lower concentration of radon when delivered to the customer.

Published estimates of indoor radon concentrations due to the use of natural gas in homes (US EPA, 1973) suggest that radon from natural gas use is typically a very small contributor to the total indoor radon levels in the home, compared to radon levels in the soil gas. Most gas appliances are vented, therefore only unvented appliances (mostly gas ranges) are assumed to contribute radon to indoor air.

A 1973 US EPA study found an average radon level in US natural gas wells of 37 picocuries per liter (pCi/L) (range: 0.2 to 1,450 pCi/L). The highest radon concentrations are from natural gas that originates in Texas, Oklahoma and Kansas. Similar estimates have been reported for natural gas from other parts of the world. A more recent study of radon in Pennsylvania natural gas wells conducted by the US Geological Survey (Rowan and Kramer, 2012) showed a radon concentration range of 1-79 pCi/L.

To determine whether radon in natural gas contributes to the overall indoor radon levels in the home, EPA made the following assumptions: home size (8000 ft3), gas usage (27 ft3/day) and number of air exchanges (1 per hour). Based on the above assumptions and an average radon concentration of 20 pCi/L (in gas at the burner) in an unvented kitchen range, the contribution from radon in natural gas results in an indoor radon

concentration of about of 0.0028 pCi/L. Using the highest reported US radon concentration (1450 pCi/L) in an unvented kitchen range shows an increase of about 0.2 pCi/L. For comparison, the average outdoor radon concentration in the US is 0.4 pCi/L, and according to the NYSDOH radon database, the average indoor radon concentration in New York State in homes that have been tested, mostly located in high radon areas, is 6.2 pCi/L. The nationwide average indoor radon concentration is 1.3 pCi/L.

The assumptions used to estimate indoor radon contribution from burning natural gas were established in 1973 and may not represent present kitchen stove usage. Current data on gas use states that a typical home uses from 4.5-12.5 ft^3/day (rather than the 27 ft^3/day used above) depending on whether or not the gas range has a pilot light (US DOE, 2009). Using these revised gas consumption values, a radon concentration of 20 pCi/L and keeping all the other parameter values the same, the contribution from an unvented gas appliance falls to 0.00046 to 0.0011pCi/L. If instead of the average radon concentration of 20 pCi/L we use the maximum measured concentration of 1450 pCi/L, the contribution to the indoor radon level from natural gas will range from 0.03 – 0.08 pCi/L. Assuming a smaller dwelling of 4,000 ft^3 the radon concentration could increase to 0.16 pCi/l from natural gas.

In summary, it is generally accepted that sources other than soil such as groundwater, consumer products (e.g., granite counter tops) and natural gas are not considered significant contributors to indoor radon concentrations. The above calculation demonstrate that natural gas has the potential to contribute a small amount of radon to the indoor air of homes from the use of unvented gas ranges. Based on the EPA methodologies, this contribution could be as high 0.16 pCi/L using the most recent data on gas consumption in a small dwelling. This contribution should be considered in the

context of what we know about radon concentrations in the environment which is that the average outdoor radon concentration in the US is 0.4 pCi/L, the nationwide average indoor is 1.3 pCi/L and according to the NYSDOH radon database, the average indoor radon concentration in New York State is 6.2 pCi/L.

Figure A New York State short-term indoor radon levels by county.

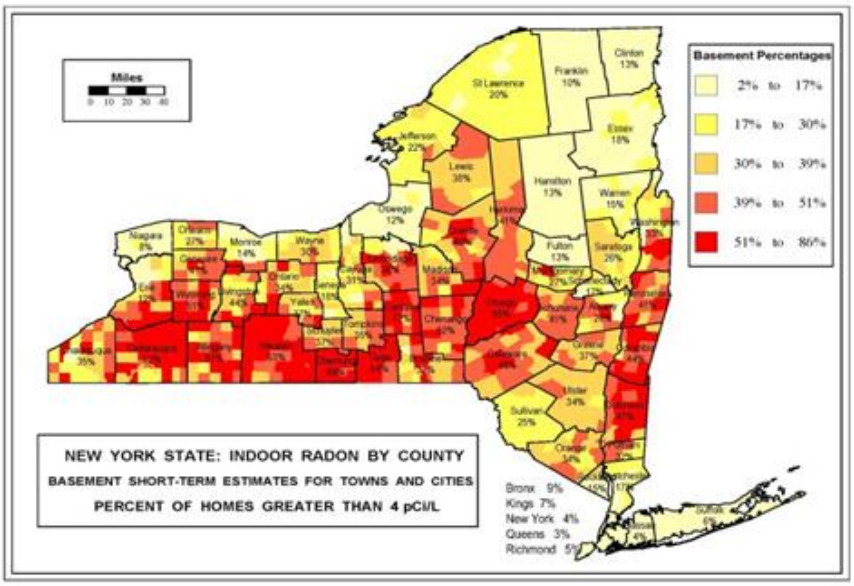
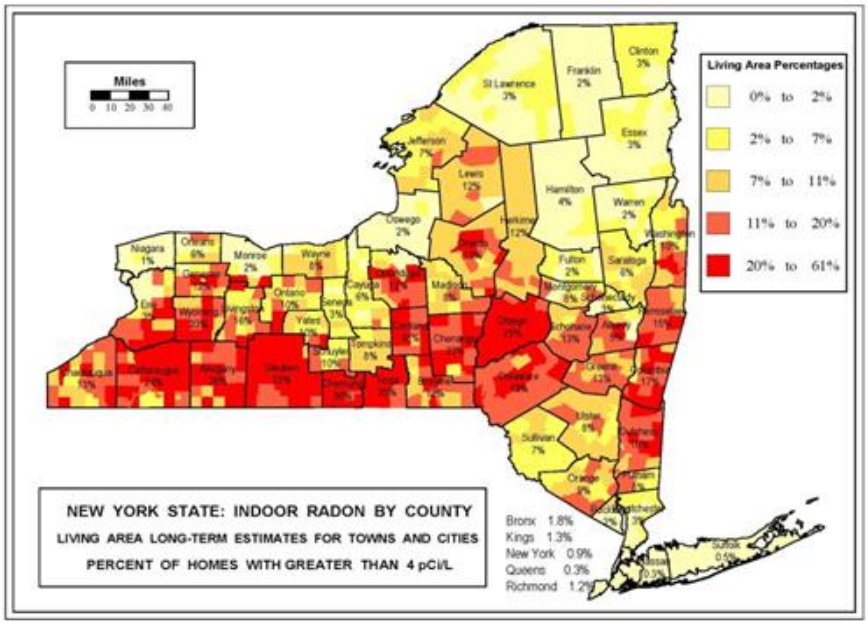


Figure B New York State long-term indoor radon levels by county.



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