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IMPACTS OF GAS DRILLING ON HUMAN AND ANIMAL HEALTH

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ABSTRACT

Environmental concerns surrounding drilling for gas are intense due to expansion of shale gas drilling operations. Controversy surrounding the impact of drilling on air and water quality has pitted industry and lease-holders against individuals and groups concerned with environmental protection and public health. Because animals often are exposed continually to air, soil, and groundwater and have more frequent reproductive cycles, animals can be used as sentinels to monitor impacts to human health. This study involved interviews with animal owners who live near gas drilling operations. The findings illustrate which aspects of the drilling process may lead to health problems and suggest modifications that would lessen but not eliminate impacts. Complete evidence regarding health impacts of gas drilling cannot be obtained due to incomplete testing and disclosure of chemicals, and nondisclosure agreements. Without rigorous scientific studies, the gas drilling boom sweeping the world will remain an uncontrolled health experiment on an enormous scale.

Keywords: hydraulic fracturing, shale gas drilling, veterinary medicine, environmental toxicology

> At what point does preliminary evidence of harm become definitive evidence of harm? When someone says, "We were not aware of the dangers of these chemicals back then," whom do they mean by *we*?
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> —Sandra Steingraber, *Living Downstream* (Da Capo Press, 2010)

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Communities living near hydrocarbon gas drilling operations have become de facto laboratories for the study of environmental toxicology. The close proximity of these operations to small communities has created a variety of potential hazards to humans, companion animals, livestock and wildlife. These hazards have become amplified over the last 20 years, due in part to the large-scale development of shale gas drilling (horizontal drilling with high-volume hydraulic fracturing), encouraged by the support of increased drilling and exploration by U.S. government agencies [1]. Yet this large-scale industrialization of populated areas is moving forward without benefit of carefully controlled studies of its impact on public health. As part of an effort to obtain public health data, we believe that particular attention must be paid to companion animals, livestock, and wildlife, as they may serve as sentinels for human exposures, with shorter lifetimes and more opportunity for data collection from necropsies.

All phases of hydrocarbon gas production involve complex mixtures of chemical substances. For example, in hydraulic fracturing fluids, chemical substances other than water make up approximately 0.5 to 1 percent of the total volume; however, the very large volumes used require correspondingly large volumes of a variety of compounds. These substances range from the relatively benign to the highly toxic. Some of these are reported to the public and others are not, but the quantities and proportions used are largely considered trade secrets. In addition to these added chemicals, naturally occurring toxicants such as heavy metals, volatile organics, and radioactive compounds are mobilized during gas extraction and return to the surface with the gas/chemical mix (wastewater); of the 5.5 million gallons of water, on average, used to hydraulically fracture a shale gas well one time [2], less than 30 percent to more than 70 percent may remain underground [3]. Hydraulic fracturing takes place over 2 to 5 days and may be repeated multiple times on the same well over the course of the potential 25- to 40-year lifetime of a well [4]. Many of these chemicals are toxic and have known adverse health effects, which may be apparent only in the long term. A discussion of these compounds and their health effects is beyond the scope of this article; however, Colborn et al. [5] have analyzed this topic in depth.

The large-scale use of chemicals with significant toxicity has given rise to a great deal of public concern, and an important aspect of the debate concerns the level of proof required to associate an environmental change with activities associated with gas drilling. Environmental groups typically invoke the precautionary principle [6]. That is, if an action is suspected of causing harm to the environment, then in the absence of a scientific consensus, the burden of proof falls on the individual or organization taking the action. The oil and gas industry has typically rejected this analysis and has approached the issue in a manner similar to the tobacco industry that for many years rejected the link between smoking and cancer. That is, if one cannot prove beyond a shadow of doubt that an environmental impact is due to drilling, then a link is rejected. This approach by the tobacco companies had a devastating and long-lasting effect on public health from which we have still not recovered [7], and we believe that a similar approach to the impacts of gas drilling may have equally negative consequences.

Although reports of petroleum hydrocarbon exposure in humans [8-14], primates [15], and several other species, including ruminants [16-26], horses [27], wildlife [28], and a dog [29], have been cited in the literature, there are few reports on exposure of animals to gas operations, and to our knowledge, no case reports on exposure of humans to hydrocarbon gas operations [30]. Adler et al. [31] observed aspiration pneumonia in sheep following exposure to gas condensate. In another study, Waldner et al. [32] found no association between the productivity of cattle and exposure to a sour gas pipeline leak; while in a longer-term study [33] in cattle, the same group reported associations between sour-gas flaring and increased risk of stillbirth across three of the four years studied, as well as increased risk of calf mortality in one of the years studied. In a study of habitat selection, Sawyer et al. [34] found that mule deer tended to move away from areas of gas development, and in a recent report [35] from the same author, the deer population dropped by 45 percent in one year, and the survival rate decreased.

Just as epidemiologic studies linked smoking to human health impacts, such studies could be used to assess the health impacts of gas drilling operations on human beings. Studies in laboratory animals have also been a powerful tool for linking components of tobacco smoke to cancer, not only because controlled studies can be done but also because breeding cycles are short and the age at which cancer develops is within a range accessible to laboratory studies. Though such controlled animal studies of the effects of gas drilling are not feasible, animals can nevertheless serve as sentinels for human health impacts. Animals, particularly livestock, remain in a confined area and, in some cases, are continually exposed to an environmental threat. Further, effects on reproduction can be more readily assessed in a herd of cattle than in a human population, simply due to the higher rates of reproduction.

