	Studies and Research Articles Regarding the Negative Effects of Hog Confinement Operations			
	Citation	Category	Brief Summary	Abstract or Summary
01	J. Herriges, S. Secchi, B.Babcock. Living with Hogs in Iowa: The Impact of Livestock Facilities on Rural Residential Property Values. Center for Agricultural and Rural Development, Iowa State University (2003).	Economic effects	Iowa study - Study found that there may be an approximate 10% drop in property value if a new livestock feeding operation is located upwind and near a residence.	To better understand the magnitude of the effects of livestock feeding operations on residential property values, we constructed a new dataset that merges data on home sales with data on the location and size of livestock feeding operations in five rural counties of Iowa. We estimated a hedonic model to explain variations in residential sales price with standard house attributes, such as number of bedrooms and square feet of living space, as well as the effects of distance and density of livestock feeding operation. We find that livestock operations have an overall statistically significant effect on property values. Predicted negative effects are largest for properties that are downwind and close to livestock operations. In addition, feeding operations that are moderate in size have more impact than do large-scale operations, most likely reflecting age, type, and management practices of the moderate-sized operations. The limited size of the estimated effects suggest that common sense rules—such as not locating feeding operations close to and upwind of residences—combined with modest compensatory payments could help rural residences co-exist with modern feeding operations. conclusion: there may be approximately a 10% drop in property value if a new livestock feeding operation is located upwind and near a residence.
02	Burkholder, JoAnn et al. Impacts of Waste from Concentrated Animal Feeding Operations on Water Quality. Environmental Health Perspectives Vol 115 Number 2 (2007)	Environmental effects	Research article - Siting of livestock operations in areas where there is a shallow water table increases the potential for environmental contamination. Sandy, well drained soils are most vulnerable to the transport of nutrients to underlying groundwater.	Siting of livestock operations in areas prone to flooding or where there is a shallow water table increases the potential for environmental contamination. Overapplication of livestock wastes can overload soils with both macronutrients such as nitrogen (N) and phosphorus (P), and heavy metals added to feed as micronutrients. Overapplication of animal wastes or application of animal wastes to saturated soils can also cause contaminants to move into receiving waters through runoff and to leach through permeable soils to vulnerable aquifers. Importantly, this may happen even at recommended application rates. Sandy, well-drained soils are most vulnerable to transport of nutrients to underlying groundwater. (Mueller et al. 1995)
03	Thu K, Donham K, Ziegenhorn R, Reynolds S, Thorne P, Subramanian P, Whitten P, Stookesberry J. A control study of the physical and mental health of resident living near a large-scale swine operation. J Agric Safe Health. 1997; 3(1):13-26.	Health effects	Iowa study - Neighbors living near a CAFO experienced higher levels of several symptoms consistent with exposure to ambient irritants and similar to those found in the occupational setting: burning eyes, runny nose, plugged ears, increased cough and phlegm, shortness of breath, wheezing, chest tightness. But, also described were symptoms more commonly arising from exposure to malodor: headache, nausea, dizziness, weakness and fainting. Questions designed to indicate depression and anxiety revealed no differences between CAFO exposed and control groups.	This article presents the results of a study assessing the physical and mental health of residents living in the vicinity of a large-scale swine confinement operation. Physical and mental health data were collected via personal interviews from a sample (n = 18) of all neighbors living within a two-mile radius of a 4,000-sow swine production facility. Results were compared to similar data collected from a random sample of demographically comparable rural residents (n = 18) living near minimal livestock production. Results indicate that neighbors of the large-scale swine operation reported experiencing significantly higher rates of four clusters of symptoms known to represent toxic or inflammatory effects on the respiratory tract. These clusters of symptoms have been well-documented among swine confinement workers. There was no evidence to suggest that neighbors of the large-scale swine operation suffered higher rates of psychological health problems manifested as anxiety or depression. A larger population-based study is needed to test the hypothesis that neighbors of large-scale swine operations experience elevated rates of physical health symptoms comparable to interior confinement workers.
04	Schiffman SS, Miller EA, Suggs MS, Graham BG. The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. Brain Res Bull. 1995;37(4):369-75.	Health effects	Study results indicated that persons living near intensive swine operations who experienced the odors reported significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects.	The effect of environmental odors emanating from large-scale hog operations on the mood of nearby residents was determined using the POMS (Profile of Mood States). The scores for six POMS factors and the TMD (total mood disturbance score) for 44 experimental subjects were compared to those of 44 control subjects who were matched according to gender, race, age, and years of education. The results indicated a significant difference between control and experimental subjects for all six POMS factors and the TMD. Persons living near the intensive swine operations who experienced the odors reported significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects as measured by the POMS. Persons exposed to the odors also had more total mood disturbance than controls as determined by their ratings on the POMS. Both innate physiological responses and learned responses may play a role in the impairment of mood found here.

05	Malodor as a Trigger of Stress and Negative Mood in Neighbors of Industrial Hog Operations. Horton et. Al., American Journal of Public Health (2009)	Health effects	North Carolina study - Study found that hog odor is related to stress and negative mood.	Hog odor, hydrogen sulfide, and semi volatile PM10 are related to stress and negative mood in disproportionately low-income communities near industrial hog operations in eastern North Carolina. Malodor should be considered in studies of health impacts of environmental injustice.
06	Wing S, Wolf S. Intensive livestock operations, health and quality of life among eastern North Carolina residents. Environ Health Perspect. 2000 Mar;108:233-38.	Health effects	North Carolina study - Residents in the vicinity of the hog operation reported increased occurrences of headaches, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes as compared to residents of the community with no intensive livestock operations. Quality of life was decreased for residents who lived near the hog operation.	People who live near industrial swine operations have reported decreased health and quality of life. To investigate these issues, we surveyed residents of three rural communities, one in the vicinity of an approximately 6,000-head hog operation, one in the vicinity of two intensive cattle operations, and a third rural agricultural area without livestock operations that use liquid waste management systems. Trained interviewers obtained information about health symptoms and reduced quality of life during the previous 6 months. We completed 155 interviews, with a refusal rate of 14%. Community divergences in the mean number of episodes were compared with adjustment for age, sex, smoke and employment status. The average number of episodes of many symptoms was similar in the three communities; however, certain respiratory and gastrointestinal problems and mucous membrane irritation were elevated among residents in the vicinity of the hog operation. Residents in the vicinity of the hog operation reported increased occurrences of headaches, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes as compared to residents of the community with no intensive livestock operations. Quality of life, as indicated by the number of times residents could not open their windows or go outside even in nice weather, was similar in the control and the community in the vicinity of the cattle operation but greatly reduced among residents near the hog operation. Respiratory and mucous membrane effects were consistent with the results of studies of occupational exposures among swine confinement-house workers and previous findings for neighbors of intensive swine operations. Long-term physical and mental health impacts could not be investigated in this study.
07	Bullers, S. Environmental Stressors, Perceived Control, and Health: The Case of Residents Near Large-Scale Hog Farms in Eastern North Carolina. *Hum Ecol* **33,** 1–16 (2005). https://doi.org/10.1007/s10745-005-1653-3	Health effects	North Carolina study - findings suggest residences nearby industrial hog farms are associated with increased reports of certain physical symptoms. Reported symptoms are related to respiratory, sinus, and nausea problems. Residences also reported increased psychological distress and decreased perceptions of control.	This study first explores the physical and psychological health effects of residence near industrial hog farms. The study compares differences in specific health symptoms, psychological distress, and perceived control between a group of 48 nearby residents and a control group ($n = 34$) with no exposure to hog farms. The process through which nearby residence affects psychological distress is then explored by examining for mediating effects of either physical health symptoms or perceived control. Findings suggest that nearby residence is associated with increases in 12 of the 22 reported physical symptoms. Most of these significantly different symptoms are related to respiratory, sinus, and nausea problems. Nearby residence is also associated with increased psychological distress and decreased perceptions of control. Nearby residence appears to affect psychological distress by increasing physical health symptoms. Although nearby residents report significantly lower perceived control, perceived control does not play a significant role in the process through which nearby residence affects psychological distress.
08	Donham, Kelley. The Concentration of Swine Production: Effects on Swine Health, Productivity, Human Health, and the Environment. Veterinary Clinics of North America: Food Animal Practice, Vol. 16, Issue 3 (2000).	Health effects	Research article - concentrates on swine health and on the individual and community health consequences of large-scale livestock operations.	As the swine production industry becomes increasingly concentrated, it is more subject to the concerns of regulatory agencies and the general public regarding worker, environmental, and community health. As veterinarians' roles are expanding to help sustain the modern livestock industry, they need to understand the effects of livestock concentration on occupational and environmental health, swine health and productivity, and community health. This article concentrates on swine health and on the individual and community health consequences of large-scale livestock operations.
09	Von Essen, Susanna et al. Health Effects from Breathing Air Near CAFOs for Feeder Cattle or Hogs. Journal of Agromedicine, Vol 10(4) 2005.	Health effects	Research article - references Schiffman, Thu and Wing and Wolf study (listed above). Article states that there is evidence from a small number of published research studies that people living in the neighborhood of large-scale hog facilities are more likely to have a variety of medical complaints.	There is evidence from a small number of published research studies that people living in the neighborhood of large-scale hog facilities are more likely to have a variety of medical complaints. These complaints range from respiratory problems to burning eyes, sore throats, nausea and diarrhea, fatigue, headaches and plugged ears. At this time, there are no published studies in which scientists have attempted to find exposure-corroborated, physiologic evidence of negative health effects in populations of neighbors of hog facilities. Psychological symptoms, including tension, depression and anger were more common in hog facility neighbors studied by the group of researchers that looked at psychological aspects of the neighborhood health issue. [based on Schiffman study, Thu study, and Wing and Wolf study]

10	Sigurdur, Siguardarson et al. School Proximity to Concentrated Animal Feeding Operations and Prevalence of Asthma in Students. CHEST Journal Vol 129, Issue 6 (2006).	Health effects	Iowa study - Study showed that children in school located 1/2 mile from a CAFO had a significantly increased prevalence of physician-diagnosed asthma.	Setting: Two rural Iowa elementary schools: the study school is located one-half mile from a CAFO, and the control school is distant from any large-scale agricultural operation. Results: Children in the study school had a significantly increased prevalence of physician-diagnosed asthma (adjusted odds ratio, 5.71; p = 0.004). Although this group was more likely to live on a farm and have parents who smoke, these potentially confounding variables did not account for increased prevalence in a multivariate model. No difference in measures of asthma severity was found between the two populations. Because different sets of physicians are responsible for the medical care of the groups of children, it is possible that physician bias is responsible for the different prevalence of asthma diagnoses. This was not explored in the study.

