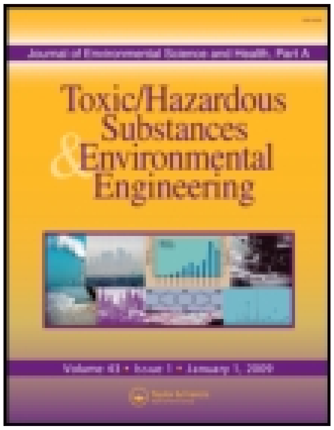

Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lesa20

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Published online: 03 Mar 2015.

To cite this article: Michelle Bamberger & Robert E. Oswald (2015) Long-term impacts of unconventional drilling operations on human and animal health, Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 50:5, 447-459

To link to this article: http://dx.doi.org/10.1080/10934529.2015.992655

Journal of Environmental Science and Health, Part A (2015) **50**, 447–459

ISSN: 1093-4529 (Print); 1532-4117 (Online)
DOI: 10.1080/10934529.2015.992655

Long-term impacts of unconventional drilling operations on human and animal health

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Public health concerns related to the expansion of unconventional oil and gas drilling have sparked intense debate. In 2012, we published case reports of animals and humans affected by nearby drilling operations. Because of the potential for long-term effects of even low doses of environmental toxicants and the cumulative impact of exposures of multiple chemicals by multiple routes of exposure, a longitudinal study of these cases is necessary. Twenty-one cases from five states were followed longitudinally; the follow-up period averaged 25 months. In addition to humans, cases involved food animals, companion animals and wildlife. More than half of all exposures were related to drilling and hydraulic fracturing operations; these decreased slightly over time. More than a third of all exposures were associated with wastewater, processing and production operations; these exposures increased slightly over time. Health impacts decreased for families and animals moving from intensively drilled areas or remaining in areas where drilling activity decreased. In cases of families remaining in the same area and for which drilling activity either remained the same or increased, no change in health impacts was observed. Over the course of the study, the distribution of symptoms was unchanged for humans and companion animals, but in food animals, reproductive problems decreased and both respiratory and growth problems increased. This longitudinal case study illustrates the importance of obtaining detailed epidemiological data on the long-term health effects of multiple chemical exposures and multiple routes of exposure that are characteristic of the environmental impacts of unconventional drilling operations.

Keywords: Companion animals, epidemiology, food animals, health impacts, hydraulic fracturing.

Introduction

The expansion of unconventional oil and gas extraction into populated areas and farmland has brought increasing attention to the public health impacts of this heavily industrialized process. A detailed risk assessment is hindered by a number of factors. First, possible chemical exposures cannot be definitively assessed because the identity of all compounds released into the environment is not routinely available, and the concentrations and mixtures can vary over time and over pathways of exposure. Even when compounds are clearly identified in the environment, the effects of mixtures of compounds and the effects at low concentrations are poorly understood.

Furthermore, intensively drilled areas have multiple well pads closely spaced (relative to possible chemical exposures) so that the risk cannot be modeled as a simple point source but rather must be considered as multiple point sources of variable and largely unknown risk. Because tight oil and shale gas extraction has proceeded into populated areas without a full assessment of the risks, humans and animals living in intensively drilled areas have inadvertently become biological integrators of the chemicals released by this industry. For these reasons, an epidemiological approach that analyzes the health effects on humans and animals in proximity to gas and oil extraction and processing has a great deal of potential for understanding possible risks. However, analytic epidemiology requires specific hypotheses to test in a quantitative manner.

To generate these hypotheses, a phase of descriptive epidemiology is required. That is, a limited number of cases are analyzed in detail in order to describe potential health impacts and generate hypotheses for more quantitative analysis. Our 2012 study[1] of 24 cases of animal and human health problems in the vicinity of oil and gas extraction was an attempt to generate hypotheses for further analytic epidemiological studies of this process. A common thread in the studies of both companion and production animals was the effects on the reproductive system of animals exposed to chemicals associated with the drilling and production processes.

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In an investigation of chemicals associated with drilling and hydraulic fracturing, Colborn and collaborators[2] have identified an extensive array of substances that could function as endocrine disruptor chemicals (EDCs). This is of particular interest because reproductive failure could be a result of toxicants that interact with endocrine receptors. Recently, Nagel and collaborators[3] have used biological assays to detect the presence of agonists and antagonists of estrogen and androgen receptors in water derived from intensively drilled areas, suggesting the presence of EDCs at biologically relevant concentrations. Water derived from areas of little extractive activity showed little or no activity on these receptors. Likewise a recent study[4] of dolphins from Barataria Bay, Louisiana, which was heavily affected by the Deepwater Horizon oil well blowout, showed significant endocrine abnormalities, in addition to a wide range of other health problems. Thus, although effects on other systems may be equally important, endocrine-mediated health impacts do seem to be associated with oil and gas exploration.

