

Shale Gas Extraction in North Carolina: Public Health Implications

Recommendations from the
Research Triangle Environmental Health Collaborative



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Abstract

The North Carolina legislature recently legalized horizontal drilling and hydraulic fracturing. In hydraulic fracturing, millions of gallons of water, sand, and chemicals are pumped underground at high pressure to crack open rocks that hold oil and natural gas. Since becoming widely used over the past decade, the combination of horizontal drilling and hydraulic fracturing has greatly increased the amount of economically recoverable oil and natural gas. Hydraulic fracturing has also presented management challenges, both in terms of regulatory oversight and public perceptions.

Unlike some areas where hydraulic fracturing is becoming widespread, North Carolina has no history of oil and gas extraction on a commercial scale. Furthermore, the state's legislative framework for regulating drilling, authored in 1945, is based on outdated technologies. North Carolina is thus in a unique position among oil- and gas-producing states. Its new legislative framework can incorporate experiences from other states and include state-of-the-art technologies and best practices.

In October 2012, the Research Triangle Environmental Health Collaborative (EHC; www.environmentalhealthcollaborative.org/summit/summit-2012) convened a summit of experts to consider the potential impacts of hydraulic fracturing in North Carolina. Participants came from diverse stakeholder groups, including the oil and gas industry, nonprofits, government organizations, and academia. 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. The recommendations, presented here, are directed towards state and local lawmakers in North Carolina to assist the work that North Carolina's Mining and Energy Commission has begun.

The summit included three working groups related to hydraulic fracturing: (1) exposure pathways, (2) health impacts, and (3) social impacts. All three groups emphasized the importance of collecting comprehensive background data before oil or gas drilling occurs. Data collection should also continue after drilling takes place. Testing should include pre- and postdrilling testing for water quality and air emissions, as well as predrilling hydrogeology mapping, including information on faults, fractures, and groundwater flow. Measuring worker exposure during oil and gas extraction was also a priority, as was promoting a strong safety culture among oil and gas workers. Identifying and monitoring vulnerable species and ecosystems that could be impacted by drilling was also considered.

The working groups also highlighted some social impacts of horizontal drilling and hydraulic fracturing. The top recommendation was to create a Community Needs and Assets Assessment (CNAA), including identifying what jobs will be available to local workers, developing citizen stakeholder forums and reporting mechanisms, undergoing careful transportation planning and safety training, and implementing strong consumer protections. The group recommended creating an ombudsman to facilitate communication between stakeholders and industry.

The working group on potential health impacts made several suggestions, including developing a comprehensive Health Impact Assessment and participating in the Centers for Disease Control and Preventions National Environmental Public Health Tracking Network. A common thread running through the health recommendations was for the state to facilitate studies on medical and demographic data, as well as studies to generate exposure information for water- and air-based

pathways. Finally, the group recommended that North Carolina mandate and fund an organization within the N.C. State Center for Health Statistics to establish baseline health data analysis of areas where hydraulic fracturing could occur.

Overview

Hydraulic Fracturing Process

Hydraulic fracturing is a method of extracting natural gas and oil (collectively called hydrocarbons) from deep within the Earth¹. Within the past decade, the combination of horizontal drilling and hydraulic fracturing has greatly increased the amount of hydrocarbons that can be extracted at commercially viable prices. Although hydraulic fracturing technology has existed for decades, the combination of horizontal drilling and hydraulic fracturing is novel, and this combination that is referred to as “hydraulic fracturing”².

Hydraulic fracturing has proven particularly useful for extracting hydrocarbons from geological formations called shales. Natural gas drawn from these formations is referred to as “shale gas,”³ and thus hydraulic fracturing also can be referred to as “shale gas extraction.” Shales have relatively low permeability [2], meaning that hydrocarbons (and other fluids) migrate slowly through shales. A gas well with a horizontal component has a longer path through the target formation than does a conventional gas well. The greater surface area of the shale exposed to the wellbore increases the amount of hydrocarbons that flow into the well and up to the surface. Horizontal drilling can extend two miles through shale formations.

Hydraulic fracturing is a process that further increases the amount of hydrocarbons that can be extracted from a well. The well is first perforated with small explosives, creating small fractures in the surrounding shale formation. This fracture network increases the surface area of the shale in contact with the well. High-pressure fracturing fluid is then pumped into the well, expanding the fracture network in the shale. The fluid contains particles, often sand, that prop open the rock fractures after the pressure of the fluid drops. Hydraulic fracturing fluid is composed primarily of water but also contains a number of chemical additives, such as corrosion inhibitors, biocides, and friction reducers, to optimize the performance of the gas well. The mix of chemicals used can vary depending on the properties of a specific well and the rock into which it is drilled. Drilling and hydraulically fracturing a single well can require several million gallons of fluid [3].

Impact on the Energy Sector

Natural gas supply in the United States has increased rapidly as a result of widespread hydraulic fracturing. Natural gas, as a fuel source to generate electricity, burns more cleanly than coal and

¹The depth of hydrocarbon-bearing shale formations varies from less than 300 to more than 4000 meters [1]. Although hydrocarbons usually are extracted from several thousand feet below the Earth's surface, water used for drinking and agriculture often is drawn from several hundred feet or less below the Earth's surface.

²Hydraulic fracturing also is spelled “fracing” in industry publications. In this context, fracing usually refers specifically to the hydraulic fracturing operation, not necessarily in combination with horizontal drilling.

³This moniker is to distinguish methane from shales from that derived from so-called conventional sources, such as vertical gas wells that are not fracked.

emits less carbon dioxide per unit of energy produced. Moreover, burning coal releases mercury and coal ash to the atmosphere, thus contributing to pollution and particulate-related climate change, whereas burning natural gas does not.

The amount of electricity generated from natural gas in the United States nearly doubled between 1993 and 2011 [4] (Figure 1) and is projected to be nearly equal to that generated from coal by 2040. Although the use of natural gas for electricity generation has increased with the growth of shale gas extraction, the widespread availability and low cost of natural gas has lessened the economic incentive for some renewable energy sources, such as wind and solar [5].

The United States has large shale gas and oil reserves⁴. Hence, natural gas is a politically popular domestic energy source. Although hydraulic fracturing has proceeded quickly in the United States, there are other countries, such as China and India, that have large hydrocarbon reserves that have not yet been accessed. It is possible that hydraulic fracturing could lead to an era of increased natural gas use worldwide [7].