For the past year, we have been documenting cases of animal and owner health problems with potential links to gas drilling. Many cases are currently in litigation. To protect individuals' privacy and due to ongoing legal action, the discussion will not include personal identifying information. We summarize the results of our investigation, provide several case studies, and conclude with recommendations for minimizing or preventing similar problems in the future. This study is not an epidemiologic analysis of the health effects of gas drilling, which could proceed to some extent without knowledge of the details of the complex mixtures of toxicants involved. It is also not a study of the health impacts of specific chemical exposures related to gas drilling, since the necessary information cannot be obtained due to the lack of testing, lack of full disclosure of the International Union of Pure and Applied Chemistry (IUPAC) names and Chemical Abstracts Service (CAS) numbers of the chemicals used, and the industry's use of nondisclosure agreements. Nevertheless, the value of this study is twofold. First, clear health risks are present in gas drilling operations. These cannot be eliminated but can be decreased by commonsense reforms. Second, our study illustrates not only several possible links between gas drilling and negative health effects, but also the difficulties associated with conducting careful studies of such a link. Again, simple commonsense policy reforms could facilitate the collection of data that would lead to a careful assessment of the health consequences of gas drilling on both humans and animals.

SUMMARY OF THE EFFECTS OF GAS DRILLING ON PRODUCTION AND COMPANION ANIMALS AND ANIMAL OWNERS

To describe how exposures may occur, and to report health effects, we conducted interviews with animal owners in six states (Colorado, Louisiana, New York, Ohio, Pennsylvania, Texas) affected by gas drilling. In all but one case, we spoke directly with animal owners. The exception was a case that had previously been documented by the state environmental regulatory agency [36]. When possible, we interviewed the owners' veterinarians. Where available, we have obtained the results of water, soil, and air testing as well as the results of laboratory tests on affected animals and their owners. Documentation was obtained from the animal owners, the veterinarians (with permission of the owners), drilling company representatives, state regulatory agencies, and a Freedom of Information Act (FOIA) request from the Pennsylvania Department of Agriculture. Cases were identified by requesting referrals from environmental groups and individuals actively involved in influencing shale gas policy and studying its effects. For each case, a standard series of questions was asked, including the exact location of each owner's property; details on wells in the area (subsequently verified by crosschecking with state records and, using software developed for this project, mapping the wells relative to the owner's property); details of seismic testing and well flaring; location of wastewater impoundments; results of water, soil, and air testing; details of animal husbandry and medical records preceding, during and following drilling, depending upon the individual case; a list of animals (species, breed, age, sex, use (e.g., livestock)), sorted into those healthy and those unhealthy; health history for all animals; observations of wildlife in the area; and health histories of the humans living in the household. As each case is different, the standard form was used as a starting point, with additional information invariably supplied by individuals being interviewed.

More than one-third of the cases involved conventional wells (shallow or deep vertical wells), with the remainder comprising horizontal wells subjected to high-volume hydraulic fracturing. Because of the scale of the horizontal well drilling operations, such wells were more commonly associated with animal health problems. However, conventional wells have also had problems associated with faulty well casings and failure of blowout preventers; in our study, wastewater dumping and leakage, failure of a blowout preventer, and affected well water involving conventional gas wells were associated with both animal and human health problems.

By the standards of a controlled experiment, this is an imperfect study, as one variable could not be changed while holding all others constant. It also is not a systematic study that will provide the percentage of farms with problems associated with gas drilling, but the design is such that the study can illustrate what can happen in areas experiencing extensive gas drilling. It is also possible to observe temporal correlations between events such as well flaring and air quality, or hydraulic fracturing and water quality leading to toxicity. In two cases, spatial differences (cows in a single herd, with some allowed access to a creek or pond and others not allowed access) could be used to compare outcomes.

Table 1 summarizes the types of wells involved and the sources of exposure, and Table 2 describes the details of each individual case. In some cases, exposure was due to accidents or negligence, but at other times, it was a consequence of normal operations. Direct exposure to hydraulic fracturing fluid occurred in two cases: in one, a worker shut down a chemical blender during the fracturing

Table 1. Number of Cases, by Type of Gas Well and Source of Exposure[a]

Type of gas well	
Shallow vertical wells	4
Deep vertical wells	3
Horizontal high-volume hydraulically fractured wells	18
Source of exposure	
Hydraulic fracturing fluid spill from holding tank	2
Drilling fluids overran well pad during blow out	1
Storm water run-off from well pad to property	3
Wastewater impoundment leak	1
Wastewater impoundment allegedly compromised	1
Wastewater spread on road	2
Wastewater dumped on property	1
Wastewater dumped into creek	3
Wastewater impoundment not contained	3
Well/spring water	17
Pond/creek water	8
Pipeline leak	1
Compressor station malfunction	2
Flaring of well	3

[a]Total number of cases is 24; one case has two types of wells.

Table 2. Summary of Individual Cases

Case	Type of gas well[a]	Source	Animal	Health impact
1	SV	Wastewater dumped on property and into creek	White-tailed deer	Body condition
2	SV	Well/spring water	Bovine	Reproduction, milk production
3	SV	Well/spring water Pond/creek water Drilling fluids overran well pad during blowout	Bovine	Reproduction
4	SV	Well/spring water Pond/creek water Wastewater impoundment allegedly compromised	Bovine Fish	Reproduction, growth Sudden death
5	DV	Well/spring water Pond/creek water	Equine Canine Human	Neurological Urological, gastrointestinal, dermatological Upper respiratory, burning of eyes, headache, gastrointestinal, dermatological
6	DV	Pond/creek water	Bovine	Reproduction
7	DV, HHV	Well/spring water	Canine Poultry Human	Reproduction, dermatological Sudden death, musculoskeletal, dermatological Upper respiratory, burning of eyes, neurological, gastrointestinal, headache
8	HHV	Well/spring water Pond/creek water Wastewater impoundment not contained Wastewater dumped into creek	Song birds Human	Sudden death Neurological, immunological
9	HHV	Pond/creek water Storm water runoff from well pad	Fish	Sudden death

Table 2. (Cont'd.)