Although the effects of drilling are often seen first in animals, perhaps due to more constant exposure to toxicants, the people living in intensively drilled areas also have reported significant health effects, as noted in our study[1] and confirmed by several other studies.[5–7] In addition to studying health impacts, Ferrar et al.[5] showed that reported symptoms increased over time and clearly demonstrated the need for close monitoring of public health in communities where unconventional extraction is occurring.

Because health effects can vary over time as do exposures, we obtained follow-up information on several case studies reported in our first article as well as a number of cases that we studied following that publication. The overall question was whether health impacts have changed over time and whether that correlated with an increase, decrease, or no change in oil and gas industrial activity. Overall, symptoms have improved for families moving out of affected areas and those living in areas where the industrial activity has decreased. The findings of this and our previous study provide the basis for a more quantitative epidemiological study of the health impacts of oil and gas extraction, production and processing.

Materials and methods

Follow-up interviews on 21 cases that had been previously interviewed are included in this study. The follow-up period (time between the first and last interviews) ranged from 15–34 months (average of 25 months). The cases came from Pennsylvania, Colorado, Arkansas, North Dakota and New York, and are located or had been located within 2 miles of a gas or oil well. As described in our previous study,[1] the information that was collected included specifics on fossil fuel drilling, processing and production activity; results of air, soil and water tests; and health problems of both animals and their owners. Exposures were then determined from a timeline consisting of all available information.

The types of wells represented are shallow vertical gas wells with low volume hydraulic fracturing (HF), deep vertical gas wells with low volume HF, horizontal gas wells with high volume HF, horizontal oil wells with high volume HF, and gas storage wells (conventional wells now used for storage). In seven cases, people primarily owned food animals, including beef and dairy cattle, goats and chickens; in five of these, the owners also kept companion animals (horses, cats, dogs and goats). In 11 cases, people primarily owned companion animals (cats, dogs, horses, goats); in two of these, owners also kept food animals (chickens). In three cases, people documented unusual wildlife losses on their properties (birds and fish); in two of these, owners also kept dogs. In more than one third of our cases, owners bred cattle, goats, chickens, horses and dogs. The number of people participating in each interview was 48. The number of food animals at the time of the first interview was 411 and included 313 cattle, 87 goats and 11 chickens; the number of food animals at the time of the second interview was 298 and included 289 cattle, 8 goats and one chicken. The number of companion animals at the time of the first interview was 119 and included 50 horses, 3 goats, 33 dogs and 33 cats; the number of companion animals at the time of the second interview was 82 and included 35 horses, 22 dogs and 25 cats.

Results and discussion

Well types

Table 1 depicts the number of cases with each type of oil or gas well at the time of the first interview and the second interview. Unconventional wells were represented in the majority of cases (19/21). Three cases had more than one

Table 1. Number of cases with each type of oil or gas well.

	Number of Cases	
Type of Well	*First Interview*	*Second Interview*
Shallow vertical gas with low volume HF	3	3
Deep vertical gas with low volume HF	2	2
Horizontal gas with high volume HF	17	15
Horizontal oil with high volume HF	1	1
Conventional gas used for storage	1	1

Note: Total number of cases is 21; three cases had more than one type of well.

type of well. In three cases, people living nearby unconventional gas extraction at the time of the first interview moved to areas with no or very little industrial activity by the time of the second interview, and in one case (Table A1, Case 18), the move occurred prior to the first interview; all data listed for this particular case under first interview pertain to the location before the move. In all four cases where people moved, the animals moved with the people except in one case (Table A1, Case 10) where a manager of a horse-breeding farm relocated with her dog, but the horses used for breeding remained at the location of the first interview.

We should note that within three months after the second interview, another case participant moved to an area with no or very little industrial activity; as this move occurred after the second interview, this case is not included with the four cases that have moved by the time of the second interview. In all cases, people are planning to move or would like to move if financially feasible.