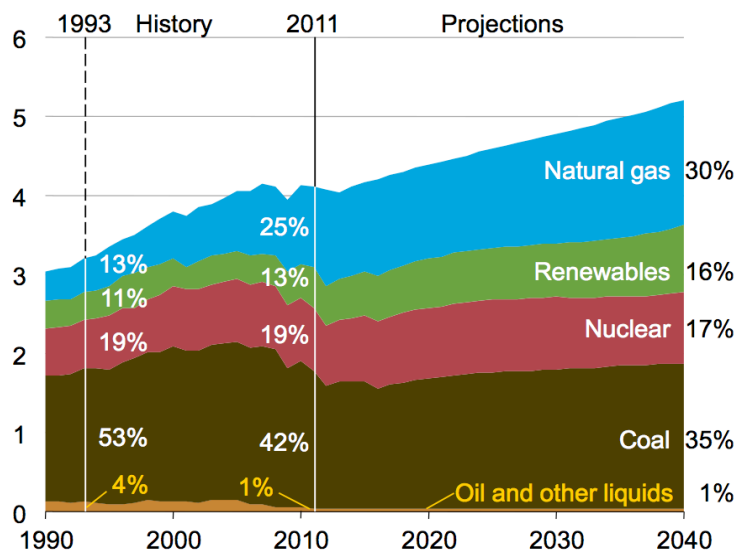


Figure 1: U.S. electricity generation by energy source, in trillion kilowatt hours. Electricity generation from natural gas has increased since hydraulic fracturing increased the natural gas supply in the mid 2000's [4].

Hydraulic Fracturing and North Carolina

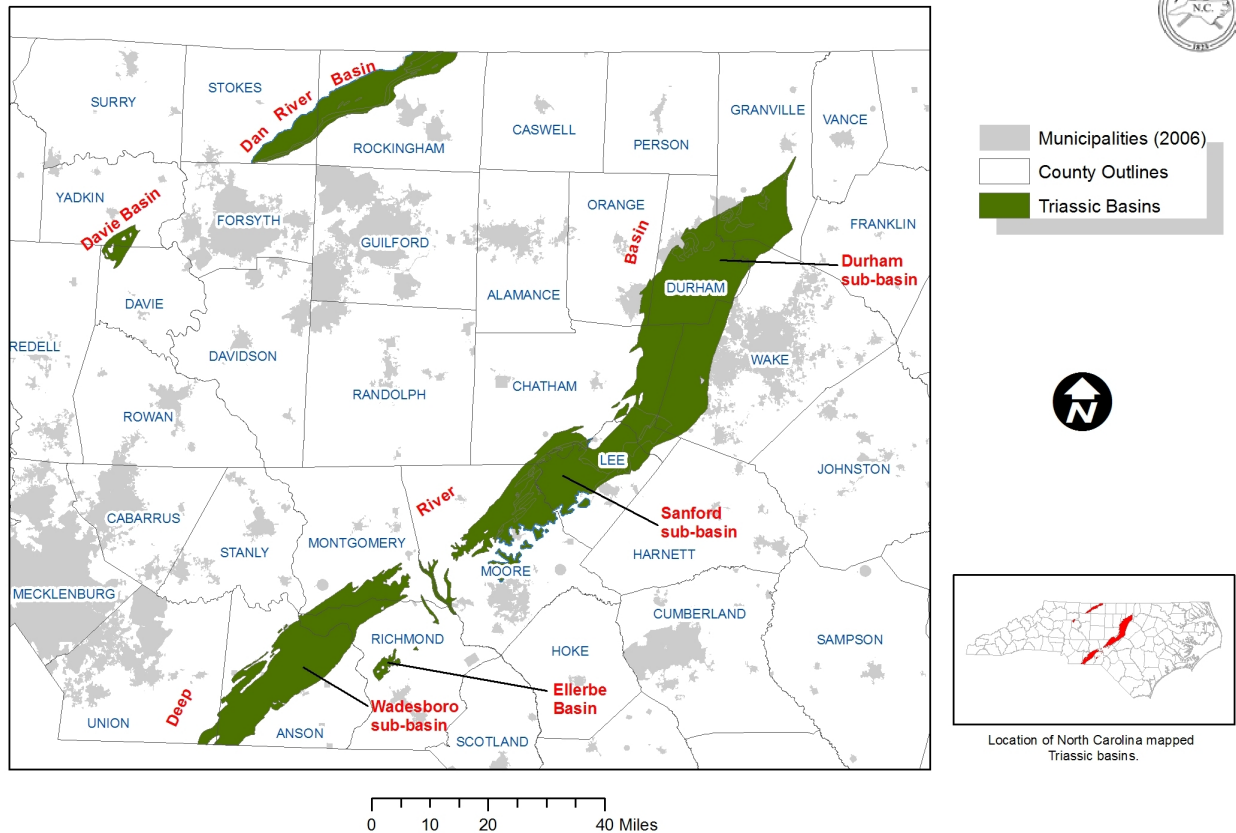
North Carolina recently took steps to legalize horizontal drilling and hydraulic fracturing. Session Law 2011-276 required the N.C. Department of Environment and Natural Resources, the N.C. Department of Commerce, and the N.C. Department of Justice to evaluate the potential impacts of horizontal drilling and hydraulic fracturing on the state [8]. Following the release of that report, the state legislature, via Session Law 2012-143, mandated the creation of a board of commissioners to oversee the development of a modern oil and gas regulatory system in North Carolina.

The areas of North Carolina that may contain hydrocarbons are geologic basins that formed during the Triassic period, about 230 million years ago [9]. There are two of these basins in North Carolina: (1) the Danville formation in northwestern North Carolina and southern Virginia and (2) the Deep River formation in central North Carolina. Of the two, the Deep River formation is the most likely to contain oil and gas⁵.

⁴The most recent estimate by the U.S. Energy Information Administration for the United States shale gas reserves is 482 trillion cubic feet of natural gas. This is enough natural gas to supply the United States, at the current rate of consumption, for about 20 years [6].

⁵The likelihood for a geologic formation to contain hydrocarbons and the form of those hydrocarbons depend on the amount and type of organic matter originally deposited in the formation, as well as the thermal history of the

Exposed North Carolina Triassic Rift Basins



Data source: NC Geologic Map of 1985, NC Center for Geographic Information and Analysis
Map prepared September 21, 2011

Figure 2: Triassic rift basins in North Carolina [8]. The Sanford sub-basin in Lee County is the area most likely to be drilled for oil and gas when drilling begins. The Durham sub-basin extends northwards through urban areas of Wake, Durham, and Chatham Counties.

