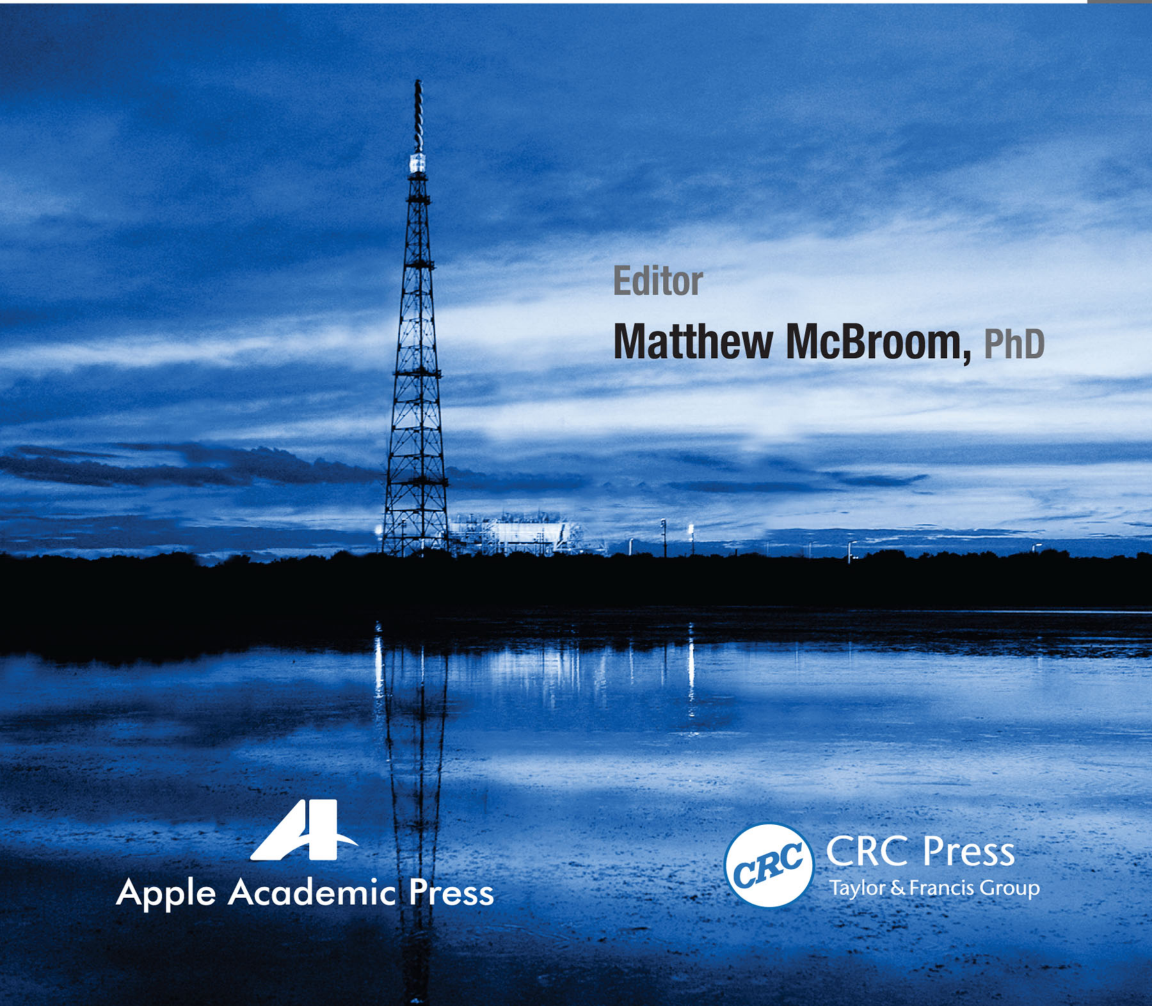
The Effects of Induced HYDRAULIC FRACTURING on the ENVIRONMENT

Commercial Demands vs. Water, Wildlife, and Human Ecosystems



Editor

Matthew McBroom, PhD

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ABOUT THE EDITOR

Matthew McBroom, PhD

Dr. Matthew McBroom is an associate professor at the Arthur Temple College of Foresrty and Agriculture at Stephen F. Austin State University in Nacogdoches, Texas, USA. His primary research interests are in the effects of land management on water resources, and how to design and implement land management activities to minimize potential impacts on water quality. The Texas Intensive Silviculture Study is one of his primary research projects, examining the effects of forest management activities such as clearcutting and site preparation with best management practices. He is also examining the dynamics of woody debris loading in the Sabine River, along with several other water resources studies.