Living with Hogs in Iowa: The Impact of Livestock Facilities on Rural Residential Property Values

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Abstract

To better understand the magnitude of the effects of livestock feeding operations on residential property values, we constructed a new dataset that merges data on home sales with data on the location and size of livestock feeding operations in five rural counties of Iowa. We estimated a hedonic model to explain variations in residential sales price with standard house attributes, such as number of bedrooms and square feet of living space, as well as the effects of distance and density of livestock feeding operation. We find that livestock operations have an overall statistically significant effect on property values. Predicted negative effects are largest for properties that are downwind and close to livestock operations. In addition, feeding operations that are moderate in size have more impact than do large-scale operations, most likely reflecting age, type, and management practices of the moderate-sized operations. The limited size of the estimated effects suggest that common sense rules—such as not locating feeding operations close to and upwind of residences—combined with modest compensatory payments could help rural residences co-exist with modern feeding operations.

Keywords: hedonic model, livestock, property values.

LIVING WITH HOGS IN IOWA: THE IMPACT OF LIVESTOCK FACILITIES ON RURAL RESIDENTIAL PROPERTY VALUES

Introduction

The methods used to raise hogs in Iowa have undergone dramatic changes in the past twenty years. In 1980, approximately 65,000 farmers in the state raised hogs, with an average of 200 hogs residing on each farm. In 2002, the number of farms with hogs had fallen to about 10,000, and the average number of hogs per farm had risen to over 1,400.[1] In the not-so-distant past, the presence of livestock on farms was the norm. When living or traveling in rural areas, one expected to smell the smells, hear the noises, and see the sights that accompany such operations. Complaints between rural neighbors about livestock operations made little sense when everybody had livestock. But the dramatic increase in the concentration of ownership now means that far fewer rural residents have a large financial interest in livestock. What once was the smell of money is now the smell of somebody else's money and an externality to be dealt with. Moreover, there is a concern that the increased concentration of the industry may be accompanied by an increased risk of environmental damage due to manure spills and further degradation of local air quality as the result of odor emanating from large-scale hog facilities.

Accompanying the changes in the industry's structure has been an increase in complaints about livestock operations. State and local agencies have responded by enacting regulations for large-scale confinement units. Since 1995, the Iowa legislature has passed three progressively stricter bills regulating livestock operations. The most recent bill, Senate File 2293, provides for a lower size threshold at which a construction permit is required, calls for larger separation distances for livestock operations, and regulates air quality by limiting emissions from confinement operations.[2] In addition to such legislative action, since the Iowa Supreme Court in 1998 limited the immunity granted to farmers raising livestock, there have been several instances in which individual landowners have filed lawsuits against hog facilities. The best-known case involves four farm couples—two of whom had raised livestock—who sued Iowa Select Farms in 2002 for the production of offensive odors, noxious gasses, and excessive flies on the company's 30,000-head hog facility in Sac County, Iowa. The plaintiffs were awarded $1.06 million in actual damages plus $32 million in punitive damages.[3] The case was settled out of court in 2003, but the terms of the settlement are confidential.

The problem facing both regulators and the judicial system is that little information exists on the extent of damages caused by livestock facilities, making regulation and assessment of damages in civil suits that much more difficult. Palmquist, Roka, and Vukina 1997 (PRV hereafter) represents one of the few studies available. Using data on 237 rural residential properties in southeastern North Carolina, PRV conducted a hedonic price analysis. The authors found that proximity to hog facilities caused a statistically significant reduction in rural housing prices, with an impact of as much as 9 percent for a facility located within ½ mile of a home. A limitation of the PRV study is that the authors did not have information on the exact location of the hog operations. Instead, the authors were forced to rely on an index of manure production within three radii of each home sale (0 to ½ mile, ½ to 1 mile, and 1 to 2 miles) provided by the state veterinarian's office. This precluded the authors from controlling for whether facilities were upwind or downwind of the residential site or the specific distance to the nearest facility. Moreover, the authors did not control for the potentially positive impact that growth in the local livestock industry might have on the demand for housing in the region.

The purpose of this paper is to address some of the limitations inherent in data available for the PRV study by using GIS (geographical information systems) data on the location of livestock facilities in Iowa. Specifically, we conducted a hedonic analysis of the impact of livestock facilities on rural residential property values. We collected data on 1,145 actual home sales in five counties (Franklin, Hamilton, Hardin, Humboldt, and Webster) for the period from 1992 through the summer of 2002. We merged these data with information from the Iowa Department of Natural Resources (IDNR) on the location and size of livestock operations requiring either a construction permit or a manure management plan to determine how close each home was to livestock facilities. The livestock operations database used in the analysis includes facilities regulated according to the 1998 law, House File 2494, which required operations with an animal weight capacity in excess of 200,000 pounds (400,000 for bovine facilities) to file a manure management plan. Construction permits were required for facilities over 625,000 pounds of bodyweight (roughly 4,167 finishing hogs) that used formed storage.[4] For each residence, we identified the nearest livestock operation, recording the operation's distance from the home, its size (live weight), and whether it was upwind of the home during the winter (i.e., northwest) or summer (i.e., south) seasons. We also computed the number of operations within a 3- and 10-mile radius to control for concentration effects and the indirect impact of industry growth on housing demand.

Literature Review

Hedonic price models have long been used to value not only the physical attributes of housing units (e.g., square footage, number of bathrooms, and air conditioning) but also the surrounding location and environmental amenities (e.g., local school quality, crime rates, and air quality).[5] Drawing on seminal work by Rosen (1974), hedonic property value studies start with the notion that the price of a home (P) reflects the bundle of attributes associated with it; that is,

$$P = P\left(z_1, z_2, \ldots, z_K\right) \tag{1}$$

where $\boldsymbol{z} = \left(z_1, z_2, \ldots, z_K\right)$ is a vector of housing attributes. The hedonic function in equation (1) is a housing market equilibrium resulting from the interplay between consumers' demands for various bundles of attributes and suppliers' costs of providing such bundles. As such, it can be used to value marginal changes in a given attribute (say, z_k) using

$$MV_k\left(\boldsymbol{z}\right) = \frac{\partial P\left(\boldsymbol{z}\right)}{\partial z_k}. \tag{2}$$

However, one must be careful in using the hedonic function to measure large (i.e., non-marginal) changes in the set of housing amenities, as this may result in a change in the market equilibrium. According to PRV (p. 115), if the changes are localized (and hence not likely to alter substantially the local housing market), the hedonic function can be used to value changes in local environmental amenities. Moreover, they argue that this is likely to be the case in considering the impact of locating a new hog facility.

The empirical literature that employs hedonic analysis to value environmental amenities is substantial in both the size and scope of amenities being valued. For example, Smith and Huang (1995) use meta-analysis to summarize nearly 40 studies of the impact of air quality on housing prices. Perhaps more relevant to the current analysis are those studies focused on Locally Undesirable Land Uses (or LULUs), including landfills, hazardous waste sites, and incinerators.[6] For example, Kohlhase (1991), Kiel (1995), McCluskey and Rausser (2001), and Smith and Desvousges (1986) all estimate the impact of hazardous waste sites on residential property values and typically find that home values are significantly reduced by proximity to such disposal sites. Similar results emerge in studying the impact of incinerator sites (Kiel and McClain 1995a,b) and landfills (Thayer, Albers, and Rahmatian 1992; Reichert, Small, and Mohanty 1992).

As previously noted, however, there are relatively few studies that focus on the impact of livestock facilities on property values, with PRV being perhaps the most well-known to date. An earlier hedonic analysis by Abeles-Allison and Conner (1990) also found a significant impact of hog facilities on property values in Michigan. However, the analysis was subject to potential sample selection bias, as properties studied were limited to those located near hog facilities for which multiple complaints had been received. Taff, Tiffany, and Weisberg (1996) and Mubarak, Johnson, and Miller (1999) conducted property value studies in Minnesota and Missouri, respectively, but were hampered by limited information on the characteristics of the properties being sold. Moreover, in the Missouri study, over 60 percent of the parcels did not include a home; those that did include a home did not control for the homes' structural characteristics. The Minnesota study, on the other hand, used only house sales data but included property located in cities or townships with populations of 2,500 people or less. It therefore did not distinguish between rural and urban sales, and it had very little information on the characteristics of the properties sold.[7] To our knowledge, the only other hedonic study that controls for the presence of livestock facilities is a recent paper by Ready and Abdalla (2003), which analyzes single-family home sales in Berks County, Pennsylvania. In this study, the authors estimate a hedonic price function, including as housing amenities the proximity of each home to open space and disamenities, such as landfills, regional airports, and large animal production facilities. The authors find that a large animal production facility located at a distance of 500 meters (or roughly 0.3 miles) depresses the sales price of a home by 6.4 percent. However, the authors do not control for the direction of the housing unit relative to the livestock facility.