The U.S. Geological Survey estimates the undiscovered natural gas resources in the Deep River Basin of North Carolina to be 1,660 billion cubic feet (1.66 trillion cubic feet) of gas and 83 million barrels of natural gas liquids [9]. The Danville Basin is far smaller, containing an estimated 42 billion cubic feet of natural gas [9]. For comparison, the estimated natural gas reserves in the Marcellus Shale, which underlies parts of Pennsylvania, New York, and West Virginia, are 84 trillion cubic feet [11].

Although significantly smaller than the Marcellus Shale in terms of surface area, hydraulic fracturing North Carolina's Deep River Triassic basin potentially could impact many people. Lee County, which contains most of the Sanford sub-basin, has a population density five times that of Bradford County, Pennsylvania, an area that overlies the Marcellus Shale and has been extensively drilled. The Deep River basin also extends into urban areas of Chatham, Wake, and Durham counties. Information about North Carolina's Triassic basins is currently limited, and it is difficult

formation. Although existing data are limited, the hydrocarbon potential of the formations in North Carolina has been assessed by Reid and Milici [10].

to predict whether future drilling in the state would extend into urban areas. Hydraulic fracturing in the state could affect residents farther from drilling sites through competition for surface water use, increased truck traffic on roads, disposal of hydraulic fracturing waste, and availability of housing and social services.

North Carolina has no history of commercial oil and gas development. Many other states in which hydraulic fracturing currently is occurring, such as Pennsylvania and Texas, have more than a century of experience with the oil and gas industry. North Carolina also currently does not have the staff in place to regulate or inspect drilling facilities.

The lack of a commercial oil and gas industry in North Carolina could be advantageous to the state. Because there has not been significant drilling for oil and gas, the state has an opportunity to collect background data before hydrocarbon exploration and development occur. This data could provide a comparison to determine how the state is impacted by hydrocarbon development if it occurs in the future. North Carolina also has the opportunity to craft new legislation that reflects current technologies, incorporates the best scientific knowledge, and builds on the experiences of other states. The Environmental Health Collaborative summit was convened to gather this knowledge into recommendations for legislation to govern North Carolina's future with oil and gas.

Background Provided by the Institute of Medicine Meeting

The EHC summit built on the Institute of Medicine (IOM) of the National Academy of Sciences Workshop on the health impacts of shale gas, held April 30 and May 1, 2012. The IOM meeting was introduced and summarized at the opening of the EHC summit, and many of the themes from the IOM meeting were addressed.

Participants at the IOM meeting acknowledged that shale gas extraction is an emerging issue that will continue to be important for years. As such, it is imperative to understand the potential short- and long-term health impacts resulting from widespread shale gas drilling. The IOM meeting also focused on assessing the impacts from the complete lifecycle of shale gas extraction, from initial development of well pads to well decommissioning and final site reclamation. Like the EHC summit, the IOM meeting did not produce comments on the appropriate future course of hydraulic fracturing in the United States or elsewhere. Rather, the goal of the meeting was for participants to use the best available science to describe what should be done to better understand and mitigate potential health impacts from the proliferation of shale gas extraction.

Specific health concerns discussed at the IOM workshop, such as occupational hazards for oil and gas workers and community impacts from non-chemical stressors, are discussed below in further detail.

Summit Recommendations

Common Themes

The Environmental Health Collaborative (EHC) summit, held on October 2 and 3, 2012, included three separate working groups, each focusing on a class of issues relating to the potential for future drilling in North Carolina: (1) exposure pathways, (2) health impacts, and (3) social impacts. Each group compiled a list of the shortcomings in the current understanding of potential impacts

of hydraulic fracturing. Groups also proposed recommendations for actions and legislation to address these gaps. Although the focuses of each group were different, there was overlap in the subjects considered and in the resulting recommendations. Themes and recommendations reached by multiple groups are described below. Recommendations by individual groups follow.

Baseline Data

The importance of collecting baseline data emerged as an important theme from every working group of the EHC summit and was also a priority identified at the IOM meeting. “Baseline data” refers to testing performed before oil and gas drilling takes place. Such data can provide a comparison to determine whether any changes have taken place as a result of activities associated with shale gas. This data then can be used to make changes in practice if necessary and may also protect both citizens and drilling companies from unfounded claims of damages.

There are a number of different types of background data that should be collected in North Carolina. Working groups at the EHC summit recommended the following statewide measurements:

- *Water quality.* The quality and quantity of ground and surface water resources potentially affected by drilling should be studied. Water sources should be assessed, at least, for major ions, trace metals, dissolved gases (such as methane), radioactivity, and a range of organic compounds.
- *Hydrogeologic framework.* There should be a detailed mapping of the hydrogeologic framework, including rock types and fault structure, in gas drilling areas.
- *Hydrocarbon characterization.* Hydrocarbons should be characterized based on chemical and isotopic composition. Knowing the signature of hydrocarbons being extracted could improve wastewater treatment and make it easier to identify contamination if hydrocarbons are released into the environment. A starting point would be to extract fresh samples of the hydrocarbons from the oil and gas wells already present in North Carolina.
- *Air quality.* Airborne pollutants were identified by participants at the summit and the IOM meeting as a potential health hazard to oil and gas workers and state residents. Emissions from drilling sites could potentially contain heavy metals, volatile organic compounds, and other contaminants. Drilling areas should undergo ambient air monitoring.
- *Ecological data.* Ecosystem health in the areas potentially affected by hydraulic fracturing should be assessed.
- *Health data.* Population health statistics are essential in understanding what impact shale gas extraction has on the short- and long-term health of residents in affected areas.

Some of these data already exist in disparate sources and need to be compiled. Other data have not yet been collected and will require further field studies. Legislation is needed to clarify who is responsible for collecting such data and make adequate funding available to collect it.

One mechanism to ensure access for background data collection is to make gas well permits contingent on site access for ambient air and water monitoring before, during, and after the drilling

and hydraulic fracturing processes. This requirement would not necessarily require drilling companies to pay for these measurements but would ensure that government and non-government researchers would be granted access to collect data where necessary.