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ACKNOWLEDGMENT AND HOW TO CITE

The chapters in this book were previously published in various places and in various formats. By bringing them together here in one place, we offer the reader a comprehensive perspective on recent investigations of hydraulic fracturing. Each chapter is enriched by being placed within the context of the larger investigative landscape.

We wish to thank the authors who made their research available for this book, whether by granting their permission individually or by releasing their research as open source articles. When citing information contained within this book, please do the authors the courtesy of attributing them by name, referring back to their original articles, using the credits provided at the end of each chapter.

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LIST OF CONTRIBUTORS

Charles R. Anderson, Jr.
Colorado Division of Parks and Wildlife, Grand Junction, Colorado 81505 USA

Joseph R. Bidwell
Department of Zoology, Oklahoma State University, 430 Life Sciences West, Stillwater, OK 74078, USA

William Bourcier
Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA, 94550

R. Terry Bowyer
Department of Biological Sciences, Idaho State University, Pocatello, Idaho 83209 USA

Terence J. Centner
Department of Agricultural and Applied Economics, College of Agricultural and Environmental Sciences, The University of Georgia, Athens, GA 30602, USA

Naomi L. Cooper
Department of Zoology, Oklahoma State University, 430 Life Sciences West, Stillwater, OK 74078, USA

Sally Entrekin
Biology Department, University of Central Arkansas, Conway, AR

Michelle Evans-White
Department of Biological Sciences, University of Arkansas, Fayetteville, AR

Souheil Ezzedine
Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA, 94550

Wang Fengfan
Key Lab of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Ocean University of China, Qingdao 266100, China

Madelon L. Finkel
Department of Public Health, Weill Cornell Medical College, New York, NY 10065, USA

Jonathan C. Fisher
Department of Zoology , Oklahoma State University, Stillwater, OK 74078

Matthew Fry
Department of Geography, University of North Texas, Denton, Texas 76203, United States

Li Gaolin
Key Lab of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Ocean University of China, Qingdao 266100, China

Bernard D. Goldstein
Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

Elizabeth Hagenbuch
Dynamac Corporation, contracted by the US EPA, Cincinnati, OH

Zhang Haiyan
Key Lab of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Ocean University of China, Qingdao 266100, China

Heather Hatzenbuhler
Department of Agricultural and Applied Economics, College of Agricultural and Environmental Sciences, The University of Georgia, Athens, GA 30602, USA

Jake Hays
Physicians Scientists & Engineers for Healthy Energy (PSE), 452 West 57th Street Apt 3E, New York, NY 10019, USA

David J. Hoeinghaus
Department of Biology, University of North Texas, Denton, Texas 76203, United States

Liu Huaishan
Key Lab of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Ocean University of China, Qingdao 266100, China

Jonathan Hunt
Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA, 94550

Brent Johnson
National Exposure Research Laboratory, US Environmental Protection Agency (EPA), Cincinnati, OH

John G. Kie
Department of Biological Sciences, Idaho State University, Pocatello, Idaho 83209 USA

Jill Kriesky
Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

Thomas W. La Point
Department of Biology, University of North Texas, Denton, Texas 76203, United States

Adam Law
Weill Cornell Medical College, Cayuga Medical Center, Ithaca, NY 14850, USA

Patrick E. Lendrum
Department of Biological Sciences, Idaho State University, Pocatello, Idaho 83209 USA

Ryan A. Long
Department of Biological Sciences, Idaho State University, Pocatello, Idaho 83209 USA

Matthew McBroom
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962, USA

Barbara Pavliakova
Graduate School of Public Health, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

Alexandra G. Ponette-Gonzalez
Department of Geography, University of North Texas, Denton, Texas 76203, United States

Sarah Roberts
Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA, 94550

Tong Siyou
Key Lab of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Ocean University of China, Qingdao 266100, China

Todd Thomas
Texas A&M Forest Service, Lufkin, TX 75901, USA

Ruthanne Thompson
Department of Biology, University of North Texas, Denton, Texas 76203, United States

Yanli Zhang
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962, USA

LIST OF ABBREVIATIONS

ADEQ	Arkansas Department of Environmental Quality
ADQ	audit of data quality
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
AU	assessment unit
BMP	best management practice
Br-DBP	brominated disinfection byproduct
BTEX	benzene, toluene, ethyl-benzene, and xylene
CASRN	Chemical Abstracts Service Registration Number
CBI	confidential business information
CBM	coalbed methane
CH_4	methane
cm	centimeter
CO_2	carbon dioxide
COGCC	Colorado Oil and Gas Conservation Commission
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWA	Clean Water Act
CWT	centralized waste treatment facility
DBP	disinfection byproduct
DEP	Department of Environmental Protection
DFW	Dallas-Fort Worth
DOE	U.S. Department of Energy
DRO	diesel range organics
DSSTox	Distributed Structure-Searchable Toxicity Database Network
EDTA	ethylenediaminetetraacetic acid
EGS	enhanced geothermal systems
EPA	U.S. Environmental Protection Agency
Fe	iron