Exposures over time

Table 2 lists the sources of exposure and the number of cases with each exposure determined up to and including the time of the first interview and the number of cases with each exposure determined after the first interview and up to and including the time of the second interview. All cases had more than one type of exposure. In cases where people had moved by the time of the second interview, exposures were based on the most current location. In the case of the horse-breeding operation mentioned above, exposures were determined for two different locations at the time of the second interview: one location for the manager and her own animals, and another location for the horses that

Table 2. Sources of exposure and the number of cases with each exposure.

	Number of Cases	
Source of Exposure	*First Interview*	*Second Interview*
Drilling/Hydraulic fracturing		
Well/spring water	16	17
Municipal water	1	1
Pond/creek water	13	5
Drilling fluids and muds pit leak/spill	3	1
Drilling fluids and muds blow-out	1	1
Drilling gel spilled into creek	1	0
Storm water run-off from well pad to property	2	1
Hydraulic fracturing fluid spill from holding tank	1	1
Casing failure	3	3
Flaring	9	9
Venting	2	1
Wastewater		
Wastewater impoundment leak	3	2
Wastewater spread on road	3	3
Wastewater dumping on property	1	2
Wastewater dumping into waterway	2	4
Wastewater impoundment not contained	4	3
Wastewater impoundment liner fire	1	0
Wastewater spills during transfer, truck accidents, valves left open	0	1
Storm water runoff from impoundment to property	0	1
Misting via aerators	3	1
Septic impoundment	3	0
Processing & Production		
Pipeline leak/rupture	2	1
Pipeline explosion	0	1
Compressor station malfunction	2	2
Compressor station emissions	0	1
Flaring of methane during oil production	1	1
Condensate tanks leak/rupture	2	1
Condensate tanks venting	1	1
Wellhead venting	2	3
Venting of methane during oil production	1	1
Condensate fluid dumping into waterway	1	1
Heater-treater malfunction	1	1

remained on the farm. In cases where surface contamination occurred and remediation was either not attempted or failed, exposures remained the same. More than half of all exposures were related to drilling and hydraulic fracturing operations, and these decreased slightly over time. More than a third of all exposures were associated with wastewater and processing and production operations, and these exposures increased slightly over time.

In the four cases where people moved to areas with no or very little oil or gas industrial activity, there was no reported air or water contamination. Most of the cases that have not moved (14/17) have experienced both air and water contamination, and nearly all (16/17) of cases that have not moved use alternative sources of water for drinking for themselves and their small animals. These sources include bottled water, filtered water or hauled water. Many owners of food animals (cattle, goats, chickens) and large companion animals (horses, goats and large breeds of dogs) were often forced to offer their animals contaminated water as they were not provided with a water buffalo or could not afford one. Approximately half of these cases also use alternative sources of water for bathing themselves and their animals, washing clothes and dishes, and all other uses except for flushing the toilet. Of cases with air contamination (14/17), only two are currently using air filters. All cases with air contamination report keeping windows shut as often as possible, keeping children and small animals inside and staying away from home as much as possible.

Health changes over time

Figure 1 depicts how health changed over time for humans, companion animals and food animals. Specific symptoms were reported in all health categories, but only health categories with the most commonly reported symptoms are shown. Table 3 lists symptoms reported under each health category for humans and animals, and Table A2 summarizes symptoms affecting 10% or more of humans or animals at the time of each interview. Changes in wildlife are not shown in Figure 1 because only one health category was reported (sudden death). Seventeen animals (song birds, raptors and game fish) were impacted in three cases at the time of the first interview. In one case, the family moved, and there is no information on wildlife numbers at the first location; in the other two cases, wildlife numbers have rebounded coincident with a decrease in industrial activity.

In people, the most common health impacts at the time of the interviews fell under the categories of neurological, respiratory, vascular, dermatologic, and gastrointestinal problems; there were no significant changes in health over time. In companion animals, the most common health impacts at the time of the interviews fell under the categories of gastrointestinal, reproductive, respiratory, neurologic, and dermatologic problems, and sudden death; as in humans, no significant changes in health were noted over time. In food animals, the most common health impacts at the time of the interviews fell under the categories of reproductive, neurologic, gastrointestinal, decrease in milk production, respiratory, and growth problems; significant changes in numbers of reported symptoms were noted over time in the categories of reproduction (decrease), respiratory (increase) and growth (increase) problems.