Water and Wastewater Management Plan

Wastewater is produced as a byproduct of most oil and gas operations and increases dramatically when high-volume hydraulic fracturing occurs. Some hydraulic fracturing fluid, referred to as flowback fluid, returns to the surface soon after a well is hydraulically fractured. Liquid can continue to return to the surface long after the well has been fractured; such fluid is often called “produced water.” Both flowback fluid and produced water can contain high concentrations of salts, organic compounds, and, in some cases, radioactivity⁶. These compounds are remnants of chemicals used in the original hydraulic fracturing fluid mixed with natural compounds resulting from interactions between fracturing fluid and rocks deep underground.

Flowback and produced waters are waste products that require careful management. Storing wastewater at the surface in containment ponds raises the possibility of unintentional leaks or discharges [13]. Wastes can be disposed of through deep injection [14], in which waste fluids are pumped underground into porous geologic formations away from groundwater sources. However, the geology is not suitable for such injection wells in most of North Carolina. Moreover, deep injection wells for waste disposal have increased the likelihood of earthquakes in some areas [15, 16, 17]. Treating waste fluid in municipal wastewater treatment facilities, as has been done in other locations [18], is undesirable because municipal treatment facilities are not designed to deal with the types of compounds typically found in hydraulic fracturing waste, such as high salt levels and radioactivity. Wastes should be pre-treated at a centralized facility to reduce salt concentrations and radioactivity before being treated in municipal facilities. Land application is not a viable disposal option and has been shown to cause significant tree mortality [19]. Many drilling companies are pursuing methods to reduce and recycle waste fluid, a positive development in locations such as the Marcellus shale.

Hydraulic fracturing can potentially impact local water availability. Drilling and hydraulic fracturing a well require large volumes of water: five million gallons or more might be used per well, depending on the specific geologic formation [3]. The impact of these added water demands depend on the local water supply and the other potentially competing water users.

North Carolina should develop a comprehensive water and wastewater management plan. This plan should address how water is allocated between users and how priority is granted. It should have a strategy to handle droughts, including policies for dealing with periods of low water availability. Water allocation has consequences for residents who rely on a local water supply for residential or commercial use.

This management plan also should establish guidelines for background water testing. Monitoring should be in place before drilling occurs. Because of seasonal and annual variations in water quality and quantity, longer data collection periods make it easier to identify long-term changes if they occur.

⁶Radioactivity is naturally occurring in some shales but not all. The Marcellus Shale in Pennsylvania, for example, is relatively more radioactive than other shales [12].

Funding and Administration

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. Current bonding laws usually pay only to cap gas wells when they are abandoned. However, performing more comprehensive environmental or health remediation should be considered in assessing bonding fees. It is important to decide, before drilling begins, how increased infrastructure maintenance costs will be apportioned. Increased truck traffic associated with shale gas can impact roads negatively, especially those in rural areas not designed to accommodate such traffic. The costs of maintenance and increased staff required to maintain roads should not be borne exclusively by the public.

More funding is needed to adequately address the potential environmental and social costs of hydraulic fracturing. Many of the recommendations in this document require funds that are not readily available and likely would not be covered by bonding measures. For example, collection of comprehensive environmental and health data can be expensive. Funding to collect this and other background data is required before, during, and after drilling occurs in the state. Monitoring and inspection should continue throughout the drilling process. Money also should be available for environmental and health remediation once drilling sites are retired, including remediation not associated with individual drilling sites.

Local, state, and regional agencies should coordinate the administration and oversight of hydraulic fracturing. Administration also should be coordinated in priorities, as well as actions, and duplication of effort between governing bodies should be minimized.

Best Management Practices

North Carolina should work with industry to promote a list of best management practices (BMPs) for drilling and hydraulic fracturing. This list should build on those developed in other states but be specific to North Carolina. 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.

Regulations are useful only to the extent to which companies comply. Effective regulations require enforcement if violations occur. Regulations must also keep pace with the rapid technological developments in the shale gas industry.

Working Group 1: Exposure Pathways

1.1 Overall Themes

The goal of analyzing potential exposure pathways is to reduce the incidence of exposure rather than mitigate exposures after they occur. Background information is essential to evaluate what chemicals are present and what can be considered a baseline state of human and environmental health. Understanding the links between chemical exposures and public health remains one of the greatest gaps in evaluating the potential impacts from shale gas.

1.2 Hydrogeologic Framework

Underground faults and fractures can serve as pathways for gas and fluid migration. It is unknown to what extent natural fault networks can facilitate migration of dissolved gases or hydraulic fracturing fluids from shale gas drilling. Nevertheless, understanding the geology and hydrology of the Deep River basin, particularly the Sanford sub-basin, is essential to evaluating the risks posed by hydraulic fracturing.

In addition to local fault structure, it is important to understand ground and surface water flows. The connectivity of groundwater sources can help assess both water availability for shale gas and spread of contamination should it occur. Surface water flows must be quantified to create a hydrologic budget that includes the water demands of shale gas. Understanding the local watershed also should include the potential for dam ruptures or breaches of hydraulic fracturing fluid ponds.

1.2 Recommendations:

- *Generate a comprehensive state geologic map.* This map should include the local fault structure, as well as historical drilling and mining activities.
- *Establish drilling setback distances from geologic formations such as faults, fractures, and dikes.*
- *Generate publicly available data as part of the gas drilling and permitting process.* Drillers should collect and publicly release geologic information collected when drilling, including the amount of liquid condensate present in extracted gas.
- *Regulate well casing and cementing designs.* The well casing and cement are the key barriers between contaminants and the environment. As such, they should be strongly safeguarded. Casing depth standards should be established and enforced. Cement bond logs generated during well construction should be required to ensure that casing is adequately set. Well site design should be regulated to minimize exposures and contain contaminants if accidental releases occur. All drilling sites and pipelines should include automatic shutoff valves.
- *Require setback distances between hydraulic fracturing well sites and sensitive areas,* including private homes and water wells, surface water bodies, and sensitive ecological areas. Children can be especially sensitive to environmental contaminants, and special consideration should be given to establishing setbacks from schools, daycares, and other facilities with large numbers of young children.
- *Determine the prevalence of natural methane in shallow aquifers in the Deep River basin.* Establishing a baseline for methane concentration in water resources used for drinking will be essential for evaluating whether dissolved gas contamination occurs in the future, should drilling occur.
- *Evaluate the radiological potential of North Carolina's geology.*

1.3 Hydraulic Fracturing Fluid and Wastes

The hydraulic fracturing process can involve numerous chemicals that are potentially toxic [20]. The composition of the hydraulic fracturing fluid used at a given site depends on the local geology and the drilling company involved. Regulations requiring the disclosure of hydraulic fracturing fluid contents vary by state [21], particularly the extent to which chemicals can be excluded based on trade-secret exemptions. Information about chemicals used in the fracking fluid for many wells can be found at the industry's voluntary chemical disclosure registry, FracFocus (<http://fracfocus.org/>).