FORTRAN	formula translation
FRAC	Fracturing Responsibility and Awareness of Chemicals Act
g	gram
GIS	geographic information system
GRO	gasoline range organics
GWPC	Ground Water Protection Council
ha	hectare
HAA	haloacetic acid
HSPF	hydrologic simulation program
INJWELL	injection well
IRIS	integrated risk information system
J	joule
kg	kilogram
L	liter
LBNL	Lawrence Berkeley National Laboratory
LOAEL	lowest observed adverse effect levels
m	meter
MCL	maximum contaminant level
mg	milligram
MGD	million gallons per day
MHz	megahertz
mm	millimeter
MSDS	material safety data sheet
NAS	National Academy of Sciences
NDIC	North Dakota Industrial Commission
NEMS	National Energy Modeling System
NH_4^+	ammonia
NHD	national hydrography dataset
NOM	naturally occurring organic matter
NO_x	nitrogen oxide
NPDES	National Pollutant Discharge Elimination System
NRC	National Response Center
NYSDEC	New York State Department of Environmental Conservation
OSPER	Osage-Skiatook Petroleum Environmental Research

PADEP	Pennsylvania Department of Environmental Protection
PCA	principle component analyses
PO_4^+	phosphate
POTW	publicly owned treatment work
PPRTV	provisional peer-reviewed toxicity value
PWS	public water systems
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RCRA	Resource Conservation and Recovery Act
rpm	rotations per minute
RRC	Railroad Commission of Texas
s	second
SDWA	Safe Drinking Water Act
SO_2	sulfur dioxide
SOP	standard operating procedure
SRB	Susquehanna River Basin
SRBC	Susquehanna River Basin Commission
SWAT	soil and water assessment tool
TDS	total dissolved solids
THM	trihalomethane
TIE	toxicity identification and evaluation
TOPKAT	toxicity prediction by komputer assisted technology
TOUGH	transport of unsaturated groundwater and heat
TSA	technical systems audit
TPH	total petroleum hydrocarbons
TSCA	Toxic Substances Control Act
TSS	total suspended solids
UCRB	Upper Colorado River Basin
UIC	underground injection control
US EIA	US Energy Information Administration
US FWS	US Fish and Wildlife Service
US GAO	US Government Accountability Office
US OMB	US Office of Management and Budget
USCB	US Census Bureau
USDA	US Department of Agriculture

USGS	U.S. Geological Survey
USHR	US House of Representatives
WET	whole effluent toxicity
WWTP	wastewater treatment plant
μm	micrometer

INTRODUCTION

Hydraulic fracturing, or “fracking” as it is commonly known, refers to the practice of using liquids at very high pressures to fragment oil and gas-bearing geologic strata, thereby allowing hydrocarbons to be harvested. This process, while it may increase energy resources, has myriad negative potential environmental impacts as well. This book looks not at the specifics of fracking as an industry, but instead at the environmental impacts. The first section looks at fracturing and the water supply; how hydraulic fracturing depletes finite water resources and contaminates water supplies. Section II looks at ecosystems and wildlife; fracking leads to habitat destruction and fragmentation, and various forms of wildlife species are either becoming endangered or are forced to find new areas to live. The final section examines the effect on human ecosystems and human health.

In the first chapter, Heather Hatzenbuhler and Terence J. Centner examine the regulation of water pollution at various horizontal drill sites. With the introduction of horizontal drilling, new commercial sources of energy have become available. Wells are drilled and injected with large quantities of water mixed with specially selected chemicals at high pressures that allow petroleum reserves to flow to the surface. While the increased economic activities and the outputs of domestic energy are welcomed, there is growing concern over negative environmental impacts from horizontal drilling in shale formations. The potential for water contamination, land destruction, air pollution, and geologic disruption has raised concerns about the merits of production activities used during extraction. The chapter looks at the impacts of horizontal drilling using hydraulic fracturing on water supplies and takes a comprehensive look at legislative and regulatory approaches to mitigate environmental risks in the Marcellus shale region. The overview identifies shortcomings associated with regulatory controls by local and state governments and offers two policy suggestions to better protect waters of the region.