The initial spike in reproductive problems in food animals occurred because several herds were exposed directly to drilling muds and fluids, fracturing fluids or wastewater; over time, these incidents decreased. However, farmers in these cases are still reporting increased reproductive problems *above* what they have seen in their many years of raising cattle, especially on farms

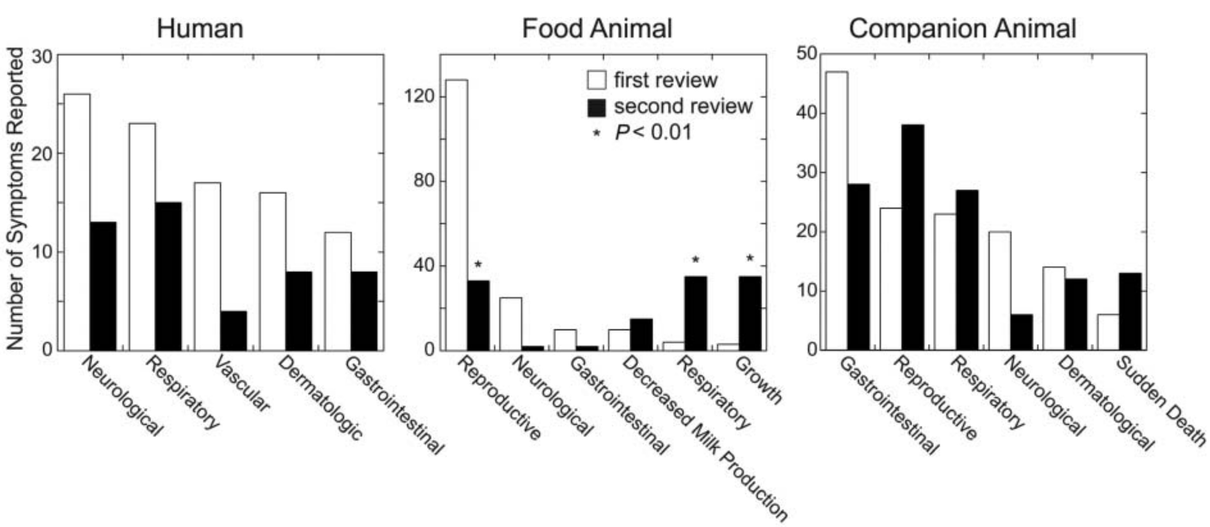

Fig. 1. Number of symptoms reported for various classes of health impacts reported in the first and second interviews for humans, food animals and companion animals. Significance was tested with a chi-square analysis.

Table 3. Symptoms reported under each health category for humans and animals.

Health Category	*Animals*	*Humans*
Neurologic	Lameness	Headaches
	Incoordination	Dizziness
	Seizures	Difficulty concentrating
	Inability to stand	Short-term memory loss
		Skin numbness and tingling sensations
		Incoordination
		Seizures
		Inability to stand
Respiratory	Coughing	Burning in the nose and throat
	Wheezing	Coughing
	Heaving	Wheezing
	Difficulty breathing	Difficulty breathing
		Asthma
Gastrointestinal	Refusal of food	Vomiting
	Vomiting	Diarrhea
	Diarrhea	Cramping
	Colic	Weight loss
	Dysphagia	Weight gain
Dermatologic	Hair loss	Hair loss
	Feather loss	Rashes
	Hoof problems	
	Rashes	
Reproductive	Failure to breed	
	Failure to cycle	
	Abortions	
	Stillbirths	
Growth	Stunting	
	Failure to thrive	
Vascular	Nosebleeds	Nosebleeds
		Stroke
Decreased milk production		

Note: The term "animals" is used to refer to nonhuman members of the animal kingdom.

where the entire herd was exposed. Respiratory symptoms in food animals increased from the first to the second interviews; this may in part be due to the slight increase over time in exposures to processing and production operations and the fact that food animals are often on site for long periods and thus have high exposure rates. Growth problems also increased over time in food animals and may potentially have many causes, but when associated with fossil fuel operations, may be indicative of exposure to endocrine disruptors.[2,3,8]

Industrial activity and location

Table A1 contains a summary of information collected on each individual case at the first and second interviews, including type of well, source of exposure, type of animals affected and health impacts, and change in industrial activity over time. In order to determine if health impacts were associated with changes in gas and oil industrial activity between the two interviews, the cases were divided into those in which the activity increased, those where there was no apparent change, and those for which activity decreased; Case 10 is listed twice because some animals remained at the original location.