Case	Type of gas well[a]	Source	Animal	Health impact
10	HHV	Well/spring water Wastewater impoundment not contained	Ovine Canine Human	Reproduction Sudden death Gastrointestinal, neurological, upper respiratory, burning of eyes, dermatological, vascular, sensory, headache
11	HHV	Wastewater impoundment leak	Bovine	Reproduction
12	HHV	Storm water runoff from well pad	Canine Human	Neurological Gastrointestinal, headache, dermatological
13	HHV	Well/spring water Pond/creek water Pipeline leak	Equine Canine Amphibian Human	Neurological, gastrointestinal, musculoskeletal, upper respiratory Urological, gastrointestinal, musculoskeletal, neurological Sudden death Upper respiratory, burning of eyes, bone marrow
14	HHV	Well/spring water Wastewater spread on road Wastewater impoundment not contained	Canine Human	Reproduction Neurological
15	HHV	Well/spring water	Canine Feline Human	Gastrointestinal, dermatological Dermatological Gastrointestinal, upper respiratory, burning of eyes, vascular, headache

Table 2. (Cont'd.)

Case	Type of gas well[a]	Source	Animal	Health impact
16	HHV	Well/spring water	Llama	Reproduction, upper respiratory
			Human	Endocrine, upper respiratory, burning of eyes, vascular, dermatological, sensory
17	HHV	Well/spring water	Canine	Urological
		Flaring of well	Feline	Gastrointestinal, dermatological
			Human	Upper respiratory, burning of eyes, urological, dermatological, headache
18	HHV	Well/spring water	Ovine	Sudden death
			Poultry	Sudden death
		Storm water runoff from well pad	Human	Vascular, gastrointestinal, headache
		Flaring of well		
19	HHV	Well/spring water	Equine	Reproduction
		Hydraulic fracturing fluid spill from tank	Ovine	Reproduction
			Human	Neurological
		Wastewater dumped into creek		
20	HHV	Compressor station malfunction	Canine	Upper respiratory
		Flaring of well		
			Human	Upper respiratory, burning of eyes
21	HHV	Well/spring water	Bovine	Neurological, reproduction
		Pond/creek water	Equine	Neurological
			Poultry	Sudden death
		Compressor station malfunction	Human	Vascular, immunological
22	HHV	Well/spring water	Ovine	Neurological
			Fish	Dermatological
			Human	Dermatological, gastrointestinal

Table 2. (Cont'd.)

Case	Type of gas well[a]	Source	Animal	Health impact
23	HHV	Well/spring water	Equine	Neurological
		Wastewater spread on road	Canine	Reproduction, gastrointestinal
			Human	Reproduction, upper respiratory, burning of eyes, vascular, sensory, headache
24	HHV	Hydraulic fracturing fluid spill from tank	Bovine	Gastrointestinal, neurological, respiratory, sudden death

[a]SV = shallow vertical well, DV = deep vertical well, HHV = horizontal high-volume hydraulically fractured well.

process, allowing the release of fracturing fluids into an adjacent cow pasture, killing 17 cows in one hour; the other was a result of a defective valve on a fracturing fluid tank, which caused hundreds of barrels of hydraulic fracturing fluid to leak into a pasture where goats were exposed and suffered from reproductive problems over the following two years. Exposure to drilling chemicals occurred during a blowout when liquids ran into a pasture and pond where bred cows were grazing; most of the cows later produced stillborn calves with congenital defects. Exposure to wastewater occurred through leakage or improper fencing of impoundments, alleged compromise of a liner in an impoundment to drain fluid, direct application of the wastewater to roads, and dumping of the wastewater on creeks and land. The most common exposure by far was to affected water wells and/or springs; the next most common exposure was to affected ponds or creeks. Finally, exposures also were associated with compressor station malfunction, pipeline leaks, and well flaring. In addition to humans, the animals affected were: cows, horses, goats, llamas, chickens, dogs, cats, and koi. Other than photographing and recording the presence of dead and dying wildlife (deer, songbirds, fish, salamanders, and frogs) in the vicinity of affected pastures, creeks and ponds, the effect on wildlife has not been well documented.

Because production animals were exposed to the environment for longer periods and in greater numbers than companion animals, and because most of the farms we documented raised beef cattle, cows were represented to a greater extent than other animals. Exposures through well water, ponds, springs, dumping of wastewater into creeks, and spills or leakage of wastewater from impoundments were believed by farmers to result in deaths over time periods typically ranging from one to three days, with cows going down and unable to rise despite symptomatic treatment. The most commonly reported symptoms were associated with reproduction. Cattle that have been exposed to wastewater (flowback and/or produced water) or affected well or pond water may have trouble breeding. When bred cows were likewise exposed, farmers reported an increased incidence of stillborn calves with and without congenital abnormalities (cleft palate, white and blue eyes). In each case, farmers reported that in previous years stillborn calves were rare (fewer than one per year). In most cases where diagnostics were pursued, no final diagnosis was made; in other cases, acute liver or kidney failure was most commonly found. Of the seven cattle farms studied in the most detail, 50 percent of the herd, on average, was affected by death and failure of survivors to breed. In one case, exposure to drilling wastewater led to a quarantine of beef cattle and significant uncompensated economic loss to the farmers.

The most dramatic case was the death of 17 cows within one hour from direct exposure to hydraulic fracturing fluid. The final necropsy report listed the most likely cause of death as respiratory failure with circulatory collapse. The hydraulic fracturing fluid contained, among other toxicants, petroleum hydrocarbons and quaternary ammonium compounds (tetramethylammonium and hexamethylenetetramine). Although petroleum hydrocarbons were reported to be found in the small intestine, lesions in the lung, trachea, liver and kidneys suggested exposure to other toxicants as well, and quaternary ammonium compounds have been described as producing similar lesions [37].