The second chapter, by Matthew McBroom et al., looks at the impacts on surface water and, relatedly, soil erosion, rather than drilled wells. In their experiment, a 1.4 ha natural gas well pad was constructed in an intermittent stream channel at the Alto Experimental Watersheds in East Texas, USA (F1), while another 1.1 ha well pad was offset about 15 m from a nearby intermittent stream (F2). V-notch weirs were constructed downstream of these well pads and stream sedimentation and water quality was measured. For the 2009 water year, about 11.76 cm, or almost 222% more runoff resulted from F1 than F2. Sediment yield was significantly greater at F1, with 13,972 kg ha^{-1} yr^{-1} versus 714 kg ha^{-1} yr^{-1} at F2 on a per unit area disturbance basis for the 2009 water year. These losses were greater than was observed following forest clearcutting with best management practices (111–224 kg ha^{-1}). Significantly greater nitrogen and phosphorus losses were measured at F1 than F2. While oil and gas development can degrade surface water quality, appropriate conservation practices like retaining streamside buffers can mitigate these impacts.

Huaishan et al. examine the interactions between water supplies and the gas that is introduced during the fracturing process in chapter 3. They discover that in a certain frequency range, gas is an effective absorber and scatterer of sound, which changes the compressibility of water, and then changes the speed and frequency of sound. Gas continues rising, deforming, and dissolving. The same bubble of natural gas has different radii at different depths. By analyzing these changes, the resonance frequency of gas bubble, and its impacts on sound wave, characteristics of the influences of gas at different depths on the incident sound wave can be obtained. The main sound features of gas are relevant to the gas size, gas content, velocity, attenuation, resonance frequency, the scattering cross-section, and so forth. Sound models with hydrate and free gas in the water and sediment are established. Through the practical application to actual data, the sound characteristics yielded when the gas (or gas hydrate dissociation) escaped the water of seismic data are very clear.

In chapter 4, Bidwell et al. investigated potential biological effects of produced water contamination derived from occasional surface overflow and possible subsurface intrusion at an oil production site along the shore of Skiatook Lake, Oklahoma. They monitored basic chemistry and acute toxicity to a suite of standard aquatic test species in produced water and in samples taken from shallow groundwater wells on the site. Toxicity identification evaluations and ion toxicity modeling were used to identify toxic constituents in the samples. Lake sediment at the oil production site and at a reference site were also analyzed for brine intrusion chemically and by testing sediment toxicity using the benthic invertebrates, Chironomus dilutus, and Hyallela azteca. Sediment quality was also assessed with in situ survival and growth studies with *H. azteca* and the Asian clam, *Corbicula fluminea*, and by benthic macroinvertebrate community sampling. They found that the produced water was acutely toxic to the aquatic test organisms at concentrations ranging from 1% to 10% of the whole produced water sample. Toxicity identification evaluation and ion toxicity modeling indicated major ion salts and hydrocarbons were the primary mixture toxicants. The standardized test species used in the laboratory bioassays exhibited differences in sensitivity to these two general classes of contaminants, which underscores the importance of using multiple species when evaluating produced water toxicity. Toxicity of groundwater was greater in samples from wells near a produced water injection well and an evaporation pond. Principle component analyses (PCA) of chemical data derived from the groundwater wells indicated dilution by lake water and possible biogeochemical reactions as factors that ameliorated groundwater toxicity. Elevated concentrations of major ions were found in pore water from lake sediments, but toxicity from these ions was limited to sediment depths of 10 cm or greater, which is outside of the primary zone of biological activity. The study was able to demonstrate the utility of ion toxicity modeling to support data from toxicity identification evaluations aimed at identifying key toxic constituents in produced water. The study also demonstrated how geographic information systems, toxicity modeling, and toxicity assessment could be used to facilitate future site assessments.

Chapter 5 is a shorter, column-like piece by Fry et al. In it, they argue that the conflicts arising in the United States over water, as water grows scarce in some areas that have a high rate of fracking, foreshadow conflicts in other countries that also have cities situated over large natural-gas deposits. They use the example of Dallas-Fort Worth in Texas, USA to illustrate the challenges that are associated with balancing both energy needs and water sustainability in cities that already have a limited water supply.

Entrekin et al. argue a need for expanded research on the impact of natural gas extraction on the environment in chapter 6. Extraction of natural gas from hard-to-reach reservoirs has expanded around the world and poses multiple environmental threats to surface waters. Improved drilling and extraction technology used to access low permeability natural gas requires millions of liters of water and a suite of chemicals that may be toxic to aquatic biota. There is growing concern among the scientific community and the general public that rapid and extensive natural gas development in the US could lead to degradation of natural resources. Gas wells are often close to surface waters that could be impacted by elevated sediment runoff from pipelines and roads, alteration of streamflow as a result of water extraction, and contamination from introduced chemicals or the resulting wastewater. However, the data required to fully understand these potential threats are currently lacking. Scientists therefore need to study the changes in ecosystem structure and function caused by natural gas extraction and to use such data to inform sound environmental policy.