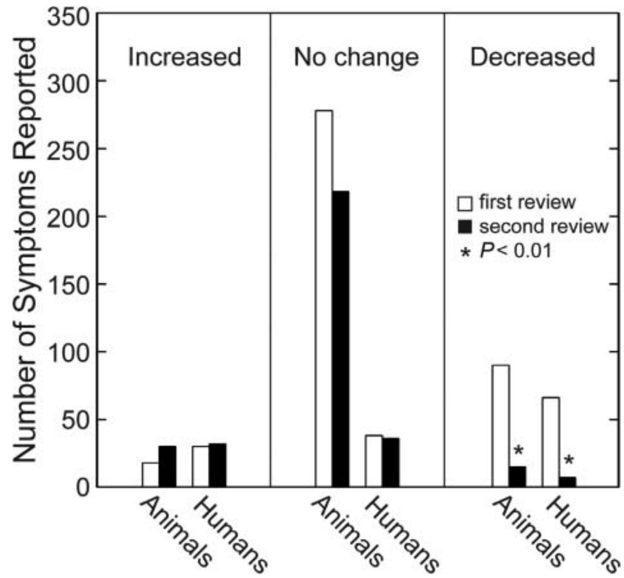

Fig. 2. Number of symptoms reported for humans and animals in the first and second interviews categorized by cases where drilling activity had increased, cases where it remained the same, and cases where it had decreased. The category of decreased activity included families who had moved away from their original location to areas with little or no drilling activity.

Figure 2 represents the total number of reported health symptoms for humans or animals living in areas where the activity was divided into these three categories. The level of industrial activity was determined through several sources: case participants, state environmental regulatory agencies, community science groups, independent researchers and documentation of incidents by case participants and neighbors. In three cases, industrial activity increased over time; no significant health changes were noted in either humans or animals. In nine cases, industrial activity remained the same over the course of this study, and there were no significant changes in the total number of reported symptoms over time. In ten cases, where industrial activity decreased over time, the total number of reported symptoms in humans and animals also decreased.

One of these cases (Table A1, Case 10) involved the horse breeding operation mentioned above and is interesting because it has a natural control group—the horses that remained behind and continually exposed. At the time of the first interview, the manager reported air and water contamination associated with the start of gas drilling operations, and health problems in her, her dog and the horses used for breeding. After more than two years at this location, the manager and her dog moved to an area with no unconventional extraction. While the health impacts of the horses have remained the same, the health of the manager and that of her dog improved greatly after a few months. However, on a recent visit to the farm, she again fell ill but recovered after leaving. In another case (Table A1, Case 16), a participant who moved due to health problems experienced by her family and animals must periodically return to the original location to check her home. After a few hours at this location, a red blotchy rash appears on her face, neck and arms that becomes progressively worse after 48 hours; the rash will clear after a week if she does not return to this location. She has been diagnosed with dermatitis due to chemical exposure.

Comparison with previous literature

A descriptive epidemiological study cannot determine prevalence of a health impact and is not designed to determine cause-and-effect definitively. Nevertheless, in our original study,[1] we did observe the effects on herd health with natural controls that approach the controls that might be used in a laboratory experiment. That is, either dairy or beef herds were split into two or more groups, and grazed on separate pastures. In each case, one pasture or water supply was inadvertently contaminated and the remainder of the herd was not exposed. The exposed cattle suffered significantly greater health impacts than the unexposed. These spatial controls were consistent with longitudinal retrospective controls, in which herd health was compared before and after drilling began. Again, herd health suffered upon the commencement of drilling. This report represents expansion of our original descriptive epidemiological study to measure longitudinal effects since the first set of interviews.

McKenzie et al.[6] reported increased noncancer risks such as short-term respiratory and neurological health effects in people living in close proximity to well sites in Colorado, especially during the phases of hydraulic fracturing and flowback; this work follows an aborted health impact assessment to identify potential risks and benefits to a small community undergoing intensive gas development.[9] Steinzor et al.[7] included respiratory, neurological, gastrointestinal and dermatological problems among common symptoms reported by people living nearby gas facilities in Pennsylvania. Ferrar et al.[5] documented dermal, digestive, upper respiratory and central nervous system symptoms as being the most common health impacts in people living close to unconventional gas development in Pennsylvania. The human health symptoms reported in these studies are consistent with our findings. Ferrar et al.[5] followed cases longitudinally over 19–22 months and found that reported symptoms increased in the majority of organ systems. However, case participants who had moved away from their communities between the first and second interviews were removed from the sample population in the Ferrar study. As these types of cases were not removed from our study, and because we accounted for changes in industrial activity over time, this may partially account for the different outcomes.