Assessing and minimizing the risk of exposure requires better knowledge of the composition of hydraulic fracturing fluid and waste waters. Environmental risk also depends on the volatility and mobility of compounds in the environment.

1.3 Recommendations:

- *Store all used fracturing fluids (flowback and produced water) and waste in closed tanks at the well site, not open pits, to minimize exposure risk and surface spills.*
- *Require inspections of well site contamination-prevention equipment, including leak detection equipment, groundwater monitoring wells, and berm integrity.*
- *Limit specific chemicals where capacity to track or assess health risk is not yet available.*
- *Develop a wastewater disposal plan.*
- *Require drilling companies to disclose hydraulic fracturing fluid composition.*

1.4 Water Quality

The surface water monitoring systems currently in place often are not designed to detect chemicals related to hydraulic fracturing. Groundwater monitoring data are also lacking in many locations. For example, there is little information on groundwater quality in the Deep River Triassic Basin at shallow depths, and to our knowledge none exist for depths greater than 1,000 feet. Heavy metals, salts, and other dissolved compounds in groundwater potentially could mix with chemicals in hydraulic fracturing fluid. Evaluating waste disposal options and potential hazards posed by flowback fluid requires knowledge of the composition of deep groundwater.

The number and quality of shallow groundwater wells in the Sanford sub-basin should also be studied. Many of these wells are used for drinking water or agriculture. Water wells that are poorly constructed could be at increased risk of damage from nearby drilling operations.

1.4 Recommendations:

- *Establish standards for baseline water testing.* These standards should prioritize analyses, as some homeowners may not be able to afford a complete suite. These standards and recommendations should be made easily available to homeowners. Potential

sources for standards and expertise include the Division of Water Quality within the N.C. Department of Natural Resources and the N.C. branch of the U.S. Geological Survey.

- *Increase capacity for testing through interagency and intersector collaborations.* Standard protocols should be established so that measurements are comparable between sites and of known quality.
- *Reach out to industries that have experience in testing for organic compounds.* These industries also have experience in minimizing exposures. Examples include pesticide companies, confined animal feeding operations, and pharmaceutical companies.
- *Do not permit water withdrawals from streams whose flow is not gauged by the U.S. Geological Survey.*
- *Quantify the proportion of water withdrawal capacity that can be allocated to drillers.* Alternative water sources, such as reclaimed gray water and wastewater, also should be considered.
- *Monitor for surface water discharges around shale gas drilling and processing sites.*
- *Have drillers submit a water resources management plan as part of the permitting process.*

1.5 Air Emissions

Hydrocarbon drilling, processing, storage, and transmission can result in atmospheric emissions of volatile organic compounds (VOCs), including methane. Methane is a powerful greenhouse gas⁷, and leaks of methane gas to the atmosphere as a result of hydraulic fracturing, gas transmission, or storage negatively impact the global climate. There currently is much debate over the approximate percentage of methane that is lost in the gas drilling and transmission processes [23]. Drilling often involves the use of heavy machinery, much of which is powered by diesel engines [24] which emit air pollutants. Each drilling operation involves many truck trips to transport water and materials to the drilling site, negatively impacting local air quality.

The quantity and type of emissions that occur during well completion⁸ can vary and are not well quantified. Potential compounds of concern include, for example, hydrogen sulfide, volatile organic compounds, and other organic compounds such as benzene, toluene, ethylbenzene, and xylene. It is not known to what extent these compounds can volatilize from hydraulic fracturing fluid impoundment ponds.

Coal extracted from the Sanford sub-basin is high in sulfur [25], and it is unknown whether drilling could introduce sulfur compounds into the atmosphere. North Carolina soils also contain radon, and thus hydraulic fracturing potentially could create new pathways for radon to enter the atmosphere.

⁷Methane is 21 times more powerful than carbon dioxide as a greenhouse warming agent on a per-molecule basis [22].

⁸“Well completion” is the process which occurs after drilling in which equipment is put in place to gather the hydrocarbons coming out of the well bore.

1.5 Recommendations:

- *Develop an air monitoring network.* This network should be based on the drilling processes in use and should integrate information from future changes in technology.
- *Establish standards for air sampling and incorporate them into industry best practices.*
- *Use air quality models to estimate regional impacts from distributed pollutant point sources.*

1.6 Employee Exposures

Oil and gas workers face numerous hazards at the job site. Absorption of compounds through the skin is a major exposure pathway for oil and gas workers. Compounds present on clothing, such as lead, also can be hazardous to family members when workers return home. Prolonged exposure to respirable silica, used as a proppant in hydraulic fracturing fluids, can cause silicosis. Workers can be exposed when silica is being offloaded from trucks or moved on conveyers. Traffic and site dust are also contributors to silica exposure.

Hydrogen sulfide gas is another threat to oil and gas workers. This gas is toxic at low levels and can be fatal in high concentrations. Hydrogen sulfide co-occurs with hydrocarbons in some geologic formations, and it is released when so-called “sour gas” is brought to the surface. Bacteria in hydraulic fracturing fluids also can produce hydrogen sulfide, and reusing fluids can increase hydrogen sulfide concentrations in the fluids.

1.6 Recommendations:

- *There should be a site specific safety and health management program developed and implemented on every shale gas extraction site to address hazards, such as but not limited to: occupational exposure to noise; confined space hazards; walking and working surfaces; flammable gases; radioactive materials; and exposure to hazardous chemicals.*
- *Sand-handling equipment designed with engineering controls that prevent the generation of airborne dust or collect dust should be used.* Retrofit engineering controls and dust suppression and collection measures should be used on existing equipment.
- *Worker access to areas where respirable dust may be generated should be limited to only those workers wearing appropriate respiratory protection who are properly trained and medically cleared to do so.* When respirators are used on a shale gas extraction site, a comprehensive respiratory protection program should be developed and implemented^a.
- *Silica sand should be replaced by a product that does not contain quartz.* Silica sand should be prohibited as an abrasive blasting agent.
- *Work site maintenance is a priority.* Because of the complexity of shale gas equipment

and the pace at which the technology is changing, unspecialized workers no longer can perform onsite repairs.