In chapter 7, Hunt et al. propose new ways of using silica gels in the fracturing process. Fractures and fracture networks are the principal pathways for migration of water and contaminants in groundwater systems, fluids in enhanced geothermal systems (EGS), oil and gas in petroleum reservoirs, carbon dioxide leakage from geological carbon sequestration, and radioactive and toxic industrial wastes from underground storage repositories. When dealing with EGS fracture networks, there are several major issues to consider, e.g., the minimization of hydraulic short circuits and losses of injected geothermal fluid to the surrounding formation, which in turn maximize heat extraction and economic production. Gel deployments to direct and control fluid flow have been extensively and successfully used in the oil industry for enhanced oil recovery. However, to the best of our knowledge, gels have not been applied to EGS to enhance heat extraction. Insitu gelling systems can either be organic or inorganic. Organic polymer gels are generally not thermostable to the typical temperatures of EGS systems. Inorganic gels, such as colloidal silica gels, however, may be ideal blocking agents for EGS systems if suitable gelation times can be achieved. In the current study, we explore colloidal silica gelation times and rheology as a function of SiO_2 concentration, pH, salt concentration, and temperature, with preliminary results in the two-phase field above 100 °C. Results at 25 °C show that it may be possible to choose formulations that will gel in a reasonable and predictable amount of time at the temperatures of EGS systems.

Chapter 8 provides an excerpt from a recent EPA study on the impacts of natural gas extraction. The first of the sections reproduced here, on scenario evaluations, shows how computer models are being used to identify conditions that may lead to impacts on drinking water resources from hydraulic fracturing. The EPA has identified hypothetical, but realistic, scenarios pertaining to the water acquisition, well injection, and wastewater treatment and waste disposal stages of the water cycle. Potential impacts to drinking water sources from withdrawing large volumes of water in semi-arid and humid river basins—the Upper Colorado River Basin in the west and the Susquehanna River Basin in the east—are being compared and assessed. Additionally, complex computer models are being used to explore the possibility of subsurface gas and fluid migration from deep shale formations to overlying aquifers in six different scenarios. These scenarios include poor well construction and hydraulic communication via fractures (natural and created) and nearby existing wells. As a first step, the subsurface migration simulations will examine realistic scenarios to assess the conditions necessary for hydraulic communication rather than the probability of migration occurring. The second section, on laboratory studies is largely focused on identifying potential impacts of inadequately treating hydraulic fracturing wastewater and discharging it to rivers. Experiments are being designed to test how well common wastewater treatment processes remove selected contaminants from hydraulic fracturing wastewater, including radium and other metals. Other experiments are assessing whether or not hydraulic fracturing wastewater may contribute to the formation of disinfection byproducts during common drinking water treatment processes, with particular focus on the formation of brominated disinfection byproducts, which have significant health concerns at high exposure levels. Samples of raw hydraulic fracturing wastewater, treated wastewater, and water from rivers receiving treated hydraulic fracturing wastewater have been collected for source apportionment studies. Results from laboratory analyses of these samples are being used to develop a method for determining if treated hydraulic fracturing wastewater is contributing to high chloride and bromide levels at downstream public water supplies. Finally, existing analytical methods for selected chemicals are being tested, modified, and verified for use in this study and by others, as needed. Methods are being modified in cases where standard methods do not exist for the low-level detection of chemicals of interest or for use in the complex matrices associated with hydraulic fracturing wastewater. Analytical methods are currently being tested and modified for several classes of chemicals, including glycols, acrylamides, ethoxylated alcohols, disinfection byproducts, radionuclides, and inorganic chemicals.

Chapter 9 moves into the section on wildlife, examining the effect of natural gas development on mule deer habitat. Lendrum et al. examine how the disruption of traditional migratory routes by anthropogenic disturbances has shifted patterns of resource selection by many species, and in some instances has caused populations to decline. Moreover, in recent decades populations of mule deer (*Odocoileus hemionus*) have declined throughout much of their historic range in the western United States. We used resource-selection functions to determine if the presence of natural-gas development altered patterns of resource selection by migrating mule deer. We compared spring migration routes of adult female mule deer fitted with GPS collars (n = 167) among four study areas that had varying degrees of natural-gas development from 2008 to 2010 in the Piceance Basin of northwest Colorado, USA. Mule deer migrating through the most developed area had longer step lengths (straight-line distance between successive GPS locations) compared with deer in less-developed areas. Additionally, deer migrating through the most developed study areas tended to select for habitat types that provided greater amounts of concealment cover, whereas deer from the least developed areas tended to select habitats that increased access to forage and cover. Deer selected habitats closer to well pads and avoided roads in all instances except along the most highly developed migratory routes, where road densities may have been too high for deer to avoid roads without deviating substantially from established migration routes. These results indicate that behavioral tendencies toward avoidance of anthropogenic disturbance can be overridden during migration by the strong fidelity ungulates demonstrate towards migration routes. If avoidance is feasible, then deer may select areas further from development, whereas in highly developed areas, deer may simply increase their rate of travel along established migration routes.