Data Collection

The study area (shaded in Figure 1) includes five counties in North-Central Iowa: Franklin, Hamilton, Hardin, Humboldt, and Webster.[8] We chose this area because there is a wide range of livestock operations in the region. As the inset map in Figure 1 indicates, the areas with lower density are the two western counties, with Webster and Humboldt counties having only 16 and 24 operations, respectively. Hamilton County, on the other hand, has 138 operations, Franklin has 76, and Hardin has 95. Moreover, the counties differ in terms of the mix of operation sizes. Whereas Franklin County has the largest share of moderate-sized facilities (i.e., hog facilities with less than 3,000 head),

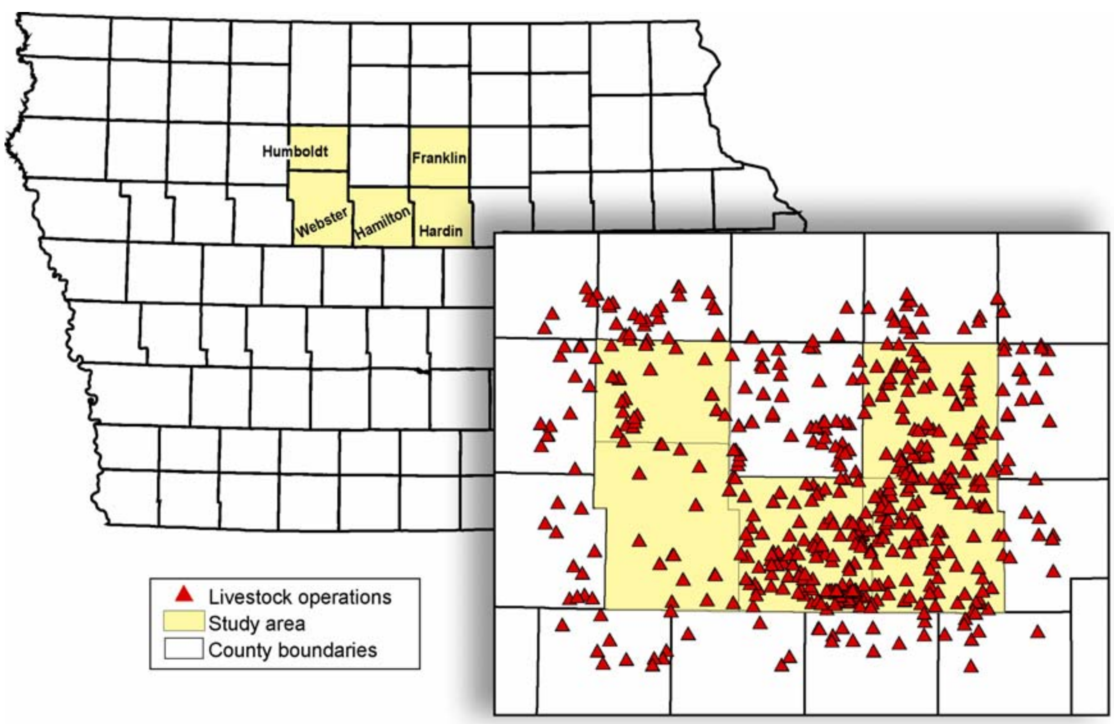

FIGURE 1. Study area

Hamilton County has the greatest number of larger facilities (i.e., over 3,000 head).[9] Over 90 percent of the facilities are hog operations, mostly growers, and the majority of them were built in the early to mid-1990s.

Livestock Facilities Data

Information on each livestock facility in the study area was obtained from the IDNR. The available data included the GIS files on the location of the operations as well as the live weight and animal type in production. We identified two types of operations using the IDNR data: facilities that need a construction permit and facilities that need to file a manure management plan with the agency. In general, according to the 1998 Iowa law, any operation with an animal weight capacity of more than 200,000 pounds (400,000 pounds bovine) must obtain a manure management permit. If a facility uses earthen storage structures for manure, such as a lagoon, it must also obtain a construction permit. If a facility uses formed storage, on the other hand, it needs a construction permit only for operations with 625,000 or more of animal weight capacity (1.6 million pounds or more for bovine).

In total, 550 livestock facilities are included in our analysis.[10] Table 1 provides summary statistics for these facilities. Because of the structure of the confinement operation dataset, the facilities included tend to be quite sizable.[11] As Table 1 indicates,

TABLE 1. Livestock facilities summary statistics

Characteristic	Mean	Median	Range
Live weight (thousands of pounds)	727	600	120 to 41,044
Manure index (millions of pounds per year)	17	14	3 to 973
Percentage of operations by type			
Hogs	98		
Cattle	1		
Hen	2		
Percentage of operations by county			
Franklin	14		
Hamilton	25		
Hardin	17		
Humbolt	4		
Webster	3		
Other	37		

their live weight ranges from 120,000 to 41,044,000 pounds, with a median of 600,000 and an average of 727,000.[12] Over 97 percent of the facilities are hog confinement units, 1 percent are cattle operations, and the remaining 2 percent are egg laying facilities.

In order to provide some comparability to PRV, we also considered manure production as an alternative measure of size in our hedonic analysis. A manure index was formed for each facility based on type of facility and using the algorithms developed by Lorimor, Powers, and Sutton (2000). Manure production levels, as excreted, for facilities included in the study ranged from 3 to 973 million pounds per year, with a median and mean, respectively, of 14 and 17 million pounds per year.

Residential Property Sales Data

Data on house sales were obtained from each county assessor's office. We restricted sales to rural residential, owner-occupied homes sold via "arms length" transactions between 1992 and 2002.[13] As in the case of PRV, we excluded properties with more than 10 acres in order to avoid units that were being marketed in part because of their agricultural production capabilities. We also excluded properties whose sale prices were less than 50 percent of their assessed values and/or sold for less than $5,000. In total, 1,145 sales were available for the analysis. Table 2 details the number of sales and earliest sale date by county.

The variables used in the hedonic regression analysis fall into three broad categories: (*a*) the physical attributes of the home and lot (e.g., square footage and number of bathrooms), (*b*) the attributes of the surrounding community, and (*c*) the attributes of the livestock facilities in close proximity to each home. The physical characteristics available for each home varied by county. In total, 11 characteristic were formed using the overlap in information across the five counties, including the size of the lot, the age of the home,

TABLE 2. Rural residential property sales by county

County	Earliest Sales Date	Number of Sales
Franklin	January 1993	141
Hamilton	January 1992	190
Hardin	January 1995	177
Humboldt	March 1995	71
Webster	January 1992	566

and the year in which it was sold, the size of the living area and any additions to the home, and the number of bathrooms, decks and fireplaces. These characteristics, listed in the first part of Table 3, are similar to those used in PRV and other hedonic studies of residential properties. Each of these characteristics, with the exception of the age of the home, is expected to have a positive impact on the price of the home.

The second broad category of explanatory variables (listed in the second section of Table 3) characterizes the amenities of the housing unit in terms of the surrounding community. These include the distance to the nearest large town (i.e., with population of 2,500 or more) and nearest high school, as well as the median income and population density for the corresponding township. The two distance variables required locating each household spatially. For two counties, Webster and Hardin, GIS files with parcel locations were available. For the other three, we used Digital Orthophoto Quarter Quads (DOQQs) of the State of Iowa combined with paper or online maps to create the GIS data layers.[14,15] An application called PCMiler was then used to calculate the distance from each home to both the local high school and the closest town with a population of more that 2,500 within the 10-mile buffer.[16] In general, we expected that an increase in either of these distances would negatively affect a home's sale price.

We also associated each home with the appropriate township and used the 2000 census to obtain median family income and population density (see Figure 2 for town and home locations). Population density is quite variable among the townships considered, ranging from less than 10 people per square mile to over 100. Median income is quite variable too, ranging from $32,000 to over $60,000. In the hedonic regression analysis, we anticipated that both median family income and population density would have a positive influence on sales price.

The third category of variables used in our hedonic regression analysis consists of measures of the proximity of each housing unit to livestock operations. We used Arc View 3.2 to analyze the spatial relationships between homes sold and livestock operations, constructing centroids for all property sales and livestock operations. We used these centroids to calculate distances between sales and livestock operation sites. In most hedonic studies, each sales property is associated with a single LULU site, typically the closest site. However, given the density of livestock facilities in some regions of the

TABLE 3. Description and summary statistics for variables used in hedonic analysis

Variable	Description	Units	Min	Max	Mean	Std. Dev.
Price	Market price	dollars	500,200	475,000	81,667.60	55,529.64
LSize	Lot size	acres	0.05	10	2.38	2.22
SYear	Sales year	years	1,992	2,002	1,997.16	2.76
Age	Age of home	years	0	142	52.62	32.59
LArea	Living area (without additions)	sq ft	224	500,112	1,171.67	503.84
AdArea	Area of additions	sq ft	0	1642	175.68	273.14
AC	Air conditioned	0/1	0	1	0.62	0.48
Baths	Number of bathrooms	number	0.5	6	1.58	0.68
Decks	Number of decks or enclosed porches	number	0	5	1.61	0.98
Fire	Number of fireplaces	number	0	3	0.39	0.54
AttG	= 1 if there is an attached garage; else =0	0/1	0	1	0.45	0.50
DetG	= 1 if there is a detached garage; else = 0	0/1	0	1	0.47	0.50
DistTown	Distance to nearest large town	miles	0.60	35.20	9.87	5.77
DistHS	Distance to nearest high school	miles	0.90	51.20	10.89	8.79
PDens	Population density by township	number/sq mi	4.00	116.76	29.54	26.90
MedInc	Median income by township	$1,000s /family	32.4	63.0	47.0	56.4
DI1	Distance to nearest livestock facility	miles	0.01	6.78	2.77	1.75
Size1	Size of nearest livestock facility	thousands of pounds	160	2,600	485.29	303.25
NW1	=1 if nearest livestock facility is northwest; else = 0	0/1	0	1	0.30	0.46
SO1	=1 if nearest livestock facility is south; else = 0	0/1	0	1	0.22	0.41
Mile3	Number of livestock facilities within 3 miles	number	0	27	2.48	3.39
Size3	Average size of facilities within 3 miles	thousands of pounds	0	1,649	342.18	331.77
NW3	Percentage of facilities within 3 miles that are northwest	percent	0	100	18.43	29.00
SO3	Percentage of facilities within 3 miles that are south	percent	0	100	16.72	27.78
Mile10	Number of livestock facilities that are within 10 miles	number	2	104	28.36	25.93