Two cases involving beef cattle farms inadvertently provided control and experimental groups. In one case, a creek into which wastewater was allegedly dumped was the source of water for 60 head, with the remaining 36 head in the herd kept in other pastures without access to the creek. Of the 60 head that were exposed to the creek water, 21 died and 16 failed to produce calves the following spring. Of the 36 that were not exposed, no health problems were observed, and only one cow failed to breed. At another farm, 140 head were exposed when the liner of a wastewater impoundment was allegedly slit, as reported by the farmer, and the fluid drained into the pasture and the pond used as a source of water for the cows. Of those 140 head exposed to the wastewater, approximately 70 died and there was a high incidence of stillborn and stunted calves. The remainder of the herd (60 head) was held in another pasture and did not have access to the wastewater; they showed no health or growth problems. These cases approach the design of a controlled experiment, and strongly implicate wastewater exposure in the death, failure to breed, and reduced growth rate of cattle.

Companion animals were defined as those animals that were kept as pets, and included horses, dogs, cats, llamas, goats, and koi. Companion animal exposures typically occurred when animals ingested affected water from a well, spring, creek or pond. Reproductive problems (irregular cycles, failure to breed, abortions, and stillbirths) and neurological problems (seizures, incoordination, ataxia) were the most commonly reported. Other commonly reported symptoms included those of gastrointestinal (vomiting, diarrhea) and dermatological (hair and feather loss, rashes) origin.

In the majority of cases, owners of animals were exposed upon using their well or spring water for drinking, cooking, showering and bathing. Upper respiratory symptoms (including burning of the nose and throat) and burning of the eyes were the most commonly reported. Headaches and symptoms associated with the gastrointestinal (vomiting, diarrhea), dermatological (rashes), and vascular (nosebleeds) systems were commonly reported.

CASES ILLUSTRATING THE EFFECTS OF GAS DRILLING ON PRODUCTION AND COMPANION ANIMALS AND THEIR OWNERS

Case 1

Two homes (A and B) are located within two miles of approximately 25 shale gas wells. The closest pad, drilling muds pit, and wastewater impoundment are within one mile of both homes; the impoundment is approximately 4.5 acres in area and is at a higher elevation than either home. Two compressor stations are located within one mile of both homes. The owners have a variety of companion and farm animals, and reported no unusual pet morbidity or mortality preceding drilling operations. Predrilling tests on water sources were not done for either home. Soon after drilling began, the owner of Home B noted that her well water had an odor and black sediment, and the owners of Home A observed a decreased quantity of their water sources (a well and a spring). Once the wastewater impoundment was constructed, the owners of Home A noted a dramatic decrease in quantity, as well as poor quality, of both the well and spring water. The spring served as the sole source of water for the owners' farm animals. Approximately nine months after drilling began, the owners of Home A began hauling water from a nearby creek, to supplement the spring water.

Since drilling operations began, both owners have observed wastewater being spread on the roads during all weather conditions, and noted that cats and dogs in their neighborhood licked their paws after walking on the road, and also drank from wastewater puddles; some of these animals became severely ill and died over a period of one to three days following these exposures. According to the owner of Home B, the wastewater impoundment was not initially fenced and animals had direct access to the wastewater. An accident involving the wastewater impoundment was noted by both owners; after filling, a truck carrying wastewater drove away from the impoundment site with an open valve, releasing approximately 20 gallons of wastewater onto the impoundment access road and onto the road near the property of Home A. Most recently, both the drilling company and the state environmental regulatory agency were notified of a spill from the wastewater impoundment that flowed past temporary barriers and into a creek; based on soil erosion patterns, the owners of Homes A and B reported that this spill had been ongoing for months. Soon after this accident, a malfunction occurred in the wastewater impoundment aeration system, producing a raw sewage smell that persisted in the air around Homes A and B for days and sickened the families in both homes. When the owner of Home A complained, the drilling company offered to pay motel expenses for her and her family; this offer was declined because the owner refused to leave her animals.

Approximately a year after drilling began, an 18-year-old intact female American Quarter Horse in Home A had an acute onset of anorexia, malaise, rapid weight loss, and mild incoordination after testing normal on a physical examination a few weeks earlier. The horse was treated symptomatically with an antibiotic, steroid, and antihistamine. A few days later, the horse had become ataxic, and was treated for equine protozoal myeloencephalitis, although no diagnosis was made. The horse did not improve after three to four days and was treated again. Within a few days, the horse's neurological symptoms had progressed such that the horse was unable to rise. Blood and clinical chemistry parameters indicated acute liver failure due to toxicity. The veterinarian suspected heavy metal poisoning as a cause of the horse's sudden illness; this was not confirmed, as toxicology tests were not done. The horse was euthanized two weeks after onset due to poor prognosis and failure to respond. Similar neurologic signs were reported in another case in this study that involved two horses living adjacent to a deep, vertical gas well operation.

In addition, both homeowners were caring for animals that were bred at this time: the owner of Home B had a three-year-old intact female Boer goat that aborted two kids in the second trimester, and the owners of Home A had a five-year-old intact female Boxer that experienced dystocia with a fourth litter (after previously whelping three normal litters), producing one stillborn pup and one pup with cleft palate that died soon after birth. This same dog subsequently whelped a fifth litter of 15 pups in which seven pups were stillborn and eight pups died within 24 hours. All the pups were afflicted with congenital hypotrichosis; that is, they were born with the complete or partial absence of normal hair.

Soon after drilling and hydraulic fracturing began for the first well, a child living in Home B began showing signs of fatigue, severe abdominal pain, sore throat, and backache. Six months later, the child was hospitalized with confusion and delirium and was given morphine for abdominal pain. After the deaths of several animals as cited above, the child's physician suspected that the child's symptoms were of toxicological origin. A toxicology test revealed arsenic poisoning as the cause of the child's sickness. The family stopped using their well water despite test results indicating that the water was safe to drink, and the child gradually recovered after losing one year of school.