Chapter 10 again represents part of a longer study, this one by the New York State Department of Environmental Conservation. The section reproduced here examines the potential adverse impacts on ecosystems and wildlife from high-volume hydraulic fracturing operations. Four areas of concern related to high-volume hydraulic fracturing are: (1) fragmentation of habitat; (2) potential transfer of invasive species; (3) impacts to endangered and threatened species; and (4) use of state-owned lands. The dSGEIS concludes that high-volume hydraulic fracturing operations would have a significant impact on the environment because such operations have the potential to draw substantial development into New York, which would result in unavoidable impacts to habitats (fragmentation, loss of connectivity, degradation, etc.), species distributions and populations, and overall natural resource biodiversity. Habitat loss, conversion, and fragmentation (both short-term and long-term) would result from land grading and clearing, and the construction of well pads, roads, pipelines, and other infrastructure associated with gas drilling. The number of vehicle trips associated with high-volume hydraulic fracturing, particularly at multi-well sites, has been identified as an activity which presents the opportunity to transfer invasive terrestrial species. Surface water withdrawals also have the potential to transfer invasive aquatic species. The introduction of terrestrial and aquatic invasive species would have a significant adverse impact on the environment. State-owned lands play a unique role in New York's landscape because they are managed under public ownership to allow for sustainable use of natural resources, provide recreational opportunities for all New Yorkers, and provide important wildlife habitat and open space. Given the level of development expected for multi-pad horizontal drilling, the dSGEIS anticipates that there would be additional pressure for surface disturbance on State lands. Surface disturbance associated with gas extraction could have an impact on habitats on State lands, and recreational use of those lands, especially large contiguous forest patches that are valuable because they sustain wide-ranging forest species, and provide more habitat for forest interior species. The area underlain by the Marcellus Shale includes both terrestrial and aquatic habitat for 18 animal species listed as endangered or threatened in New York State that are protected under the State Endangered Species Law (ECL 11-0535) and associated regulations (6 NYCRR Part 182). Endangered and threatened wildlife may be adversely impacted through project actions such as clearing, grading and road building that occur within the habitats that they occupy. Certain species are unable to avoid direct impact due to their inherent poor mobility (e.g., Blanding's turtle, club shell mussel). Certain actions, such as clearing of vegetation or alteration of stream beds, can also result in the loss of nesting and spawning areas.

The final two chapters focus on the potential impact on human health. In chapter 11, Goldstein et al. examine the role of the environmental public health community in the case of the Marcellus Shale, a vast natural gas field underlying parts of Pennsylvania, New York, West Virginia, Virginia, and Maryland. Response to public concern about potential adverse environmental and health impacts has led to the formation of state and national advisory committees. Here, they review the extent to which advisory committees formed in 2011 by President Obama and governors of the states of Maryland and Pennsylvania contain individuals with expertise pertinent to human environmental public health. They also analyze the extent to which human health issues are of concern to the public by reviewing presentations at the public meeting of the Secretary of Energy Advisory Board (SEAB) Natural Gas Subcommittee formed by the U.S. President's directive. They find that at a public hearing held by the SEAB Natural Gas Subcommittee 62.7% of those not in favor of drilling mentioned health issues. Although public health is specified to be a concern in the executive orders forming these three advisory committees, we could identify no individuals with health expertise among the 52 members of the Pennsylvania Governor's Marcellus Shale Advisory Commission, the Maryland Marcellus Shale Safe Drilling Initiative Advisory Commission, or the SEAB Natural Gas Subcommittee. Despite recognition of the environmental public health concerns related to drilling in the Marcellus Shale, neither state nor national advisory committees selected to respond to these concerns contained recognizable environmental public health expertise.

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

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PART I

FRACTURING AND WATER POLLUTION

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CHAPTER 1

REGULATION OF WATER POLLUTION FROM HYDRAULIC FRACTURING IN HORIZONTALLY-DRILLED WELLS IN THE MARCELLUS SHALE REGION, USA

HEATHER HATZENBUHLER and TERENCE J. CENTNER

1.1 INTRODUCTION

In the last four years, horizontal drilling using many fractures along a horizontal wellbore has been used commercially to access the deepest shale gas (over 1800 m below the surface) in the United States [1,2]. Horizontal drilling employs turning a downward-plodding drill bit to continue drilling within a layer underneath the ground. Accompanying horizontal drilling is hydraulic fracturing, a well-stimulation technique that maximizes extraction of oil and natural gas in unconventional reservoirs such as shale, coalbeds and tight sands. Hydraulic fracturing involves injecting specially engineered fluids consisting of chemicals and granular material into the wells at incredible pressure to break up the fuel stores and stimulate the flow of natural gas or oil to the surface [1]. Once the well has been fractured, the pressure forces out some of the injection fluids containing chemicals, brines, metals, radionuclides and hydrocarbons [3]. For some wells, the toxic flowback fluids are removed and later injected into class II injection wells [4]. In other situations, the fluids are recycled or are transported to local wastewater treatment facilities. As a result of horizontal drilling, there has been a significant increase in the natural gas supply and a reduction in wholesale spot price of natural gas by nearly 50% [5].