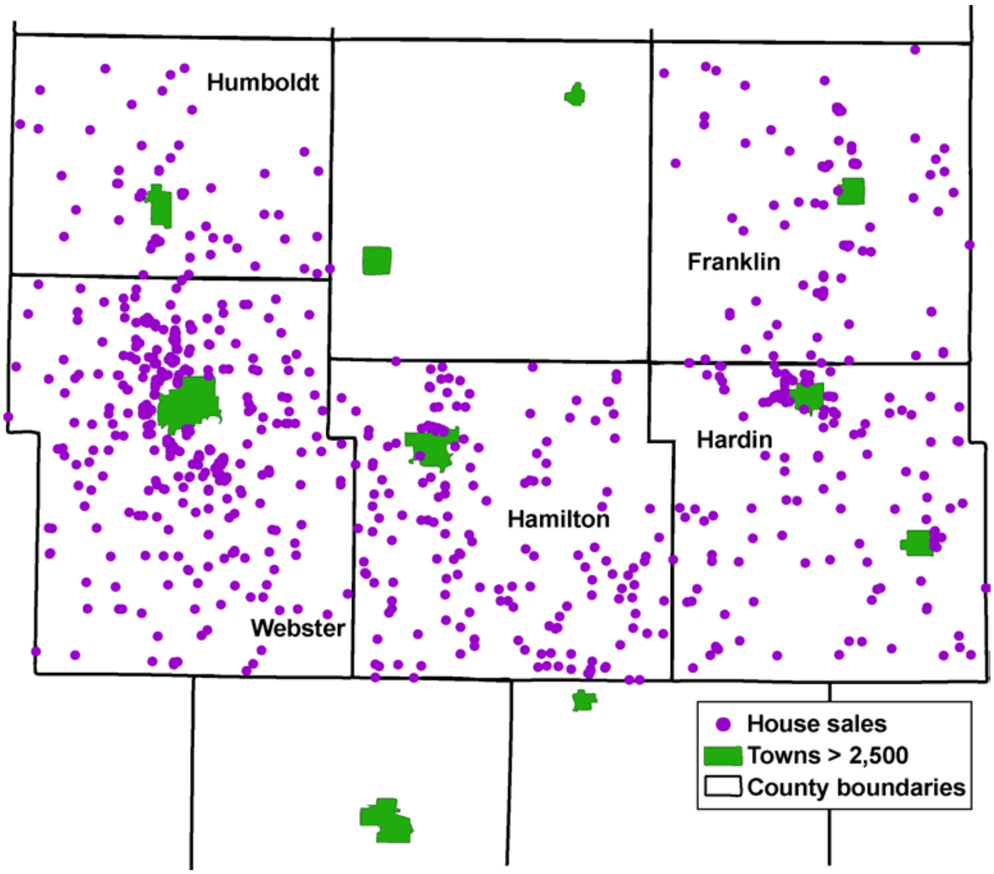

FIGURE 2. Residential sales locations

study site, we wanted to control for the possibility that a property could be affected by more than one facility. Three groups of livestock facilities were identified for each residential sales property: (*a*) the closest operation, (*b*) operations within 3 miles of the property, and (*c*) operations within 10 miles of the property. The dataset contains 47 property sales that have at least one confinement located at ½ mile or less, 149 properties with a confinement between ½ and 1 mile, and 491 properties with a confinement between 1 and 3 miles.[17] For the closest livestock operation, we calculated the distance to the property (*Dist1*), the size of the nearest livestock facility (*Size1*), and whether the facility was upwind of the property during the winter (*NW1*) or summer (*SO1*) seasons.[18] As Table 3 indicates, the average distance to the nearest livestock facility is 2.8 miles and ranges from just 0.01 to 6.8 miles. Roughly 30 percent of the nearest livestock facilities are upwind of the sales sites during the winter months and 22 percent are upwind during the summer months.

While the nearest livestock facility is likely to have the most direct impact on the residential property value, the concentration of facilities in the region also may have an impact. In addition to computing the total number of facilities within a 3-mile radius of each property (*Mile3*), we also computed the average size of these facilities (*Size3*) and the percentage that are upwind during the winter (*NW3*) and summer (*SO3*) seasons. As Table 3 indicates, there is considerable variation in the concentration of facilities around the residential sales site. While on average there are 2.5 livestock facilities within 3 miles of the properties sold, this number ranges from 0 to 27 in the data set.[19]

Finally, we calculated the number of confinements in a 10-mile radius of each property centroid. We hypothesized that the presence of a large number of confinements within such a large radius might have a positive impact on local economic activity, while the distance from the residential properties would be too large for odor to affect sale values. As Table 3 indicates, the number of livestock confinements in the 10-mile radius averages 28.4 and ranges from 2 to 104.

Model Specification and Hypotheses

Theory provides little or no guidance in terms of the choice of functional form for the hedonic price function. Instead, it is standard practice to consider a variety of functional forms in order to determine the sensitivity of the results to form choice and to choose the form that provides the best fit to the data. We investigate four broad classes of models in the current analysis:

$$\text{Model 1: } P_i = \alpha' Z_i + \left(\beta' X_{1i}\right) DI_i^{-1} + \left(\delta' X_{3i}\right) Mile3_i + \gamma Mile10_i \,, \tag{3}$$

$$\text{Model 2: } \ln\left(P_i\right) = \alpha' Z_i + \left(\beta' X_{1i}\right) DI_i^{-1} + \left(\delta' X_{3i}\right) Mile3_i + \gamma Mile10_i \,, \tag{4}$$

$$\text{Model 3: } P_i = \alpha' Z_i + \left(\beta' X_{1i}\right) \ln\left(DI_i\right) + \left(\delta' X_{3i}\right) Mile3_i + \gamma Mile10_i \,, \tag{5}$$

and

$$\text{Model 4: } \ln\left(P_i\right) = \alpha' Z_i + \left(\beta' X_{1i}\right) \ln\left(DI_i\right) + \left(\delta' X_{3i}\right) Mile3_i + \gamma Mile10_i \,, \tag{6}$$

where Z_i denotes the vector of structural and location characteristics for each sales unit (i.e., the first two sets of variables in Table 3), X_{1i} denotes the vector of characteristics of the nearest livestock facility for each home (i.e., size and wind direction dummies), and X_{i3} denotes the vector of characteristics of the facilities within 3 miles of each home. The differences among the four groups of models lie in the forms of the dependent variable and the distance to the nearest livestock facility. Models 1 and 3 have the sales price enter linearly, whereas Models 2 and 4 use log-price as the dependent variable. In Models 1 and 2, the inverse distance to the nearest livestock facility is used, whereas in Models 3 and 4, the distance to the nearest livestock facility enters in logarithmic form.[20] In general, the results of the hedonic regression analysis were similar across these four classes of models. However, Model 4 (the double-log specification) provided the best fit.[21]

In addition to the basic model variations in equations (3) through (6), two alternative measures of size were used for each livestock facility: live weight (pounds) and manure production (pounds per year). Again, the qualitative finding reported as follows did not change with the choice of these size measures. However, the models that include the live weight measure dominated those based on manure production. In the results section, we report only the results based on live weight measure. Thus, using the notation for the variables listed in Table 3, the final model becomes

$$\begin{aligned}\ln\left(Price_i\right) = {} & \alpha_0 + \alpha_Z \widetilde{LSize}_i + \alpha_{YR} \widetilde{SYear}_i + \alpha_{AG} \widetilde{Age}_i + \alpha_{LA} \widetilde{LArea}_i + \alpha_{Ad} \widetilde{AdArea}_i \\ & + \alpha_{AC} AirC_i + \alpha_{Bt} \widetilde{Baths}_i + \alpha_{Dk} \widetilde{Decks}_i + \alpha_{Fr} \widetilde{Fire}_i + \alpha_{AG} \widetilde{AttG}_i + \alpha_{DG} \widetilde{DetG}_i \\ & + \alpha_{Tw} \widetilde{DistTown}_i + \alpha_{HS} \widetilde{DistHS}_i + \alpha_{PD} \widetilde{PDens}_i + \alpha_{MI} \widetilde{MedInc}_i \\ & + \left[\beta_0 + \beta_Z \ln\left(\widetilde{Size1}_i\right) + \beta_N \widetilde{NW1}_i + \beta_S \widetilde{SO1}_i\right] \ln\left(DI_i\right) \\ & + \left[\delta_0 + \delta_Z \ln\left(\widetilde{Size3}_i\right) + \delta_N \widetilde{NW3}_i + \delta_S \widetilde{SO3}_i\right] \widetilde{Mile3}_i \\ & + \gamma \widetilde{Mile10}_i\end{aligned} \tag{7}$$

where the tildes above each variable indicate that they are measured relative to the mean in the sample.[22]

There are a number of hypotheses of interest in terms of the hedonic price function. Specifically, we consider the following four hypotheses:

- $H_0^A : \beta = \delta = \gamma = 0$. This hypothesis corresponds to a test as to whether the livestock facilities have any effect on rural residential property values.
- $H_0^B : \delta = 0$. This hypothesis corresponds to a test as to whether concentration of livestock facilities in the region has any effect on rural residential property values, over and above the impact of the nearest facility.
- $H_0^C : \delta = \gamma = 0$. This hypothesis corresponds to a test as to whether only the nearest livestock facility affects a property.
- $H_0^D : \beta_k = \delta_k = 0 \forall k \neq 0$. This hypothesis corresponds to a test as to whether the characteristics of the livestock facilities (i.e., size and wind direction) have any effect on rural residential property values.

Results

Table 4 provides the results of estimating the hedonic price equation in (7). Coefficient estimates are presented for the unconstrained model and under each of the hypotheses outlined in the previous section.

All of the structural characteristics of the home have the expected signs and are statistically different from 0 at the 1 percent level or better. For example, each year of age of the home reduces its value by roughly 0.4 percent, while a deck increases the home value by 5 percent, and each fireplace increases the value by 8 percent. Moreover, the coefficients change little across the various model specifications. Likewise, the location variables, with the exception of distance to high school, have the expected size and signs. Each mile away from the nearest large town diminishes the property value by approximately 0.7 percent, whereas homes in areas with greater population densities and/or higher median income levels are generally more valuable. The only unusual result among the non-livestock factors is the coefficient on the distance to the nearest high school. In general, one would expect that this coefficient would be negative, indicating that easy access to the education system would increase the value of a home. However, under all the model specifications considered, the coefficient on *DistHS* is positive and significant at a 5 percent level or higher.