The major finding of this study is that health impacts dropped for families and animals moving out of intensively drilled areas or remaining in areas where drilling activity decreased. In the cases of families that remained in the same area and for which drilling activity either remained the same or increased, no change in health impacts was observed. This is particularly interesting because, in some of the cases, the initial interview was done after an incident, such as a wastewater leak from an impoundment.

The distribution of symptoms was unchanged for humans and companion animals, but was significantly changed for food animals. Reports of reproductive failure fell, while respiratory issues and stunted growth were reported more often. Although this may be a consequence of the selection of cases, it represents an interesting change. In some of the cases involving food animals, the initial interview was conducted following an incident such as the leak of wastewater into a pasture or into the source of drinking water for the herd. These incidents were strongly associated with the failure to breed. In the second interview, the contaminated areas were made inaccessible or remediated; in one case, the herd was provided an alternative source of water.

The respiratory and growth issues identified in the second interview were more likely associated with lingering effects of the first exposure or another exposure pathway, such as air contamination. Two epidemiological studies of human births[10, 11] are consistent with the stunted growth seen here in food animals. Both show a decrease in birth weight and low APGAR scores were associated with proximity to shale gas operations. The effects were observed up to 3 miles from the nearest well, suggesting air as the most likely route of exposure. The finding that the results were not different for mothers using private water supplies and those using public water sources supports the supposition that air may be the most likely source of exposure.[11]

Conclusion

Because of the complexities of multiple exposure pathways, multiple possible chemical toxicants, multiple sources of contamination, and changes in toxicant concentration over time, direct measurement of chemical contamination is problematic. For these reasons, studying the health effects of humans and animals living near gas and oil drilling and processing facilities provides a more direct measure not only because health consequences represent the actual variables of interest but also because they reflect the integration of toxic insult over time and multiple exposure pathways. The work reported here represents only the first stages in the epidemiological analysis of the health effects of gas and oil drilling. Both this study and our previous work[1] support the need for further analytical measures of the prevalence of health problems among humans, companion animals and food animals in areas of gas and oil extraction.

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Appendix

Table A1. Summary of Individual Cases.

Case (activity)	*Interview*	*Type of Well*	*Source of Exposure*	*Animal*	*Health Impact*
1 (increased)	First	HHV-g	well/spring water	canine	dermatological
			drilling gel spill into creek		neurological
			flaring, casing failure		gastrointestinal
			wastewater spread on road	human	neurological
					respiratory
					gastrointestinal
					cancer
					urological
					vascular
	Second	HHV-g	well/spring water	canine	neurological
			flaring, casing failure	feline	sudden death
			wastewater spread on road	human	neurological
			wastewater dumping into waterway		respiratory
					gastrointestinal
					opthalmalogical
					cancer
					urological
2 (increased)	First	HHV-g	well/spring water	canine	neurological
			flaring		musculoskeletal
			condensate fluid dumping into		urological
			waterway	feline	neurological
					gastrointestinal
					dermatological

(*Continued on next page*)

Table A1. Summary of Individual Cases. *(Continued)*

Case (activity)	*Interview*	*Type of Well*	*Source of Exposure*	*Animal*	*Health Impact*
				human	neurological respiratory fatigue opthalmalogical urological dermatological
	Second	HHV-g	well/spring water flaring, casing failure condensate fluid dumping into waterway	feline	neurological gastrointestinal dermatological
				human	neurological respiratory fatigue opthalmalogical urological dermatological vascular
3 (increased)	First	HHV-g	well/spring water flaring misting via aerators wastewater impoundment not contained septic impoundment wastewater impoundment leak drilling fluids and muds pit leak wastewater spread on road	canine	reproduction neurological gastrointestinal cancer
				equine	neurological gastrointestinal
				human	vascular neurological respiratory fatigue sensory
	Second	HHV-g	well/spring water flaring wastewater impoundment not contained wastewater impoundment leak drilling fluids and muds pit leak wastewater spread on road wastewater dumping on property wastewater dumping into waterway wastewater spilled during transfer, truck accidents and valves left open	canine equine	reproduction neurological gastrointestinal
				human	neurological gastrointestinal respiratory fatigue sensory sleep disorder cancer urological
4 (same)	First	SV, HHV-g	well/spring water pond/creek water drilling muds and fluids blowout well head venting pipeline leak/rupture	bovine	reproduction
				human	dermatological
	Second	SV, HHV-g	well/spring water pond/creek water drilling muds and fluids blowout well head venting pipeline leak/rupture	bovine	reproduction mastitis growth
				human	dermatological
5 (same)	First	SV, DV	well/spring water pond/creek water	bovine	reproduction neurological
	Second	SV, DV, HHV-g	well/spring water	bovine	none
6 (same)	First	HHV-g	well/spring water storm water runoff from well pad	canine	neurological
				human	neurological gastrointestinal dermatological