The risks associated with all aspects of fracturing have been looked at from a variety of perspectives, but most concerns revolve around the use of water resources and their potential contamination [6]. Other risks are associated with surface spills [7,8]. The United States Environmental

Protection Agency (EPA) has been investigating drinking water contamination and is expected to complete an extensive study on all aspects of hydraulic fracturing in 2014 [9]. A conclusion that may be drawn from a review of recent scientific studies and incidences is that horizontal drilling accompanied by hydraulic fracturing poses threats to local environmental conditions and the health and safety of persons using land, water, and air resources.

1.2 FEDERAL AND REGIONAL POLICIES

Several federal and regional policies have been adopted to oversee potential risks related to hydraulic fracturing. However, amendments to the federal laws have limited the federal government's oversight of activities accompanying the development of shale gas resources. An overview of relevant legislation, summarized in Table 1, enumerates the role EPA and other agencies could play in minimizing negative impacts of natural gas production.

TABLE 1 Summary of federal and regional legislation

Legislation	Authority/Jurisdiction	Potential oversight for hydraulic fracturing
CERCLA–1980	None currently*/Clean-up of hazardous waste sites	Might hold companies responsible for clean-up and damages due to releases of hazardous materials at well sites and require reporting of toxic chemicals used in the fracturing process.
CWA–1972	EPA/Waters of the United States	NPDES stormwater permit required for discharges from well sites but could be extended to apply to temporary holding pits.
RCRA–1976	None currently*/ Hazardous wastes	Could require the listing of hazardous substances used in the injection fluids in addition to regulation of the resulting wastewater flowback.
SDWA–2005 amendment	None currently*/Drinking water of the United States	The UIC program could regulate subsurface emplacement fluids that would include injection for gas development and underground storage of waste fluids.
SRBC–1971 and DRBC–1961	Commissioners/Susquehanna and Delaware River Basins	Regulates deposits or withdrawals from the river basin so that fracturing operations need permits to withdraw water for injecting into wells or for depositing wastewaters back into the river system.

Note: * Exemptions exist that prohibit EPA from applying these standards to oil and gas extraction.

In 1972, the Clean Water Act (CWA) delineated the basic structure for regulating discharges of pollutants into waters and for establishing quality standards for surface waters under the authority of EPA [10]. Under the CWA's National Pollutant Discharge Elimination System program, stormwater permits were required for sediment runoff from construction sites and discharges of pollutants into surface waters [11]. The permitting system requires adoption of technology-based and water quality-based effluent limits [11,12]. Fracturing activities that inject liquid into the ground or store waters in temporary pits without any discharge are not regulated under the CWA. Thus, there is no federal oversight of fracturing activities until there is proof of fracturing contaminants in surface waters [13].

Congress acted to protect drinking water in the Safe Drinking Water Act of 1976 with protection through the implementation of an Underground Injection Control program regulating subsurface injections and storage of fluids. But, in the Energy Policy Act of 2005, Congress enacted an exclusion to this program.

> The term "underground injection"—(A) means the subsurface emplacement of fluids by well injection; and (B) excludes—(i) the underground injection of natural gas for purposes of storage; and (ii) the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities [14].

While the Safe Drinking Water Act specifically excludes hydraulic fracturing from regulation, the use of diesel fuel in fracturing is regulated since it is defined as a hazardous contaminant [14].

Congress regulated hazardous waste from inception to disposal under the Resource Conservation and Recovery Act (RCRA) and EPA has developed a list of regulated substances [15]. However, RCRA does not regulate hazardous wastes involved in oil and gas extraction and production under RCRA Subtitle C. These materials are subject to state regulation under the less stringent RCRA Subtitle D solid waste regulations as well as other federal regulations, although states are also free to adopt more demanding provisions. In a publication regarding the exemption EPA says, "Although they are relieved from regulation as hazardous wastes, the exemption does not mean these wastes could not present a hazard to human health and the environment if improperly managed" [16].The absence of any federal requirement to disclosure hazardous chemicals used in fracturing is a major issue [17].