TABLE 4. Parameter estimates

Variable	Unconstrained	$H_0^A: \beta = \delta = \gamma = 0$	$H_0^B: \delta = 0$	$H_0^C: \delta = \gamma = 0$	$H_0^D: \beta_k = \delta_k = 0 \ \forall k \neq 0$
Intercept	11.07***	11.11***	11.08***	11.11***	11.08***
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)
LSize	0.059***	0.061***	0.059***	0.062***	0.058***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
SYear	0.059***	0.059***	0.059***	0.059***	0.058***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Age	-0.004***	-0.004***	-0.004***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
LArea	0.00029***	0.00028***	0.00029***	0.00028***	0.00030***
	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)
AdArea	0.00034***	0.00035***	0.00034***	0.00034***	0.00035***
	(0.00005)	(0.00005)	(0.00005)	(0.00005)	(0.00005)
AirC	0.31***	0.31***	0.31***	0.31***	0.31***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Baths	0.17***	0.18***	0.17***	0.18***	0.17***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Decks	0.046***	0.046***	0.044***	0.044***	0.046***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Fire	0.076***	0.081***	0.077***	0.076***	0.084***
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
AttG	0.16***	0.17***	0.16***	0.16***	0.16***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
DetG	0.09***	0.10***	0.09***	0.09***	0.09***
	(0.04)	(0.03)	(0.03)	(0.03)	(0.04)
DistTown	-0.0065**	-0.0070***	-0.0068***	-0.0066***	-0.0070***
	(0.0025)	(0.0025)	(0.0026)	(0.0026)	(0.0025)
DistHS	0.0036**	0.0030**	0.0035**	0.0026*	0.0040**
	(0.0016)	(0.0016)	(0.0016)	(0.0016)	(0.0016)
PDens	0.0011**	0.0013**	0.0012**	0.0014***	0.0012**
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
MedInc	0.015***	0.013***	0.014***	0.013***	0.014***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)

TABLE 4. Continued

Variable	Unconstrained	$H_0^A: \beta = \delta = \gamma = 0$	$H_0^B: \delta = 0$	$H_0^C: \delta = \gamma = 0$	$H_0^D: \beta_k = \delta_k = 0 \ \forall k \neq 0$
LN(DI1)	-0.009		-0.011	-0.038*	0.029
	(0.029)		(0.026)	(0.021)	(0.025)
*Size1*LN(DI1)*	-0.064		-0.086**	-0.075*	
	(0.042)		(0.040)	(0.040)	
*NW1*LN(DI1)*	0.052*		0.045	0.047	
	(0.029)		(0.029)	(0.029)	
*SO1*LN(DI1)*	0.036		0.031	0.033	
	(0.029)		(0.029)	(0.029)	
Mile3	0.0010				0.0080
	(0.0079)				(0.0066)
*Size3*Mile3*	-0.0060				
	(0.0169)				
*NW3*Mile3*	0.00043*				
	(0.00025)				
*SO3*Mile3*	0.00027				
	(0.00022)				
Mile10	0.0015		0.0018**		0.0011
	(0.0009)		(0.0008)		(0.0009)
LogLik	-638.9	-649.2	-641.3	-644.3	-645.5
χ^2		20.6***	4.8	10.8*	13.2**
Df		9	4	5	6
P-value		0.01	0.31	0.06	0.04

*Statistically different from zero at a 10% level. **Statistically different from zero at a 5% level. ***Statistically different from zero at a 1%level.

Turning to the livestock proximity factors, the unconstrained model in column 2 of Table 4 indicates that few of these coefficients are individually significant. The exceptions are the two wind direction variables associated with the winter season. Specifically, the coefficient on the interaction term *NW1*ln(DI1)* is positive and statistically significant at a 10 percent level. This indicates that for homes downwind of a livestock facility during the winter season, an increase in the distance to the facility is associated with a higher property value (i.e., proximity to the livestock facility is a disamenity). While a similar point estimate applies to the summer wind direction variable, it is not statistically significant. On the other hand, the coefficient on the interaction term *NW3*Mile3* is positive and significant at a 10 percent level, indicating that a higher number of facilities in the region is generally associated with higher property values. This may be capturing the positive impact of economic activity in the region on property values.

While the livestock factors are not measured precisely on an individual basis, it is apparent that they are significant as a group. In column 3 of Table 4, the hedonic price coefficient estimates are presented under the hypothesis that all of the livestock factors are 0. The associate likelihood ratio test statistic ($\chi^2_{df=9}$ =20.6) clearly rejects this hypothesis with a p-value of 0.01. Livestock facilities apparently do have a significant effect on rural residential property values in Iowa.

The lack of individual coefficient significance for the livestock variables may be due in part to the high degree of correlation among some of the explanatory variables. In particular, for many housing units the closest livestock facility is also the only livestock facility within a 3-mile radius, resulting in substantial correlation among the *ln(DI1)* and *Mile3* variables. Column 4 of Table 4 considers a simpler specification for the livestock variables, restricting the *Mile3* factors all to 0. This hypothesis is not rejected at any reasonable level. However, restricting both the *Mile3* and *Mile10* factors to be 0, as in column 5, is clearly rejected. Finally, ignoring the size and wind direction characteristics of the surrounding livestock facilities (as in the model presented in column 6) is also rejected as a restriction.

To illustrate the implications of the livestock factors for housing prices, Table 5 presents the price elasticity of housing with respect to the distance to the nearest livestock facility. Using equation (7), this elasticity is given by

$$\begin{aligned}\eta_{DI1} &= \frac{\partial \ln\left(Price_i\right)}{\partial \ln\left(DI_i\right)} \\ &= \beta_0 + \beta_Z \ln\left(\widetilde{Size1}_i\right) + \beta_N \widetilde{NW1}_i + \beta_S \widetilde{SO1}_i\end{aligned}, \tag{8}$$

and depends on both the wind direction and size of the nearest operation. In Table 5, we calculate this elasticity for three sizes of operations (250,000; 450,000; and 650,000 live weight) and three wind direction scenarios (*NW1*=1, *SO1*=1, and *NW1*=*SO1*=0). In general, if the nearest livestock facility is a disamenity, one would expect the elasticity η_{DI1} to be positive, indicating that the value of the rural residential property increases as the distance to the nearest livestock facility increases.

Several patterns emerge in terms of the distance elasticities in Table 5. First, point estimates for these elasticities are largest if the nearest facility is upwind in the winter months (i.e., northwest) and smallest if the facility is downwind from the property (column 4). Second, while the distance elasticities are generally positive, as expected, they are statistically significant only in two cases: when the livestock facility is moderately sized (250,000) and when it is upwind of the home. While this finding first seems counterintuitive, the size of the facilities may be serving as a proxy for other

TABLE 5. Price elasticities

Size of nearest facility (live weight)	Wind direction *NW=1*	*SO=1*	*NW1=SO1=0*
250,000	0.098***	0.085**	0.053
	(0.034)	(0.036)	(0.039)
450,000	0.044	0.031	-0.009
	(0.029)	(0.029)	(0.026)
650,000	0.024	0.011	-0.022
	(0.033)	(0.032)	(0.027)

** Statistically different from zero at a 5% level. *** Statistically different from zero at a 1% level.

unobserved attributes of the confinement unit, including its age and the type of storage system. In particular, most of the largest facilities in Iowa are relatively new and rely on liquid manure storage systems. Additional research, including information on the management and infrastructure of each livestock facility, is needed in order to disentangle the dependence of the distance elasticity on facility size.

Finally, consider a rural residential property that currently has no livestock facility located within a 3-mile radius. Tables 6a through 6c provide the predicted reductions in property value that would result from a new livestock facility locating at various distances away from a residence.[23] For example, Table 6a considers locating the new facility ¼ mile away from the home. The pattern of results, not surprisingly, is similar to that found for the distance elasticities reported in Table 5. The impact is largest if the new facility is located upwind of the home and is moderate in size (i.e., 250,000 pounds live weight). Moreover, the property value reductions are statistically significant at a 95 percent confidence level only for the upwind and the moderate-sized facilities. In these cases, the new facility would reduce the property value on average by 26 percent if located northwest of the home and 22 percent if located south. For the average-sized facility of 450,000 live weight, the percentage reductions are substantially smaller (less than one-half) and statistically insignificant in all cases. Locating the new facility ½ mile away from the residence (as in Table 6b) reduces the impact by 30 to 40 percent, but the pattern remains the same in terms of statistical significance and the influence of wind direction and size. Finally, locating the facility 1½ miles from the property (Table 6c) further reduces the impact, with the property value reduction now ranging from roughly 0 to 6 percent.

Conclusions

Iowa is an ideal place to raise livestock. The state has relatively few people, abundant land, its crop sector imports fertilizer, and it has the lowest-cost feed. Yet, currently it is quite difficult to build a new livestock feeding operation in Iowa because of the opposition of rural residents. The estimated effects of proximity to livestock feeding operations on property values in this study help explain the stalemate in siting new

TABLE 6A. Percentage reduction in property value from a new facility located ¼ mile away[a]

	Wind Direction		
Size of Facility (live weight)	***NW=1***	***SO=1***	***NW1=SO1=0***
250,000	26** (5,49)	22** (1,45)	13 (-6,34)
450,000	11 (-5,29)	7 (-7,24)	-1 (-13,13)
650,000	3 (-15,22)	-1 (-16,17)	-8 (-20,6)

Note: 95% confidence bounds in parentheses.
**Statistically different from zero at a 5% level.

TABLE 6B. Percentage reduction in property value from a new facility located ½ mile away

	Wind Direction		
Size of Facility (live weight)	***NW=1***	***SO=1***	***NW1=SO1=0***
250,000	18** (4,33)	15** (1,31)	9 (-4,24)
450,000	8 (-4,20)	5 (-5,17)	-1 (-9,9)
650,000	2 (-11,16)	0 (-12,12)	-6 (-15,5)

Note: 95% confidence bounds in parentheses.
**Statistically different from zero at a 5% level.