(*Continued on next page*)

Table A1. Summary of Individual Cases. *(Continued)*

Case (activity)	*Interview*	*Type of Well*	*Source of Exposure*	*Animal*	*Health Impact*
	Second	HHV-g	well/spring water	canine	respiratory
			storm water runoff from well pad	human	neurological
					opthalmalogical
					musculoskeletal
7 (same)	First	HHV-g	well/spring water	equine	reproduction
			hydraulic fracturing fluid spill	caprine	reproduction
			from holding tank	human	neurological
			wastewater dumping into waterway		musculoskeletal
	Second	HHV-g	well/spring water	equine	dermatological
			hydraulic fracturing fluid spill		musculoskeletal
			from holding tank	caprine	reproduction
			wastewater dumping into waterway	human	musculoskeletal
					respiratory
8 (same)	First	SW	well/spring water	equine	neurological
			pond/creek water		gastrointestinal
			compressor station malfunction	bovine	reproduction
				chickens	sudden death
				human	vascular
					immunological
					gastrointestinal
	Second	SW	well/spring water	bovine	growth
			pond/creek water	human	respiratory
			compressor station malfunction		gastrointestinal
9 (same)	First	HHV-o	well/spring water	caprine	neurological
			pond/creek water		respiratory
			flaring, venting		fatigue
			flaring of methane during	bovine	vascular
			oil production		gastrointestinal
			venting of methane during		respiratory
			oil production		neurological
			heater-treater malfunction		dermatological
					decreased milk
					production
				feline	respiratory
					gastrointestinal
					sudden death
				canine	respiratory
					gastrointestinal
					fatigue
				human	vascular
					neurological
					respiratory
					gastrointestinal
					dermatological
					musculoskeletal
	Second	HHV-o	well/spring water	caprine	respiratory
			pond/creek water	bovine	respiratory
			flaring, venting		growth
			flaring of methane during		decreased milk
			oil production		production
			venting of methane during		gastrointestinal
			oil production		neurological
			heater-treater malfunction		reproductive

(*Continued on next page*)

Table A1. Summary of Individual Cases. *(Continued)*

Case (activity)	*Interview*	*Type of Well*	*Source of Exposure*	*Animal*	*Health Impact*
				feline	respiratory sudden death cancer
				canine	respiratory gastrointestinal fatigue
				human	respiratory neurological dermatological vascular gastrointestinal musculoskeletal sensory
10 (same)	First	HHV-g	well/spring water flaring	equine	reproduction gastrointestinal
	Second	HHV-g	well/spring water flaring	equine	reproduction gastrointestinal endocrinological
11 (same)	First	HHV-g	well/spring water flaring	canine	dermatological gastrointestinal
			misting via aerators septic impoundment wastewater impoundment liner fire	feline	neurological dermatological sudden death
				human	neurological respiratory gastrointestinal sensory vascular
	Second	HHV-g	well/spring water flaring	canine	dermatological gastrointestinal
				feline	dermatological
				human	respiratory sensory cardiovascular
12 (same)	First	SV, HHV-g	flaring wastewater impoundment not contained condensate tanks leak/rupture	equine	dermatological neurological vascular gastrointestinal
			condensate tanks venting	canine	gastrointestinal
			wellhead venting wastewater dumping on property	human	dermatological respiratory neurological musculoskeletal vascular opthalmalogical
	Second	SV, HHV-g	well/spring water flaring wastewater impoundment not contained condensate tanks leak/rupture condensate tanks venting	equine	respiratory dermatological neurological vascular gastrointestinal endocrinological
			wellhead venting	canine	behavioral
			wastewater dumping on property	human	dermatological

(*Continued on next page*)