During high-volume hydraulic fracturing, substances that occur naturally in the shale, including arsenic, come to the surface in wastewater. In this case, the wastewater was stored in the impoundment, where aerators misted the chemicals into the air, increasing the chances of inhalation by animals and people; also, surface spillage of wastewater, as noted above, could have contaminated the ground water. Tests on well water from both Homes A and B, and the spring from Home A, did not show elevated levels of arsenic; however, it is possible that, given fluctuations in the water table and water quality, high levels of arsenic may have initiated symptoms in the child in Home B and then dropped to low levels before water testing was done more than one year later. Also, reported arsenic levels may be deceptively low because arsenic can be converted to arsine-a toxic gas that dissipates rapidly [38]. In people, both acute and chronic oral exposure to inorganic arsenic causes gastrointestinal effects as well as effects on the nervous system: short-term effects include headaches, weakness, and delirium, while long-term effects include peripheral neuropathy [39]. Acute exposure of people to arsine can produce many effects including abdominal pain and headaches [39]. Animals exposed acutely to inorganic arsenic may show many symptoms including staggering gait, extreme lethargy, and intense abdominal pain, while animals exposed over a longer period of time may manifest signs including anorexia, depression, and partial paralysis of the rear limbs [40]. Animal studies show that arsenic can also cause fetal malformations and fetal death [41].

As the family in Home B continued to be screened for toxicants, random urine tests on all family members were positive for phenol, a metabolite of benzene, with dramatic increases over a period of a few months. Based on occupational health studies [e.g., 42], the testing laboratory judged these results to be consistent with chronic exposure to 0.5 to 4.0 ppm benzene in the air. The most recent symptoms observed by families in both homes include extreme fatigue, headaches, nosebleeds, rashes, and sensory deficits (smell and hearing). The child in Home B also had difficulty breathing, and again had to be taken out of school. Doctors of the families in both homes warned them to leave their homes for at least 30 days or suffer more severe health consequences. The owner of Home B followed her doctor's advice, and moved her children out of her home, returning each day to care for her animals; the owners of Home A elected to remain at their home to care for their animals. After one month of being away, the phenol levels as well as the symptoms of the children in Home B decreased, while the owner of Home B, who returns to the home for a few hours each day, has increased phenol levels and worsening of symptoms. One of the owners in Home A, who works at home, has experienced worsening of symptoms.

This case illustrates the importance of considering both animal and human health. Animals live among us and are exposed to the same environmental influences; however, they tend to suffer more direct exposure and have shorter life and reproductive cycles. If it were not for the numerous deaths of animals soon after shale gas operations began in this neighborhood, the child's doctor might not have ordered toxicology tests, as arsenic poisoning is not a common diagnosis.

Case 2

In this case, a beef cattle farmer had a herd of 96 cattle (Angus Limousine cross) that was divided among three pastures. The farm is located in an area of intensive gas drilling, with two active shallow vertical gas wells on the farmer's property and approximately 190 active gas wells within five miles of the property; of these, approximately 11 are shale gas wells and approximately 26 are deep vertical gas wells. In one pasture, 60 cows (a mixed herd, mostly 5- to 10-year-old bred cows) had access to a creek as a source of water. In a second pasture, 20 cows (bred yearlings) obtained water from hillside runoff, and in a third pasture, 14 feeder calves (8 to 14 months old) and two bulls had access to a pond. Over a three-month period, 21 head from the creek-side pasture died (17 adult bred cows and 4 calves). All the cattle were healthy before this episode. Despite symptomatic treatment, deaths occurred 1 to 3 days after the cows went down and were unable to rise. Basic diagnostics were done, but no cause of death was determined. On rendering, 16 of the 17 adults were found to have dead fetuses, nearly doubling this farmer's losses. Of the 39 cows on the creek-side pasture that survived, 16 failed to breed and several cows produced stillborn calves with white and blue eyes. The health of the cattle on the other two pastures was unaffected; on the second pasture, only one cow failed to breed. Historically, the health of the herd was good, the farmer reporting average losses of 1-2 cows a year in his herd of nearly 100 cattle.

This is an interesting case because it has a natural control group. That is, the cattle that were kept along the creek suffered severe problems while the cattle in pastures at a higher elevation and away from the creek experienced no morbidity or mortality. As discussed below, the contamination of the creek may have been caused by illegal dumping of wastewater. Fortunately, these cows were not taken to slaughter, as they died on the farm. However, they still may have entered our food chain as well as that of our pets: rendering plants produce feed for many non-ruminants including chickens, pigs, cats, dogs and horses, so it is possible that chickens, raised for egg production or meat, and pigs were fed the flesh from these cattle.

Case 3

This case concerns farmers that have raised beef cattle (Herford Simmental cross) for the past 21 years. Before drilling operations began the farmers lost one or two animals out of a closed herd of 33 (yearlings, heifers, mature cows, two bulls) every few years to illness or accident. There is one active shale gas well on the farmers' 530-acre property, and approximately six active shale gas wells within two miles of their property. A private well provides water for the family's use; the water for the herd comes from a creek that originates from springs above and below the well pad, and spillover from a pond below the well pad. The gas wellhead is 300 feet from the farmers' house and 250 feet from their water well. The well pad is 75 feet from their barn at higher elevation, and slopes directly down to the door. A one-acre impoundment, used to collect wastewater from the high-volume hydraulic fracturing operations, and a 1/3-acre drilling muds pit, used to collect the chemicals and fluids brought to the surface during drilling operations, were both within 350 feet of the farmers' water well, and within 200 feet of the creek and the pond where the cattle drink.

Soon after hydraulic fracturing operations concluded, the farmers noticed that on the far bank of the wastewater impoundment, two dark spots could be seen adjacent to a 20-acre cow pasture. According to the farmers, these two spots were a concern as they grew in size from day to day; approximately one month after first observing these spots, the farmers found ankle-deep water in one-third of an acre of the pasture with the wet area extending another one-quarter of an acre into the pasture; the pasture grass in these areas appeared to be burned. Fearing their herd drank the wastewater, they voluntarily quarantined their farm and notified the state environmental regulatory agency.