TABLE 6C. Percentage reduction in property value from a new facility located 1½ miles away

	Wind Direction		
Size of Facility (live weight)	***NW=1***	***SO=1***	***NW1=SO1=0***
250,000	6** (1,12)	6** (0,11)	3 (-2,9)
450,000	3 (-1,7)	2 (-2,6)	0 (-4,3)
650,000	1 (-4,6)	-1 (-16,17)	-2 (-6,2)

Note: 95% confidence bounds in parentheses.
**Statistically different from zero at a 5% level.

operations in Iowa. The results suggest that there may be approximately a 10 percent drop in property value if a new livestock feeding operation is located upwind and near a residence. This drop in value helps explain opposition by rural residents to large-scale feeding operations. Livestock supporters often admit there could be circumstances whereby livestock facilities might affect property values, but they argue that the costs are worth bearing because of the need to support a competitive industry in the state. From their perspective, a 10 percent drop in the price of a $100,000 home is not large when compared to investment costs of more than $300,000 for a new operation. The siting stalemate reflects the political stalemate in Iowa. The state's political leaders do not seem to be able to resolve the problem because of the conflicting interests of important political constituents.

This is a classic problem in which a production externality cannot be internalized because of a lack of property rights. If rural residents were granted the right to be free of damage, then our estimate of the magnitude of the effects of livestock facilities on property values suggests room for mutually beneficial trading. If the willingness to pay to site a feeding operation in Iowa exceeds the willingness to accept the damage caused by the facility, then one would expect private negotiations to result in an agreement whereby livestock operators would pay residents for the right to locate their feeding operations nearby.

The results suggest that the magnitude of the payments that would have to be made would be relatively modest if operators followed common sense siting rules. For example, we cannot reject the hypothesis that siting a facility out of the path of prevailing winds causes no damage. And the results are consistent with the expected finding that the greater the distance between the facility and the residence, the less the damage. Thus, if an operator would negotiate with residents located within a mile or so of a proposed site, the site were located no closer than ½ mile of a resident, and no residence was located downwind of the site, then we would expect the required payments to obtain the acquiescence of the residents to be relatively modest.

Of course, our point estimates are only our best prediction of the average damages. Actual damages depend on unmodeled effects such as local topographic features, site-specific management practices, the type of manure storage and land application techniques used, and other factors. Agreements between livestock feeders and rural residents would have to include good faith provisions in which operators followed prescribed management practices that are shown to reduce damage and subsequently residents agreed to allow the feeding facility to remain in operation.

More precise estimates of the effects of feeding operations on property values could be obtained by gathering more data about the attributes of the operations. In particular, our finding that proximity to moderate-sized operations (250,000 pounds live weight) results in greater damage to property values than proximity to large operations likely is a result of different management practices employed at smaller units. Greater knowledge of the management practices used on the various-sized units would allow us to better estimate the effects of size on damage.

Endnotes

1. As Palmquist, Roka, and Vukina (1997) note, similar trends toward industry concentration have emerged in North Carolina, the second largest pork producer in the nation. By 1993, 13 percent of the producers were responsible for 95 percent of the state's total swine production (Hurt and Zering 1993).

2. For the text of the bill, see <http://www.legis.state.ia.us/GA/79GA/Legislation/SF/02200/SF02293/Current.html>.

3. The case, heard by a Sac County jury, was *Blass et al.* vs. *Iowa Select Farms, Inc*.

4. Construction permits were also required for confinement feeding operations that used earthen storage and had an animal weight capacity of 200,000 pounds or more (400,000 or more pounds for bovine).

5. Freeman (2003, chap. 11) and Palmquist (1991) provide more complete overviews of theory underlying hedonic pricing analysis.

6. Farber (1998) provides a summary of recent studies of the impact of LULUs on property values.

7. Specifically, the house variables were the square footage, the age of the house, the number of bedrooms and bathrooms, and the assessor's estimate of the ratio of house value to property value.

8. Wright County was originally included in our study area but eventually was dropped because of problems in obtaining residential sales data for the county.

9. Specifically, among the counties with a high density of livestock operations, Franklin has over 36 percent of moderate-sized facilities, Hamilton has 22 percent, and Hardin has 29 percent.

10. In order to properly account for proximity to animal operations for rural residential properties that were close to the county boundaries, we added a 10-mile buffer around the study area and included livestock facilities found in the buffer. The averages in Table 1 include facilities in the five-county study area (349) and the buffer zone (201).

11. There are two limitations to the livestock facilities data available for our analysis. First, we have information on only those operations in the five-county study area that are sufficiently large to require a manure management plan and/or a construc-

tion permit. Thus, we are not able to control for the impact of smaller livestock operations on rural residential property values. However, we were able to obtain data on all of the livestock facilities for Franklin County. This additional information did not change qualitatively the regression results for Franklin County. Second, the IDNR data does not provide a time series on the size (i.e., live weight) of each of the livestock facilities. Instead, we assumed that the operation size and locations were those reported in the manure management plan or construction permit filing and were constant over the study period. This creates a potential measurement error problem, particularly for those housing sales during the early 1990s. However, sensitivity analysis, excluding homes sold prior to 1996, again did not change the nature of the results.

12. The largest operation in the data set corresponds to an egg laying operation.

13. Because each assessor's office had different filing systems, in some counties we were unable to obtain data for sales in the early 1990s.

14. DOQQs are available at <http://cairo.gis.iastate.edu/doqqs.html>.

15. Specifically, we used Sidwell's online maps (<http://www.sidwellmaps.com/>) for Franklin and Humboldt counties, and copies of the assessor's paper maps for Hamilton County. All data were analyzed in UTM Zone 15, NAD83.

16. We chose the 2,500 population cutoff in consultation with Daniel Otto, an Iowa State University Extension expert in economic and rural development. Towns over 2,500 were deemed large enough to serve as a hub of local economic activity, both in terms of employment and shopping.

17. It is worth noting that, according to Iowa law, operations built after January 1, 1999, have to comply with regulations on minimum distance to buildings and public use areas that range from 750 to 1,875 feet. Details about the regulation are available at the web site of the Iowa Department of Natural Resources, Water Quality Bureau.

18. The latter two wind direction variables were based on prevailing wind directions in Iowa (Mukhtar and Zhang 1995). Specifically, $SO1$=1 if the angle between the closest confinement and the house was between 135° and 255°, and $NW1$ = 1 if the angle between the closest confinement and the house was between 270° and 360°.

19. There are 458 properties that have no confinements within a 3-mile radius and 524 that have one to five operations within it. The remaining 163 properties have between 6 and 27 operations in the 3-mile radius.

20. Note that both the inverse distance and log distance ensure that the impact of a negative externality diminishes with distance.

21. The choice between the linear and logarithmic price specifications (i.e., Models 1 and 3 versus Models 2 and 4) was the most straightforward. Following PRV

(endnote 4), the sum of squared residuals from the two specifications were compared, after first normalizing observed prices by their geometric means. Palmquist and Danielson (1989) show that this is equivalent to using the Box-Cox criterion. The differences between using inverse distance and log-distances to the nearest site were less substantial, but the log-distance specification (i.e., Model 4) consistently dominated in terms of log-likelihood.

22. For example, $\widetilde{Age}_i \equiv Age_i - \overline{Age}_i$ where $\overline{Age}_i$ denotes the mean house age in the sample.

23. For the purposes of this exercise, we use the simpler hedonic price specification in column 4 of Table 4.

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Impacts of Waste from Concentrated Animal Feeding Operations on Water Quality

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Waste from agricultural livestock operations has been a long-standing concern with respect to contamination of water resources, particularly in terms of nutrient pollution. However, the recent growth of concentrated animal feeding operations (CAFOs) presents a greater risk to water quality because of both the increased volume of waste and to contaminants that may be present (e.g., antibiotics and other veterinary drugs) that may have both environmental and public health importance. Based on available data, generally accepted livestock waste management practices do not adequately or effectively protect water resources from contamination with excessive nutrients, microbial pathogens, and pharmaceuticals present in the waste. Impacts on surface water sources and wildlife have been documented in many agricultural areas in the United States. Potential impacts on human and environmental health from long-term inadvertent exposure to water contaminated with pharmaceuticals and other compounds are a growing public concern. This workgroup, which is part of the Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions, identified needs for rigorous ecosystem monitoring in the vicinity of CAFOs and for improved characterization of major toxicants affecting the environment and human health. Last, there is a need to promote and enforce best practices to minimize inputs of nutrients and toxicants from CAFOs into freshwater and marine ecosystems. *Key words:* ecology, human health, poultry, swine, water contaminants, wildlife. *Environ Health Perspect* 115:308–312 (2007). doi:10.1289/ehp.8839 available via *http://dx.doi.org/* [Online 14 November 2006]

Background and Recent Developments

Concentrated animal feed operations and water quality. Animal cultivation in the United States produces 133 million tons of manure per year (on a dry weight basis) representing 13-fold more solid waste than human sanitary waste production [U.S. Environmental Protection Agency (U.S. EPA) 1998]. Since the 1950s (poultry) and the 1970s–1980s (cattle, swine), most animals are now produced for human consumption in concentrated animal feeding operations (CAFOs). In these industrialized operations, the animals are held throughout their lives at high densities in indoor stalls until they are transported to processing plants for slaughter. There is substantial documentation of major, ongoing impacts on aquatic resources from CAFOs, but many gaps in understanding remain.

Contaminants detected in waste and risk of water contamination. Contaminants from animal wastes can enter the environment through pathways such as through leakage from poorly constructed manure lagoons, or during major precipitation events resulting in either overflow of lagoons and runoff from recent applications of waste to farm fields, or atmospheric deposition followed by dry or wet fallout (Aneja 2003). The magnitude and direction of transport depend on factors such as soil properties, contaminant properties, hydraulic loading characteristics, and crop management practices (Huddleston 1996). Many contaminants are present in livestock wastes, including nutrients (Jongbloed and Lenis 1998), pathogens (Gerba and Smith 2005; Schets et al. 2005), veterinary pharmaceuticals (Boxall et al. 2003; Campagnolo et al. 2002; Meyer 2004), heavy metals [especially zinc and copper; e.g., Barker and Zublena (1995); University of Iowa and Iowa State Study Group (2002)], and naturally excreted hormones (Hanselman et al. 2003; Raman et al. 2004). Antibiotics are used extensively not only to treat or prevent microbial infection in animals (Kummerer 2004), but are also commonly used to promote more rapid growth in livestock (Cromwell 2002; Gaskins et al. 2002; Liu et al. 2005). In addition, pesticides such as dithiocarbamates are applied to sprayfields (Extension Toxicology Network 2003). Although anaerobic digestion of wastes in surface storage lagoons can effectively reduce or destroy many pathogens, substantial remaining densities of microbial pathogens in waste spills and seepage can contaminate receiving surface- and groundwaters (e.g., Burkholder et al. 1997; Mallin 2000). Pharmaceuticals can remain present as parent compounds or degradates in manure and leachates even during prolonged storage. Improper disposal of animal carcasses and abandoned livestock facilities can also contribute to water quality problems. Siting of livestock operations in areas prone to flooding or where there is a shallow water table increases the potential for environmental contamination.