Table A1. Summary of Individual Cases. *(Continued)*

Case (activity)	*Interview*	*Type of Well*	*Source of Exposure*	*Animal*	*Health Impact*
					respiratory neurological musculoskeletal vascular gastrointestinal
13 (decreased)	First	DV	well/spring water pond/creek water casing failure	equine canine	neurological urological gastrointestinal dermatological
				human	respiratory neurological gastrointestinal dermatological
	Second	DV	well/spring water pond/creek water casing failure	human	neurological
14 (decreased)	First	HHV-g	well/spring water pond/creek water wastewater impoundment not contained wastewater dumping into waterway	songbirds human	sudden death neurological immunological
	Second	HHV-g	well/spring water pond/creek water wastewater impoundment not contained wastewater dumping into waterway wellhead venting	human	neurological respiratory
15 (decreased)	First	HHV-g	pond/creek water storm water runoff from well pad condensate tanks leak/rupture	fish human	sudden death cardiovascular gastrointestinal musculoskeletal
	Second	N/A	N/A	human	none
16 (decreased)	First	HHV-g	well/spring water wastewater impoundment not contained septic impoundment wastewater impoundment leak drilling fluids and muds pit leak misting via aerators wastewater spread on road	caprine canine human	reproduction sudden death vascular neurological respiratory sensory fatigue gastrointestinal musculoskeletal dermatological
	Second	N/A	N/A	human	none
17 (decreased)	First	HHV-G	wastewater impoundment leak drilling fluids and muds pit leak	bovine	reproduction
	Second	HHV-g	wastewater impoundment leak	bovine	reproduction endocrinological
18 (decreased)	First	HHV-g	well/spring water pond/creek water	canine	respiratory neurological

(*Continued on next page*)

Table A1. Summary of Individual Cases. *(Continued)*

Case (activity)	*Interview*	*Type of Well*	*Source of Exposure*	*Animal*	*Health Impact*
			venting, pipeline leak/rupture	equine	respiratory
					musculoskeletal
					neurological
					gastrointestinal
				human	vascular
					neurological
					respiratory
					fatigue
					gastrointestinal
					musculoskeletal
					dermatological
					cardiovascular
	Second	N/A	wastewater spread on road	equine	dermatological
				human	endocrinological
					respiratory
					cardiovascular
19 (decreased)	First	HHV-g	flaring	canine	respiratory
			compressor station malfunction	human	respiratory
					opthalmalogical
	Second	HHV-g	well/spring water	canine	respiratory
			flaring		
			misting via aerators		
			compressor station malfunction		
20 (decreased)	First	HHV-g	well/spring water	bovine	reproduction
			casing failure		decreased milk production
					mastitis
					urological
					gastrointestinal
	Second	HHV-g	well/spring water	bovine	none
			casing failure		
10 (decreased)	First	HHV-g	well/spring water	canine	gastrointestinal
			flaring		behavioral
				human	neurological
					dermatological
					vascular
					fatigue
	Second	N/A	N/A	canine	none
				human	none
21 (decreased)	First	HHV-g	municipal water	raptors	sudden death
			flaring	human	neurological
					respiratory
					dermatological
					sensory
					vascular
					sleep disorder
	Second	HHV-g	municipal water	human	none
			flaring		
			pipeline explosion		
			compressor station emissions		

HHV-g, horizontal high volume-gas; HHV-o, horizontal high volume-oil; SV, shallow vertical well; DV, deep vertical well; SW, storage well.
Case 18 moved before the first interview; data listed for this case under first interview pertains to the location before the move.
Case 10 is listed twice because there were two different locations at the time of the second interview.

Table A2. Number and percentage of humans or animals with individual symptoms of 10% or more.

Humans	*Interview 1 (48 subjects)*	*Interview 2 (48 subjects)*
Headaches	17 (35%)	6 (13%)
Memory loss	4 (8%)	5 (10%)
Burning in nose and throat	12 (25%)	6 (13%)
Coughing	5 (10%)	4 (8%)
Rash	13 (27%)	4 (8%)
Nosebleeds	16 (33%)	3 (6%)
Food Animals	*Interview 1(411 subjects)*	*Interview 2 (298 subjects)*
Stillborn	88 (21%)	19 (6%)
Difficulty breathing	4 (<1%)	35 (12%)
Growth (stunting and failure to thrive)	3 (<1%)	35 (12%)
Companion Animals	*Interview 1 (119 subjects)*	Interview 2 (82 subjects)
Coughing	22 (19%)	26 (32%)
Refusal of food	22 (19%)	9 (11%)
Stillborn	4 (3%)	17 (21%)
Failure to cycle	9 (8%)	8 (10%)