According to the farmers, drilling company workers informed them that the liners of both the wastewater impoundment and the drilling muds pit had two-foot tears, and that the tear in the liner of the wastewater impoundment had caused the leak into the cow pasture. Except for the two bulls, the entire herd was exposed to the wastewater leakage.

Four notices of violations were issued to the drilling company by the state environmental regulatory agency: failure to notify the agency, improperly lined impoundment (pressure testing of liner revealed a failed patch), pollution of a spring and farm pond due to leakage of the impoundment, and mismanagement of residual waste (wastewater leaked from the impoundment onto the ground and surfaced in an adjacent pasture).

Testing of the wastewater in the impoundment indicated the presence of calcium, iron, magnesium, manganese, potassium, sodium, strontium, fluoride, chloride, sulfate, and bromide; there was no reported testing for any organic compounds. Strontium was of most concern: it can be toxic to both animals and people because it replaces calcium in bone, especially in the young, and because it may take years to be eliminated from the body [43]. The state environmental regulatory agency placed a quarantine on the herd such that mature cows would be held from slaughter for six months, yearlings would be held for nine months, calves exposed in utero would be held for eight months, and growing calves would be held for two years. Six of the exposed cows eventually went on to slaughter, and, according to the farmers, there was no testing before or after slaughter.

Pre-drilling tests were not done on any of the cattle’s sources of water; post-drilling tests were done and revealed no significant findings. Soil tests done on the cow pasture contaminated by the leaked wastewater revealed high levels of chloride, sulfate, sodium, and strontium when compared to background samples. The liners from both the wastewater impoundment and drilling-muds pit were removed, the affected soil removed, and areas remediated; sulfate concentrations remained at high levels in the cow pasture despite remediation.

During the spring of the first calving season following the leakage of wastewater into their cow pasture, the farmers lost two calves: one calf was aborted late-term, and the other calf lived for approximately seven days before dying [44]; both calves were exposed in utero to the wastewater. In the second calving season post-drilling, the farmers lost 11 out of 17 calves: seven were stillborn, three died a few months after birth and one was born alive but severely ill; the dams of all the calves had previously been exposed to the wastewater. The severely ill calf and a stillborn calf were sent for necropsy: the ill calf was diagnosed with *E. coli* septicemia, and the stillborn calf was diagnosed with goiter (diffuse thyroid hyperplasia); both calves were also diagnosed with low liver vitamin E and selenium.

This case illustrates several important points. First, the testing was not complete. According to the farmers, they were not informed of the chemicals used during either drilling or hydraulic fracturing operations. Testing of the water well and cattle's sources of water excluded organic compounds except for a pasture spring; the wastewater analysis also excluded organic compounds. No toxicology tests were done on live cattle, and the tests at necropsy omitted volatile organic compounds, endocrine disruptors, and many minerals present in the wastewater. The cattle's sources of water were tested only after the farmers lost many calves. Soil tests were not done in the area affected by the leakage of the drilling-muds pit. Second, the cattle were exposed to sulfate in the wastewater for at least one month and to elevated sulfate in the grass and soil [45, 46] for over a year. Studies show that increasing dietary sulfur decreases the bioavailability of selenium [47-50], and that Vitamin E and selenium deficiency is associated with reproductive failure in cattle [51, 52]. Third, the liner tear and subsequent leakage of drilling fluids onto the farmers' land were not considered a potential problem and not officially recorded as a violation by the state environmental regulatory agency. Due to gas drilling operations on their property, the farmers now have 26 head of cattle instead of 33, and have lost 40 to 50 acres of hayfields. These farmers received no compensation from the drilling company for the loss of their animals, damage to their land, or the treatment of the animal health problems they have encountered since gas drilling began.

DISCUSSION

The most striking finding of our investigations was the difficulty in obtaining definitive information on the link between hydrocarbon gas drilling and health effects. However, the results point to a number of ways policies can be changed to facilitate better data collection and to avoid obvious risks to animal and human health.

Practices for Providing Better Assessment of Health Impacts

Nondisclosure Agreements

Nondisclosure agreements between injured parties and corporations make it difficult to document incidents of contamination. Compensation in the form of cash, payment for all settlement expenses, an offer to buy the property and/or payment for medical expenses in exchange for a nondisclosure agreement prevents information on contamination episodes and health effects from being documented and analyzed. Nondisclosure agreements are common in all areas of business and are often essential to protect intellectual property. However, when documentation of health problems associated with gas operations is shielded from public scrutiny by a nondisclosure agreement, this is clearly a misuse of this important business tool and should be prohibited. Likewise the lack of prior testing of air and water, and of follow-up testing during drilling and after incidents of suspected contamination, impedes the analysis of health impacts. Even when testing is done, the results are being withheld from interested parties either by government agencies (e.g., by incomplete responses to FOIA requests) or by the industry. If the industry, government agencies, and the public truly want the facts, then appropriate testing must be done, and full disclosure of all data associated with both baseline and incidents of suspected contamination must be made. Without full disclosure of all facts, scientific studies cannot properly be done. Science should drive decisions on whether or not to use a practice such as shale gas drilling, and until scientific studies can proceed unimpeded, then an accurate assessment cannot be made.

Food Safety

A major problem is the lack of federal funding for food safety research. We documented cases where food-producing animals exposed to chemical contaminants have not been tested before slaughter and where farms in areas testing positive for air and/or water contamination are still producing dairy and meat products for human consumption without testing of the animals or the products. Some of these chemicals could appear in milk and meat products made from these animals. In Case 3, a quarantine was instituted after cattle were exposed to wastewater. However, basic knowledge, such as hold times for animals exposed to chemical contaminants as a result of gas operations, is lacking, and research in this area is desperately needed to maintain an adequate level of food safety in our country [53]. Without this information, contaminants in the water, soil and air from gas drilling operations could taint meat products made from these animals, thus compromising the safety of the food supply.