The nutrient content of the wastes can be a desirable factor for land application as fertilizer for row crops, but overapplication of livestock wastes can overload soils with both macronutrients such as nitrogen (N) and phosphorous (P), and heavy metals added to feed as micronutrients (e.g., Barker and Zublena 1995). Overapplication of animal wastes or application of animal wastes to saturated soils can also cause contaminants to move into receiving waters through runoff and to leach through permeable soils to vulnerable aquifers. Importantly, this may happen even at recommended application rates. As examples, Westerman et al. (1995) found 3–6 mg nitrate (NO_3)/L in surface runoff from sprayfields that received swine effluent at recommended rates; Stone et al. (1995) measured 6–8 mg total inorganic N/L and 0.7–1.3 mg P/L in a stream adjacent to swine effluent sprayfields. Evans et al. (1984) reported 7–30 mg NO_3/L in subsurface flow draining a sprayfield for swine wastes, applied at recommended rates. Ham and DeSutter (2000) described export rates of up to 0.52 kg ammonium m^{-2} $year^{-1}$ from lagoon seepage; Huffman and Westerman (1995) reported that groundwater near swine waste lagoons averaged 143 mg inorganic N/L, and estimated export rates at 4.5 kg inorganic N/day. Thus, nutrient losses into receiving waters can be excessive relative to levels (~ 100–200 µg inorganic N or P/L)

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known to support noxious algal blooms (Mallin 2000). In addition to contaminant chemical properties, soil properties and climatic conditions can affect transport of contaminants. For example, sandy, well-drained soils are most vulnerable to transport of nutrients to underlying groundwater (Mueller et al. 1995). Nutrients can also readily move through soils under wet conditions (McGechan et al. 2005).

Presence of contaminants in water sources. The presence of many contaminants from livestock waste has been documented in both surface water and groundwater supplies in agricultural areas within the United States (e.g., Campagnolo et al. 2002; Kolpin et al. 2002; Meyer 2004). Urban wastewater streams also contain these contaminants, and efforts to accurately determine sources of contamination are under way (Barnes et al. 2004; Cordy et al. 2004; Kolpin DW, unpublished data). The U.S. Geological Survey (USGS) began pilot surveillance programs for organic wastewater contaminants in 1999 and expanded that effort to a national scale over the past 5 years (Kolpin et al. 2002). Recent USGS efforts have focused specifically on water quality in agricultural locations (Kolpin DW, unpublished data). Nutrient levels have been detected in high parts per million (milligrams per liter) levels; pharmaceuticals and other compounds are generally measured in low levels (ppb [micrograms per liter]). In Europe, surveillance efforts conducted in Germany documented the presence of veterinary pharmaceuticals in water resources (Hirsch et al. 1999).

Animal wastes are also rich in organics and high in biochemical oxygen-demanding materials (BOD); for example, treated human sewage contains 20–60 mg BOD/L, raw sewage contains 300–400 mg BOD/L, and swine waste slurry contains 20,000–30,000 mg BOD/L (Webb and Archer 1994). Animal wastes also carry parasites, viruses, and bacteria as high as 1 billion/g (U.S. EPA 1998). Swine wastes contain > 100 microbial pathogens that can cause human illness and disease [see review in Burkholder et al. (1997)]. About one-third of the antibiotics used in the United States each year is routinely added to animal feed to increase growth (Mellon et al. 2001). This practice is promoting increased antibiotic resistance among the microbial populations present and, potentially, increased resistance of naturally occurring pathogens in surface waters that receive a portion of the wastes.

Contaminant impacts. Some contaminants pose risks for adverse health impacts in wildlife or humans. The effects of numerous waterborne pathogens on humans are well known, although little is known about potential impacts of such microorganisms on aquatic life. With respect to nutrients, excessive phosphorus levels can contribute to algal blooms and cyanobacterial growth in surface waters used for recreation and as sources of drinking water. Research is beginning to investigate the environmental effects, including endocrine disruption and antibiotic resistance issues (Burnison et al. 2003; Delepee et al. 2004; Fernandez et al. 2004; Halling-Sorensen et al. 2003; Sengelov et al. 2003; Soto et al. 2004; Wollenberger et al. 2000). However, knowledge is limited in several crucial areas. These areas include information on metabolites or environmental degradates of some parent compounds; the environmental persistence, fate, and transport and toxicity of metabolites or degradates (Boxall et al. 2004); the potential synergistic effects of various mixtures of contaminants on target organisms (Sumpter and Johnson 2005); and the potential transport and effects from natural and synthetic hormones (Hanselman et al. 2003; Soto et al. 2004). Further, limited monitoring has been conducted of ecosystem health in proximity to CAFOs, including monitoring the effects on habitats from lagoon spills during catastrophic flooding (Burkholder et al. 1997; Mallin et al. 1997; Mallin et al. 2000).

Ecologic and wildlife impacts. Anoxic conditions and extremely high concentrations of ammonium, total phosphorus, suspended solids, and fecal coliform bacteria throughout the water column for approximately 30 km downstream from the point of entry have been documented as impacts of waste effluent spills from CAFOs (Burkholder et al. 1997; Mallin et al. 2000). Pathogenic microorganisms such as *Clostridium perfringens* have been documented at high densities in receiving surface waters following CAFO waste spills (Burkholder et al. 1997). These degraded conditions, especially the associated hypoxia/anoxia and high ammonia, have caused major kills of freshwater fish of all species in the affected areas, from minnows and gar to largemouth bass, and estuarine fish, including striped bass and flounder (Burkholder et al. 1997). Waste effluent spills also stimulated blooms of toxic and noxious algae. In freshwaters, these blooms include toxic and noxious cyanobacteria while in estuaries, harmful haptophytes and toxic dinoflagellates arise. Most states monitor only water-column fecal coliform densities to assess whether waterways are safe for human contact. World Health Organization (WHO) guidelines for cyanobacteria in recreational water are 20,000 cyanobacterial cells/mL, which indicates low probability of adverse health effects, and 100,000 cyanobacterial cells/mL, which indicates moderate probability of adverse health effects (WHO 2003). Yet fecal bacteria and other pathogenic microorganisms typically settle out to the sediments where they can thrive at high densities for weeks to months following CAFO waste effluent spills (Burkholder et al. 1997).

The impacts from CAFO pollutant loadings to direct runoff are more substantial after such major effluent spills or when CAFOs are flooded and in direct contact with surface waters (Wing et al. 2002). Although the acute impacts are often clearly visible—dead fish floating on the water surface, or algal overgrowth and rotting biomass—the chronic, insidious, long-term impacts of commonly accepted practices of CAFO waste management on receiving aquatic ecosystems are also significant (U.S. EPA 1998). One purpose of manure storage basins is to reduce the N content of the manure through volatilization of ammonia and other N-containing molecules. Many studies have shown, for example, that high nutrient concentrations (e.g., ammonia from swine CAFOs, or ammonia oxidized to NO_3, or phosphorus from poultry CAFOs) commonly move off-site to contaminate the overlying air and/or adjacent surface and subsurface waters (Aneja et al. 2003; Evans et al. 1984; Sharpe and Harper 1997; Sharpley and Moyer 2000; Stone et al. 1995; U.S. EPA 1998; Webb and Archer 1994; Westerman et al. 1995; Zahn et al. 1997). Inorganic N forms are added to the atmosphere during spray practices, and both ammonia and phosphate can also adsorb to fine particles (dust) that can be airborne. The atmospheric depositions are noteworthy, considering that a significant proportion of the total ammonium from uncovered swine effluent lagoons and effluent spraying (an accepted practice in some states) reenters surface waters as local precipitation or through dry fallout (Aneja et al. 2003; U.S. EPA 1998, 2000). The contributed nutrient concentrations from the effluent greatly exceed the minimal levels that have been shown to promote noxious algal blooms (Mallin 2000) and depress the growth of desirable aquatic habitat species (Burkholder et al. 1992). The resulting chronically degraded conditions of nutrient overenrichment, while not as extreme as during a major waste spill, stimulate algal blooms and long-term shifts in phytoplankton community structure from desirable species (e.g., diatoms) to noxious species.

A summary of the findings from a national workshop on environmental impacts of CAFOs a decade ago stated that there was "a surprising lack of information about environmental impacts of CAFOs to adjacent lands and receiving waters" (Thu K, Donham K, unpublished data). Although the knowledge base has expanded since that time, especially regarding adverse effects of inorganic N and P overenrichment and anoxia, impacts of many CAFO pollutants on receiving aquatic ecosystems remain poorly understood. As examples, there is poor understanding of the impacts of fecal bacteria and other microbial pathogens from CAFO waste effluent contamination on aquatic communities; impacts of antibiotic-resistant bacteria created from CAFO wastes on aquatic life; impacts of organic nutrient forms preferred by certain noxious plankton; impacts from the contributed pesticides and heavy metals; and impacts from these pollutants acting in concert, additively or synergistically. This lack of information represents a critical gap in our present ability to assess the full extent of CAFO impacts on aquatic natural resources.

Despite their widespread use, antibiotics have only recently received attention as environmental contaminants. Most antibiotics are designed to be quickly excreted from the treated organism. Thus, it is not surprising that antibiotics are commonly found in human and animal waste (Christian et al. 2003; Dietze et al. 2005; Glassmeyer et al. 2005; Meyer 2004) and in water resources affected by sources of waste (Glassmeyer et al. 2005; Kolpin et al. 2002). Although some research has been conducted on the environmental effects from antibiotics (e.g., Brain et al. 2005; Jensen et al. 2003), much is yet to be understood pertaining to long-term exposures to low levels of antibiotics (both individually and as part of complex mixtures of organic contaminants in the environment). The greatest risks appear to be related to antibiotic resistance (Khachatourians 1998; Kummerer 2004) and natural ecosystem functions such as soil microbial activity and bacterial denitrification (Costanzo et al. 2005; Thiele-Bruhn and Beck 2005).