- *Specific safety training is needed.* Rapid technological changes have led to numerous smaller companies providing well site services, some with little safety experience.
- *All injuries should be reported.* Current reporting of nonfatal injuries is incomplete.
- *There should be a competent person or other technically qualified person on site at all times who is responsible for ensuring that worker safety and health policies, practices, and procedures are implemented.*
- *Legislation and best practices should incorporate the best and most current information on shale gas worker safety and injury prevention.* Sources of information include the Occupational Safety and Health Administration^b and The Centers for Disease Control and Prevention^c.

^aThe program should be in compliance with 29 CFR 1920.134, and should apply even if employee exposure is below the permissible exposure limit (PEL).

^bwww.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html

^cwww.cdc.gov/niosh/programs/oilgas/default.html

1.7 Ecosystem Exposures

Shale gas drilling can impact other species and ecological communities. Pet and livestock illness and mortality have been reported near drilling sites in Pennsylvania, Texas, and elsewhere [26]. Drilling can also impact natural ecosystems through chemical exposures and land use changes.

It is important to determine what stressors are most likely to affect ecosystem health, which can help identify which components of an ecosystem are most at risk. Sentinel species, sensitive indicators of ecosystem health, include mussels, amphibians, and benthic macroinvertebrates. Other important species to consider are pollinators and recreational game and fish. Direct chemical exposure is not the only pathway by which natural gas extraction may affect wildlife. For example, in northern New Mexico, noise from natural gas compressor stations has altered bird species abundance toward those better able to communicate in a high-noise environment [27]. Analyses should include direct and indirect exposures⁹, as well as acute and cumulative long-term effects.

The roads, pipelines, well pads, and other infrastructure associated with shale gas extraction can fragment forests and streams [28]. Expansion of sand mines in eastern North Carolina to provide silica for hydraulic fracturing fluids could create further habitat changes.

1.7 Recommendations:

- *Identify which species are most sensitive to chemical exposure.* The N.C. Division of Water Quality's macroinvertebrate monitoring and the N.C. Wildlife Resources Commission's mussel monitoring programs could be expanded to help quantify these poten-

⁹Indirect chemical exposures include contact with compounds that persist in the environment and are transported from the original emissions source. Examples could include drinking water contaminated by gas migrating from a hydraulic fracturing well or breathing air that contains particulates or volatile organic compounds emitted from a drilling site

tial indicator species. Toxicity assessments should be conducted to establish thresholds of concern.

- *Identify which species are most sensitive to habitat loss.* Species distribution within the Triassic Basin is also important.
- *Identify areas that require special protections via setbacks and buffers.* These areas could include conservation lands and wildlife corridors and areas important to resource-based industries such as forestry, agriculture, and fishing. The N.C. Wildlife Resource Commissions Green Growth Toolbox and the N.C. Department of Environment and Natural Resources Conservation Planning Tool could help identify areas that would be most sensitive to land use changes.
- *Monitor ecosystem health.* Baseline ecosystem health information should include pollutant levels in plant and animal tissues and evidence for adverse effects from chemical exposure. The distribution and density of populations, and their organismal pollutant levels, should be remeasured regularly. These measurements should inform future recommendations to further minimize exposure and health effects.
- *Establish numeric quality standards.* These standards should establish acceptable environmental levels of chemicals found in hydraulic fracturing fluids.

Working Group 2: Social Impacts

2.1 Community Needs and Assets Assessment

The primary recommendation to emerge from Working Group 2 was to *create a Community Needs and Assets Assessment (CNAA)*. This document should be created in partnership between a community and local drilling companies before drilling takes place. Such documents are considered an industry best practice. The CNAA should identify methods that the industry can use to communicate the contents of the CNAA to the public. The recommendations presented below are intended to raise awareness of what a CNAA can and should include.

2.2 Economy

2.2.1 Distribution of Costs and Benefits

Much of the gas drilling currently occurring in the United States takes place on privately held property¹⁰. Because terms of leases are negotiated individually, and because not all property is equally suitable for shale gas extraction, income from shale gas is not distributed equally within a community. Inequality, actual or perceived, can lead to tension among residents.

Potential gas-producing areas in North Carolina are fairly rural, and the income from shale gas can be a large boost to the local economy. However, there is potential for shale gas to affect vulnerable populations more acutely than others. Residents in an economically depressed area

¹⁰Even in areas held by the Bureau of Land Management, mineral rights may be held separately from surface rights. For example, 90% of the mineral rights to the Allegheny National Forest in Pennsylvania are held privately [29].

may be more willing to accept oil and gas leases with unfavorable terms than those who have other income sources.

2.2 Recommendations:

- *Fully identify costs and benefits associated with shale gas.* Where a cost-benefit analysis is not possible, case studies drawn from the experiences of other areas can provide insight.
- *Maximize revenue available from industry.* Revenue can be generated through bonding fees on well permits and taxes assessed.
- *Identify what jobs will be available for local workers and how the shift in available workers could affect the local economy.* Unemployment in shale gas areas tends to be low. However, as a result, it can be difficult for some industries to recruit entry-level or unskilled workers [30].

2.2.2 Boom and Bust Dynamic

The sudden influx of economic activity based around a single resource is vulnerable to boom and bust cycles. When resources are exhausted or economic conditions change, jobs can disappear quickly. Natural gas prices are historically volatile [31], and swings in price could affect production, especially in a smaller resource area like North Carolina. Concerns over an end to shale gas booms in other areas have already been expressed [32].

2.2 Recommendations:

- *Build capacity to sustain economic activity.* Lawmakers and area planners should consider cultivating other industries that are less vulnerable to boom and bust cycles to maintain economic activity.
- *Identify where the industry will be operating and for how long.* Communities should prepare for times when industry is no longer present. Planners may have to look ahead decades to prepare for this eventuality.

2.3 Community Identity

2.3.1 Loss of Control over Community Identity

The economic and industrial activity accompanying shale gas could be a rapid and drastic transition for the Sanford sub-basin. This transition can be jarring for residents and can impact their quality of life. Examples of negative experiences resulting from this transition include

- increased truck traffic, resulting in road damage and higher levels of potentially harmful vehicle exhaust;

- disturbances and reduced access to private or public lands. For example, hunters in Pennsylvania have lost access to popular hunting areas on public land because of nearby shale gas extraction [33].

Shale gas can be a polarizing issue. As mentioned above, the land leasing system for shale gas can lead to real or perceived economic disparities among members of a community. The perception of a threat to one's health or environment, based on facts or emotions, can powerfully sway opinion. As a result of these deep divisions, relations within a community can become contentious.