Routes of Exposure

The major route of exposure in the cases documented here is through water contamination. This is perhaps the most obvious problem (seen in all three case studies), but other routes of exposure are of serious concern. Soil contamination can be significant in situations such as that described in Case 3. Although the cases we have documented thus far include only a handful of exposures through affected air, the actual incidence of health effects may be underestimated due to a lack of air sampling. In Case 1, toxicological testing suggested high levels of ambient benzene due to a nearby impoundment pond, but air canister tests were not done at the time. Neither drilling companies nor state environmental regulatory agencies routinely offer air canister tests as a part of testing protocols, and due to the expense, many property owners are reluctant to pursue them on their own. Nevertheless, the effects of air pollution on cardiovascular and respiratory health have been well documented [54], and we believe that exposure to contaminated air may contribute significantly to the health problems of both people and animals living near gas drilling operations. In several cases where air monitoring was done, the results confirmed the presence of carcinogens commonly known to originate from gas industrial processes such as exploration, drilling, flaring, and compression. Thus, the Environmental Protection Agency (EPA) must include a study of air in its congressionally mandated hydraulic fracturing study [55] if it is to be complete.

Testing

The most important requirement for an assessment of the impact of gas drilling on animal and human health is complete testing of air and water prior to drilling and at regular intervals after drilling has commenced. This includes chemicals used in the drilling muds, fracturing fluid and wastewater (the latter contains heavy metals and radioactive compounds normally found in a particular shale [56]). Currently, the extent of testing (particularly for organic compounds) is frequently inadequate and limited by lack of information on what substances were used during the drilling process. In a number of the cases that we have studied, drinking water is clearly unsuitable for human and animal consumption, based not only on the smell and turbidity, but also on pathological reactions to drinking the water. Nevertheless, because of inadequate testing, the water is deemed fit for consumption and use, and neither bottled water nor the large plastic containers known as “water buffaloes” are typically provided for the affected individuals-and even less commonly for animals living on those farms. In Case 1, water was reluctantly provided for the humans (after considerable effort) but not to the animals living on the farm. Even when identified, the health effects of chemicals associated with the drilling process are unknown in many cases. No Maximum Contaminant Levels (MCLs) have been set by the EPA for many of the compounds used, and those that have been set are based on older data that does not take into consideration effects at significantly lower concentrations (e.g., endocrine disruption [5]). Furthermore, the disclosure of all chemicals involved in the drilling and hydraulic fracturing processes is not required if a component can be justified as a "trade secret." In order to be complete, air, soil and all sources of potable water used for humans and animals in the vicinity of a well site (at least within 3,000 feet for soil and water tests [57], and five miles for air monitoring, based on dispersion modeling of emissions from compressor stations [58]) must be tested for all components that are involved in drilling and are likely to be found in wastewater, before any work on the site commences. Sampling must then be repeated at intervals following the commencement of drilling as well as upon suspicion of adverse effects. The following practices must be part of a testing protocol:

1. The sampling must be done by a disinterested third party with a clear chain of custody between sampling and testing. A certified independent laboratory must do the testing, and the results must be available to all interested parties.
2. All chemicals (with IUPAC names and CAS numbers) used in the hydraulic fracturing fluid at any concentration for each well must be disclosed to the property owners within a five-mile radius, testing laboratories, local governments, and state agencies. Material Safety Data Sheets (MSDSs) for each chemical and chemical mixture must accompany this disclosure. Following this procedure will allow prior testing to be targeted to specific chemicals to be used in the drilling process for a specific well, as well as providing valuable information to first responders and hospital personnel in the case of an accident.
3. Upon suspicion of adverse health effects, testing must include air, soil, wastewater, all sources of drinking water, and blood, urine and tissue samples from affected animals and humans. If methane is present in drinking water, isotopic analysis to determine the origin (thermogenic vs. biogenic) must be done.
4. As illustrated by several cases we documented, air canister tests are essential. This must be done as a baseline before drilling begins and during and after well flaring. It must also be done after a wastewater impoundment and a compressor station have been established.
5. Any fracturing fluid chemicals and chemicals released from the shale that are known or possible human carcinogens, are regulated under the Safe Drinking Water Act, or are listed as hazardous air pollutants under the Clean Air Act must have MCLs, which are set by the EPA. Many of the chemicals to which both people and animals are exposed as a result of high-volume hydraulic fracturing are not listed as primary contaminants, and thus have no enforceable MCL. More than half of the chemicals listed as toxic chemicals in a recently released U.S. House of Representatives report [59] have no MCL.

6. All testing expenses must be a part of the cost of doing business for gas drilling companies.

Testing before and during drilling operations is an important part of documenting health effects. If health effects are related to a chemical pre-existing in a pond or well, this would prevent a false association between drilling and water contamination. Alternatively, if a change in chemical composition is correlated to health changes, then a strong justification for compensation is provided. In numerous cases that we documented, compensation was not provided because adequate prior testing had not been done. By doing complete testing, at the proper times, a clear scientific justification can be made for providing or denying compensation. Beyond that, a better understanding of what practices lead to water contamination can be obtained. This will be a benefit to people living in the midst of shale gas drilling and will, in fact, benefit the industry by providing consistent and useful data to guide operations. The current practice of under-testing and denying any link between drilling and water, air, or soil contamination is beneficial to neither the public nor the industry.

Practices for Avoiding Animal and Human Exposure to Environmental Toxicants

As shale gas drilling expands across the northeastern United States, exposure of animals and humans to environmental toxicants can result from negligence, illegal actions, catastrophic accidents (at drilling pads or compressor stations), or normal operations. Negligence and illegal actions are difficult to prevent and may have contributed to the health problems we documented. Suspected illegal dumping of wastewater and the alleged compromise of the liner of a wastewater impoundment were most likely responsible for cattle deaths in two instances that we studied. Cases of alleged wrongdoing [60] illustrate the vulnerability of agricultural operations in the midst of large volumes of toxic waste. Dumping and other intentional violations are difficult to prevent or regulate given the large numbers of small companies involved in servicing drilling operations and the lack of willingness and funding on the part of state environmental regulatory agencies to investigate and fine the gas industry. The prevalence of small subcontractors increases the possibility that best practices will not be followed due to inadequate training and supervision.