Hydraulic fracturing, like any deep drilling operation, is subject to the risk of leaks and spills that can cause areas to be contaminated by hazardous waste. In 1980, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provided for the clean-up of abandoned hazardous waste and established liability to those who released the wastes to pay for clean-up [18]. Yet oil and gas exploration is exempt from clean-up of accidental spills, leaks, and problems from underground injection via the Energy Policy Act of 2005 [19]. Exploration and production companies cannot be held liable for damages under CERCLA, nor may they be sued by any entity for replacement of drinking water supplies or any health problems created as a result of their operations [20].

Applicable to fracturing regulation are two regional commissions that have jurisdiction over all water withdrawals from specific watersheds: the Delaware River Basin Commission and the Susquehanna River Basin Commission. Figure 1 illustrates the overlap of the Marcellus shale formation and several river basins. Because of regulations adopted by these commissions, all oil and gas production operations must obtain permits before they can pump millions of gallons of water to use in their wells. Therefore, these commissions play a critical role in the continuation of oil and gas development in the Marcellus shale region because hydraulic fracturing cannot occur without significant quantities of water.

The Delaware River Basin Commission is a regulatory body that was established in 1961 by a congressional compact. It includes a division engineer from the US Army Corps of Engineers and representatives from New York, Pennsylvania, New Jersey, and Delaware who are appointed individually by the executive office in each state [21]. Any decision of the Commission involves the approval of all members. The Commission has full water resource management authority, including water allocations and diversions. Any project that will withdraw or discharge water in or from the basin must be approved by a process that includes a public hearing. In 2009, the Delaware River Basin Commission banned new exploration and production of shale gas

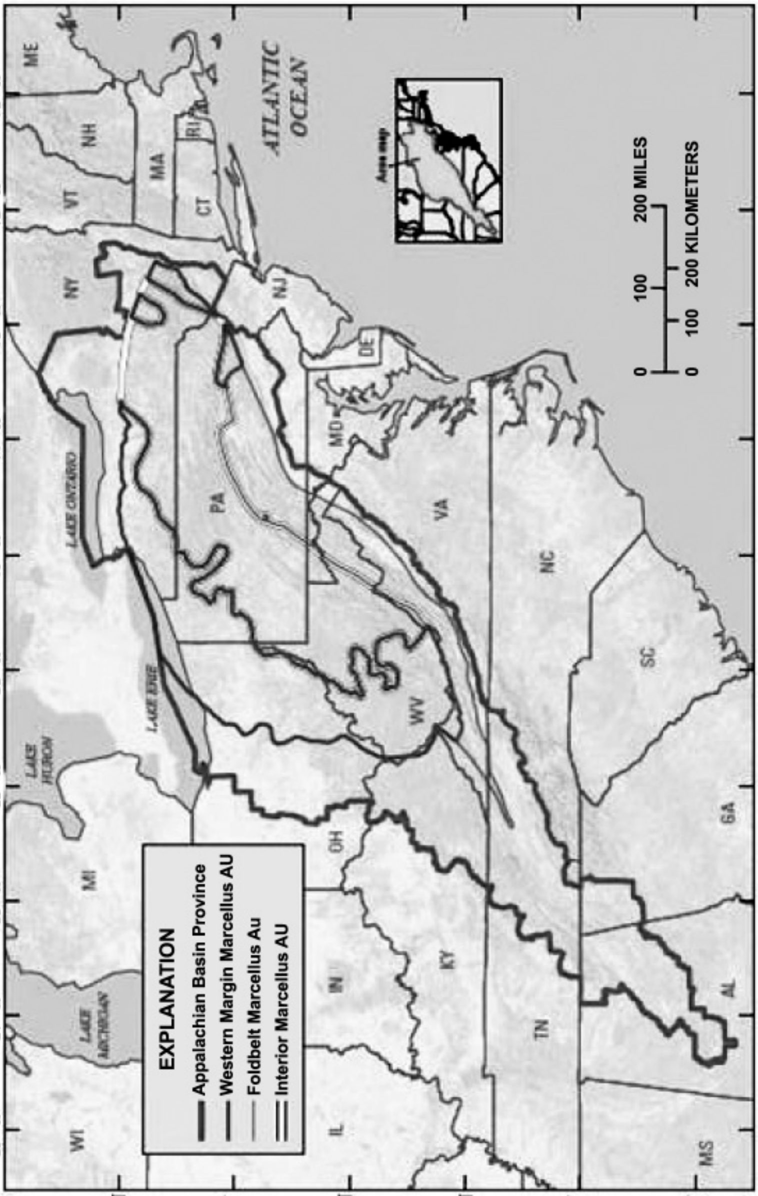

FIGURE 1: Map of the Marcellus shale assessment units (AU) which are located within the Appalachian Basin Province.