2.3 Recommendations:

- *Communities should maintain control over local quality of life issues*, including local authority over zoning regulations.
- *Develop and promote mediation resources.*
- *Increase support to services that deal with mental health and psychosocial impacts.*

2.3.2 Quality of Life and Environmental Health

Shale gas activities can create odors, light pollution, noise, and dust. These and other environmental health impacts are especially important to consider near schools.

2.3 Recommendations:

- *Identify best practices and regulations to mitigate these impacts.*
- *Develop citizen reporting mechanisms.* These can include phone hotlines or online contact mechanisms, as well as publicly available maps of reported and confirmed violations.

2.4 Community Engagement

Effectively integrating shale gas into a community requires ongoing communication between drilling companies and that community.

2.4 Recommendations:

- *Identify who in the community is affected by shale gas development and who has the jurisdiction to take action.*
- *Create stakeholder forums.* These forums should aim to create two-way dialogs between public policy leaders and affected populations. Efforts should be made to include vulnerable populations in these forums.

- *Offer workshops for government officials.* Local officials should be briefed on what to expect when shale gas enters their community. These workshops would provide an avenue for community leaders to learn from and build on experiences in other areas.
- *Create educational mechanisms for potentially impacted communities.* Topics to discuss with residents include the following: how long the oil and gas industry could be present in the community, potential impacts from shale gas extraction, liability and consumer protection mechanisms, and air and water quality test results and how to obtain them.
- *The state should take the lead in community engagement, while maintaining contact with local officials and industry.*
- *Outreach events should be convened by a credible neutral party and include all stakeholders.*

2.5 Infrastructure

2.5.1 Roads and Vehicle Safety

Hydraulic fracturing of a single well site can require a thousand truck trips to and from the well site. Many roads, especially in rural areas, are not designed to handle this large amount of truck traffic. Roads and bridges can rapidly degrade when engineered capacity is exceeded. Increased truck traffic also can be dangerous for drivers not used to driving in heavy truck traffic.

2.5 Recommendations:

- *Transportation planning agencies should plan ahead for increased traffic and capacity.*
- *New road permitting should be implemented in conjunction with oil and gas well permitting.* Roads necessary to provide supplies to shale gas sites should be included as part of the well site permit. These roads should be adequately engineered during the permitting process to withstand expected truck traffic.
- *Map transportation routes to and from sites.* Identify potential water sources, which could become heavy traffic areas. Understanding truck traffic patterns can help identify roads that are likely to need increased maintenance.
- *Coordinate school bus and trucking routes to separate them.*
- *Implement traffic pattern changes where necessary to protect vulnerable roads.*
- *Add signage to warn drivers of additional hazards.*
- *Widen roads and add pullouts for trucks.* Long trucks may need road modifications to navigate turns.

- *Ensure that industry pays incremental costs of road construction and safety measures.*
- *Trucks should be bonded, signed, and travel only on approved roads.*

2.5.2 Job Opportunities

Shale gas development can create jobs. The oil and gas industry requires many workers, but these workers are not always hired locally because of the need for specific worker training or lack of interest amongst local workers. Many other industries that support shale gas, however, such as trucking, restaurants, gas stations, and hotels, can see large upswings in business.

2.5 Recommendations:

- *Create educational programs to train local workers for available oil and gas jobs.*

2.5.3 Physical Infrastructure

The influx of people associated with shale gas can put increased strain on physical infrastructure, such as municipal water and sewer capacity and facilities.

2.5 Recommendations:

- *Ensure the infrastructure needs of the local community are met.*

2.5.4 Emergency Services

Shale gas extraction can be hazardous to workers. Emergency responders will be called on to deal with situations relating to gas extraction. The large influx of people associated with shale gas also will entail more emergency incidents simply because of the increase in population.

2.5 Recommendations:

- *Shale gas extraction operators should provide the following information to the county and municipality with jurisdiction and to emergency response agencies that have a role under the contingency plan:*
 - information on the nature and type of operations to occur at the facility;
 - identification of the properties of the hazardous materials managed at the facility;
 - a copy of the contingency plan for the facility.
- *Shale gas extraction operators should maintain an up to date record of the quantity, type, location, and hazards of the chemicals used, produced and stored at the facility. This information should be stored offsite, and should be made available to the Department of Environment Health and Natural Resources, any municipality with jurisdiction*

over the site of the facility, and to emergency response agencies that have a role under the contingency plan for the facility.

- *State and local governments should coordinate to map potential hazard areas.* These include well sites and gas transmission pipelines. These maps should be publicly accessible and provided to emergency response system dispatchers and responders.
- *Drilling companies should help provide training to local emergency medical services personnel where needed.* This should include additional training in areas such as hazardous materials and confined space rescue.
- *Fund staff needed to handle increased emergency services capacity.*

2.5.5 Social Services

Rapid population growth can cause strain on many social services. Shale gas can heighten needs for particular social services, such as

- attorneys with oil and gas experience;
- affordable housing supply, especially for transient or temporary residents (Prices for small housing and hotel rates have shot up in many areas of shale gas extraction, as workers without family in the area struggle to find housing [34]);
- schools, which can see a large influx of transient students that are children of oil and gas workers; and
- law enforcement, courts, and correctional facilities.

2.5 Recommendations:

- *Community planners should expand local infrastructure in advance where possible.*

2.6 Landowner and Consumer Protection

Most homeowners in North Carolina have no prior experience with oil and gas development activities and may not be able to fully assess financial and environmental risks associated with shale gas leases. Moreover, there are few lawyers in North Carolina that have experience with the oil and gas industry to provide adequate legal guidance.

2.6 Recommendations:

- *Clarify liabilities of industry and landowner.*
- *Establish insurance mechanisms for property owners.*
- *Fund state laboratories to provide low-cost baseline water and air testing.* Tests that are inexpensive or free provide necessary protections to low-income communities.

Provide education about mineral leases.

- *Create an ombudsman role to facilitate communication among homeowners, industry, and legal representatives.*
- *Invest in databases to compile water testing results and site history. These data sources should be accessible to the public.*
- *North Carolina needs to study the issues of compulsory forced pooling more closely^a.*

^a“Compulsory forced pooling” refers to the practice of requiring homeowners to engage in a gas lease if the owners of many surrounding properties already have done so, subject to certain other conditions as well.