Although accidents might be minimized with strict safety standards and careful inspection, regulatory agencies would require sufficient staff to monitor operations. This is obviously not the case in Pennsylvania, where 666 environmental health and safety violations have been reported in 2011 as of June [61]. With a staff of 37 inspectors [62] and 64,939 active wells (as of December, 2010), regulatory oversight is essentially impossible. The situation is even worse in New York State, where only 16 inspectors are currently on the staff of the Department of Environmental Conservation. Although the number of staff positions required to police this industry adequately would necessarily be very large, hiring of new inspectors is essential if environmental and health damages are to be minimized. New York, Pennsylvania, and Iowa are the only active drilling states that have no severance tax for drilling operations. A severance tax could fund additional inspectors and help insure compliance with existing regulations, although this will require the political will to levy a tax sufficient to fund the required number of inspectors. Given the high probability that accidents will happen [63], increasing setbacks between homes, barns, schools, ponds, and streams would provide some additional security. The current regulation in Pennsylvania is a setback of 200 feet from water supply springs and wells, 100 feet from surface water bodies, and 200 feet from wetlands. The revised draft supplemental generic environmental impact statement in New York indicates a 500-foot setback from private water wells. Increasing these setbacks 5- to 10-fold would decrease but not eliminate the impacts of accidents such as the April 20, 2011 spill in Bradford County, PA [64]. Contamination of the air by compressor station blowouts and contamination of streams leave an imprint that cannot be easily mitigated by even the most stringent setbacks.

Normal practices can be modified to reduce but not eliminate exposure of humans and animals to toxicants associated with gas drilling. One of the important problems associated with shale gas drilling is the huge volume of wastewater generated. This wastewater, which includes flowback and produced water, contains at different times in the process the chemicals used in the hydraulic fracturing fluid as well as compounds and minerals extracted in the fluid flowing back with hydrocarbon gas. The materials extracted from underground can be equally or more toxic than the hydraulic fracturing fluid, and include radioactive material (e.g., radium-226, radon-222, and uranium-238), arsenic, lead, strontium, barium, benzene, chromium and 4-nitroquinoline-1-oxide [56]. However, despite the actual toxicity of this material, according to the EPA, "drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of . . . natural gas" are considered "solid wastes which are not hazardous wastes" [65]. This allows the substances to be spread on roads as deicing solutions and as solutions to minimize dust and sets up a potentially lethal threat, particularly to companion animals, wildlife, and children. Typically these solutions contain high salt concentrations and attract dogs and cats, as was illustrated in Case 1. This hazard can be easily mitigated by not allowing wastewater to be spread or sprayed on roads.

Before wastewater is removed from a drilling site, it is often stored in large impoundments (sometimes serving multiple well pads) where the volume is decreased by evaporation. This increases the concentration of some toxic substances in the impoundment (salts, heavy metals) and also introduces other toxicants into the atmosphere (e.g., volatile organics such as benzene and toluene). In addition, impoundments are associated with a number of deaths of both cattle and wildlife [66]. These effects raise the question of whether wastewater should be stored in open impoundments. Whereas this may be economically advantageous to the drilling company, the environmental and agricultural impacts are too great to allow this practice to continue. In Pennsylvania, some progress has been made in recycling increasing fractions of the wastewater. This decreases the total volume of wastewater but increases its toxicity due to the successive increase in the concentrations of total dissolved solids. The alternative is to store wastewater in metal containers at the drilling site before it is removed for disposal.

Finally, the disposal of wastewater presents significant environmental risks. Cases of alleged dumping of untreated wastewater in streams have been documented in the press (e.g., [60]). In the southwestern United States, wastewater is disposed of in injection wells; however, the prevalence of nonporous sandstones and shales in Pennsylvania and New York State largely precludes the use of disposal wells. An earthquake of magnitude 3.2 was associated with injection into a hydraulically fractured vertical well on February 3, 2001 near Avoca, New York [67], suggesting that seismic considerations may further limit the development of injection wells in New York State. Similar seismic occurrences in other parts of the country, most recently in Ohio [68], may mean that New York and Pennsylvania will have fewer options for disposal of wastewater due to shale gas drilling. In May 2011, a voluntary moratorium was placed on the acceptance of hydraulic fracturing wastewater at sewage treatment plants in Pennsylvania. These plants are not equipped to handle either the radioactive and toxic compounds or the high salt content of this waste, and the increased use of recycling has magnified the problem. Discharge of water treatment plants into the Monongahela River led to the contamination of drinking water in Pittsburgh in 2010 [63]. Sewage treatment plants clearly are not a viable option for disposal of wastewater, and despite the industry's progress in recycling, suitable injection wells are unlikely to be located to support the scale of drilling planned in Pennsylvania and possibly New York State.

CONCLUSION

Animals, especially livestock, are sensitive to the contaminants released into the environment by drilling and by its cumulative impacts. Documentation of cases in six states strongly implicates exposure to gas drilling operations in serious health effects on humans, companion animals, livestock, horses, and wildlife. Although the lack of complete testing of water, air, soil and animal tissues hampers thorough analysis of the connection between gas drilling and health, policy changes could assist in the collection of more complete data sets and also partially mitigate the risk to humans and animals. Without complete studies, given the many apparent adverse impacts on human and animal health, a ban on shale gas drilling is essential for the protection of public health. In states that nevertheless allow this process, the use of commonsense measures to reduce the impact on human and animals must be required in addition to full disclosure and testing of air, water, soil, animals, and humans.

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