Working Group 3: Health Impacts

3.1 Incomplete Information

Some of the data that are essential for evaluating the potential health risks associated with shale gas are not publicly accessible. For example, state laws vary in the extent to which the chemicals in hydraulic fracturing fluids are disclosed. Animal toxicity studies are typically performed with a single chemical, whereas fracturing fluid can contain many chemicals of varying concentrations.. Without more complete knowledge of the chemicals involved, their concentrations in the fluid, and their toxicity, it is difficult to assess their potential impact on human or animal health.

Other essential data have yet to be collected. Limited epidemiological data exist for populations potentially affected in North Carolina. These datasets are not sufficiently complete to serve as an adequate baseline for assessing future health changes at a population level.

3.1 Recommendations:

- *Leverage existing baseline health data in North Carolina and other states.*
- *Where data are not available, leverage knowledge of known chemicals and their toxicological effects. Health care providers need to learn to identify possible symptoms of exposure to air- or water-borne contaminants from shale gas operations*
- *Improve medical record keeping. Move to electronic record keeping as much as possible.*
- *North Carolina should become part of the Centers for Disease Control and Preventions National Environmental Public Health Tracking Network.*

3.2 Health Impact Assessment

3.2.1 Overview

*North Carolina should conduct a comprehensive Health Impact Assessment (HIA)*¹¹. This assessment should gather available health data about communities in the Sanford sub-basin potentially affected by shale gas. The end product of this process should be a document to guide legislative decision making. An HIA is carried out prospectively and should be initiated during the planning stages of shale gas legislation. An effective HIA should aim to avoid or mitigate future impacts. The HIA should include the entire life cycle of the hydraulic fracturing process and all associated activities.

The HIA should employ a broad definition of health, as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity [35].” A successful HIA should be specific to the local community and should incorporate decision makers and potential stakeholders, including but not limited to property owners, industry, local regulators, local health agencies, and healthcare providers. The HIA can include the health of livestock and wildlife in addition to human health.

3.2.2 Components

- *Local, regional, and state level medical and demographic data.* These include electronic medical records, ideally with accompanying spatial data. Location information is important to determine residents proximity to potential sources of contamination, such as well pads or gas processing facilities. Demographic data can be used to identify potentially vulnerable groups within the population. Existing data sources include N.C. Detect for hospital and emergency room visits, N.C. Occupational Health and Safety for fatalities and catastrophes; N.C. Department of Transportation for road accidents; and workers compensation programs for worker injuries and illnesses.
- *Tracking of health problems encountered in other states.* Monitoring outside of the state could provide early warning of health problems which might occur in North Carolina in the future. Preventive action could then be taken.
- *Exposure information.* The HIA should analyze potential acute and chronic exposure pathways. Cumulative and individual chemical toxicity should be considered, to the extent possible without knowledge of specific chemical contaminant mixtures.
- *Psychological and other stressors.* The HIA should include all factors that could impact community health beyond direct chemical exposure, such as increased road traffic, light and noise pollution, and increased prevalence of sexually transmitted infections.
- *Economic analyses, including costs associated with health impacts.* These additional costs could include, for example, water remediation and increased asthma rates.
- *Common metrics.* Establishing standard metrics enables all parties contributing to the HIA to be on equal footing. These metrics should establish what should be monitored and should be tailored to the goals and priorities of the HIA.

¹¹More information about Health Impact Assessments can be found at www.cdc.gov/healthyplaces/hia.htm

3.3 Ongoing Health and Baseline Trend Analysis

North Carolina currently has limited surveillance for the types of medical conditions most likely to occur as a result of shale gas activities. The large influx of workers associated with shale gas could result in a change in the prevalence of sexually transmitted infections. In the most extreme scenario, if shale gas activities cause an increase in the amount of endocrine-disrupting chemicals in the environment, there could be increases in cancers, birth defects, and developmental disorders. The prevalence of other health conditions not currently being monitored also could change.

Evaluating potential health effects requires metrics that are easily quantifiable, comparable when evaluated by a variety of health care providers, and robust with a limited response rate.

3.3 Recommendations:

- *Use standard survey forms to establish baseline health effects.* These surveys can begin to build a database that will enable long-term tracking of a variety of medical conditions. These forms should be available to local health departments and administered as a routine part of visits at local doctors offices.
- *Use data types that are conducive to database tracking.* Use yes/no questions when possible. Provide units on forms so that all responses are consistent. Provide a standard list of health issues and symptoms that can be selected. Ideally, these data should have location information associated with them so that they can be geo-referenced.
- *Fund and mandate an organization within the N.C. State Center for Health Statistics for baseline health data analysis.*

3.4 Predictive Forecasting

Predictive forecasting prior to drilling should be included as part of a comprehensive HIA. Predictive models exist for risk assessment in situations in which information is limited [36]. These models should be used to capitalize on the predictive power of available data.

Predictive forecasting models should be further improved with follow-up epidemiological studies. To the extent possible, these studies should examine correlations predicted by forecasting models. The goal of subsequent studies should be to revise the predictive model and update the available data.

Predictive models have limitations. Regulators and lawmakers should not rely on models alone without acknowledging the limitations of those models. Moreover, creating such models and doing the field work to validate them requires time and money. These models should be used to the extent that they are helpful in evaluating risk, but their implementation should not delay conducting an HIA before drilling occurs.

3.5 Public Awareness

Education can help ease the transition as a community begins to experience the effects of oil and gas drilling. The more residents know about the potential impacts of shale gas, the better prepared

they are to make informed decisions about whether to lease land to drilling companies. Information should be available about the potential ecological and economic impacts of shale gas. Educational programs also can connect residents with potential avenues of assistance.

3.5 Recommendations:

- *Generate support and gain assistance from local community outlets.* Potential avenues for communication with residents include Area Health Education Centers, the N.C. Cooperative Extension Service, local government Web sites, pharmacy brochures, information in libraries and schools, public service announcements, physicians, programs in retirement communities, and contact with support groups such as the Society of Asthma.
- *Provide pathways for communication among residents, officials, and industry representatives.* Sharing concerns early can help prevent future misunderstandings.
- *Collaborate with existing state agencies and resources.* These include the EPA Region 4 Office of Environmental Justice, the N.C. Division of Public Health Office of Minority Health, Legal Aid of North Carolina, the North Carolina Justice Center for Community Engagement, the Environmental Health State of Practice Committee, the N.C. Medical Society, and the N.C. Institute of Medicine.

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