Human health impacts. Exposure to waterborne contaminants can result from both recreational use of affected surface water and from ingestion of drinking water derived from either contaminated surface water or groundwater. High-risk populations are generally the very young, the elderly, pregnant women, and immunocompromised individuals. Recreational exposures and illnesses include accidental ingestion of contaminated water that may result in diarrhea or other gastrointestinal tract distress from waterborne pathogens, and dermal contact during swimming that may cause skin, eye, or ear infections. Drinking water exposures to pathogens could occur in vulnerable private wells; under normal circumstances community water utilities disinfect water sufficiently before distribution to customers. Cyanobacteria (blue–green algae) in surface water can produce toxins (e.g., microcystins) that are known neurotoxins and hepatotoxins. Acute and chronic health impacts from these toxins can occur from exposures to both raw water and treated water (Carmichael et al. 2001; Rao et al. 2002). Removal of cyanotoxins during drinking water treatment is a high priority for the drinking water industry (Hitzfield et al. 2000; Rapala et al. 2002). The WHO has set a provisional drinking water guideline of 1 µg microcystin-LR/L (Chorus and Bartram 1999). While there are no drinking water standards in the United States for cyanobacteria, they are on the U.S. EPA Unregulated Contaminant Monitoring Rule List 3 (U.S. EPA 2006).

Exposure to chemical contaminants can occur in both private wells and community water supplies, and may present health risks. High nitrate levels in water used in mixing infant formula have been associated with risk for methemoglobinemia (blue-baby syndrome) in infants under 6 months of age, although other health factors such as diarrhea and respiratory disease have also been implicated (Ward et al. 2005). The U.S. EPA drinking water standard of 10 mg/L NO_3–N and the WHO guideline of 11 mg/L NO_3–N were set because of concerns about methemoglobinemia. (Note: "nitrate" refers to nitrate–nitrogen). Epidemiologic studies of noncancer health outcomes and high nitrate levels in drinking water have reported an increased risk of hyperthyroidism (Seffner 1995) from long-term exposure to levels between 11–61 mg/L (Tajtakova et al. 2006). Drinking water nitrate at levels < 10 mg/L has been associated with insulin-dependent diabetes (IDDM; Kostraba et al. 1992), whereas other studies have shown an association with IDDM at nitrate levels > 15 mg/L (Parslow et al. 1997) and > 25 mg/L (van Maanen et al. 2000). Increased risks for adverse reproductive outcomes, including central nervous system malformations (Arbuckle et al. 1988) and neural tube defects (Brender et al. 2004; Croen et al. 2001), have been reported for drinking water nitrate levels < 10 mg/L.

Anecdotal reports of reproductive effects of nitrate in drinking water include a case study of spontaneous abortions in women consuming high nitrate water (19–26 mg/L) from private wells (Morbidity and Mortality Weekly Report 1996).

While amassing experimental data suggest a role for nitrate in the formation of carcinogenic *N*-nitroso compounds, clear epidemiologic findings are lacking on the possible association of nitrate in drinking water with cancer risk. Ecologic studies have reported mixed results for cancers of the stomach, bladder, and esophagus (Barrett et al. 1998; Cantor 1997; Eicholzer and Gutzwiller 1990; Morales-Suarez-Varela et al. 1993, 1995) and non-Hodgkin lymphoma (Jensen 1982; Weisenburger 1993), positive findings for cancers of the nasopharynx (Cantor 1997), prostate (Cantor 1997), uterus (Jensen 1982; Thouez et al. 1981), and brain (Barrett et al. 1998), and negative findings for ovarian cancer (Jensen 1982; Thouez et al. 1981). Positive findings have generally been for long-term exposures at > 10 mg/L nitrate. Case–control studies have reported mixed results for stomach cancer (Cuello et al. 1976; Rademacher et al. 1992; Yang et al. 1998); positive results for non-Hodgkin lymphoma at > 4 mg/L nitrate (Ward et al. 1996) and colon cancer at > 5 mg/L (De Roos et al. 2003); and negative results for cancers of the brain (Mueller et al. 2001; Steindorf et al. 1994), bladder (Ward et al. 2003), and rectum (De Roos et al. 2003), all at < 10 mg/L. Cohort studies have reported no association between nitrate in drinking water and stomach cancer (Van Loon et al. 1998); positive associations with cancers of the bladder and ovary at long-term exposures > 2.5 mg/L (Weyer et al. 2001); and inverse associations with cancers of the rectum and uterus, again at > 2.5 mg/L (Weyer et al. 2001).

Exposure to low levels of antibiotics and other pharmaceuticals in drinking water (generally at micrograms per liter or nanograms per liter) represent unintentional doses of substances generally used for medical purposes to treat active disease or prevent disease. The concern is more related to possible cumulative effects of long-term low-dose exposures than on acute health effects (Daughton and Ternes 1999). A recent study conducted in Germany found that the margin between indirect daily exposure via drinking water and daily therapeutic dose was at least three orders of magnitude, concluding that exposure to pharmaceuticals via drinking water is not a major health concern (Webb et al. 2003). It should be noted that when prescribing medications, providers ensure patients are not taking incompatible drugs, but exposure via drinking water is beyond their control.

Endocrine-disrupting compounds are chemicals that exhibit biological hormonal activity, either by mimicking natural estrogens, by canceling or blocking hormonal actions, or by altering how natural hormones and their protein receptors are made (McLachlan and Korach 1995). Although very low levels of estrogenic compounds can stimulate cell activity, the potential for human health effects, such as breast and prostate cancers, and reproductive effects from exposure to endocrine disruptors, is in debate (Weyer and Riley 2001).

Workshop Recommendations

Priority research needs.

- Ecosystems monitoring: Systematic sustained studies of ecosystem health in proximity to large CAFOs are needed, including effects of input spikes during spills or flooding events.
- Toxicologic assessment of contaminants: Identification and prioritization of contaminants are needed to identify those that are most significant to environmental and public health. Toxicity studies need to be conducted to identify and quantify contaminants

(including metabolites), and to investigate interactions (synergistic, additive, and antagonistic effects).

- Fate and transport: Studies of parent compounds and metabolites in soil and water must be conducted, and the role of sediment as a carrier and reservoir of contaminants must be evaluated.
- Surveillance programs: Programs should be instituted to assess private well water quality in high-risk areas. Biomonitoring programs should be designed and implemented to assess actual dose from environmental exposures.

Translation of science to policy.

- Wastewater and drinking water treatment: Processes for water treatment must be monitored to ensure adequate removal or inactivation of emerging contaminants.
- Pollution prevention: Best management practices should be implemented to prevent or minimize release of contaminants into the environment.
- Education: Educational materials should be continued to be developed and distributed to agricultural producers.

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A Control Study of the Physical and Mental Health of Residents Living Near a Large-scale Swine Operation

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Abstract

This article presents the results of a study assessing the physical and mental health of residents living in the vicinity of a large-scale swine confinement operation. Physical and mental health data were collected via personal interviews from a sample (n = 18) of all neighbors living within a two-mile radius of a 4,000-sow swine production facility. Results were compared to similar data collected from a random sample of demographically comparable rural residents (n = 18) living near minimal livestock production. Results indicate that neighbors of the large-scale swine operation reported experiencing significantly higher rates of four clusters of symptoms known to represent toxic or inflammatory effects on the respiratory tract. These clusters of symptoms have been well-documented among swine confinement workers. There was no evidence to suggest that neighbors of the large-scale swine operation suffered higher rates of psychological health problems manifested as anxiety or depression. A larger population-based study is needed to test the hypothesis that neighbors of large-scale swine operations experience elevated rates of physical health symptoms comparable to interior confinement workers.

Keywords. **Large-scale swine operation, Environment, Neighbor health.**

The movement from pasture-based or partially enclosed to totally enclosed swine production first occurred in the United States in the early 1970s. This transformation was patterned in part after changes in the poultry industry in the 1960s (Donham et al., 1977). The last decade has witnessed a dramatic proliferation of large-scale swine confinement operations throughout the United States. Large-scale facilities often have over a thousand sows with multi-acre manure lagoons located at a single site. While there is no single quantitative definition of "large-scale" swine production, it can be characterized by several features: (1) separation of ownership, management, and labor; (2) nonlocal capital; (3) owners, management, and labor do not all live on, or in many cases, in the vicinity of the operation; (4) a nonfamily corporate or company organizational structure; and (5) family labor plays a limited role if any in the operation.

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The proliferation of large-scale swine production facilities has resulted in considerable concern among neighboring farmers and other rural residents over their environmental, social, economic, and health consequences (DeLind, 1995; Thu, 1995/96; Thu and Durrenberger, 1994). Among these concerns are the potential health and quality of life consequences for neighbors exposed to gases, dusts, and odors emanating from such facilities.

Beginning in the mid 1970s and continuing to the present, research has been devoted to understanding human exposures and health consequences of working in swine confinement environments (Donham, 1990; Donham et al., 1977; Kiekhaefer et al., 1995; Thorne et al., 1992). The results indicate swine confinement workers experience a number of health problems. A notable problem area is the range of respiratory conditions resulting from exposure to gases and dusts while working inside these facilities (Donham, 1993). However, very little research has been conducted on exposures to external emissions.

Research on exterior conditions has primarily targeted the reduction and elimination of odor emissions from swine operations. This research has concentrated on identifying compounds producing odors (Merkel et al., 1969; O'Neill and Phillips, 1992; Ritter, 1989), mechanisms for measuring odor (Hobbs, 1995; Longhurst, 1995; Mannebeck, 1995; Sweeten, 1988), and the development of control technologies (Fullhage, 1995; Voermans, 1995; Yokoyama, 1995). In addition, considerable research has been devoted to the uptake of ammonia from animal manure and the environmental consequences of its redeposition as rain in Europe (ApSimon and Kruse-Plass, 1991; Legg, 1990). However, little work has been devoted to understanding odor-related complaints and health problems among residents living near large livestock operations.

Emerging research (Schiffman, 1995; Schiffman et al., 1995) has investigated relationships between the psychological health of neighbors and swine-generated odors. This research indicates deleterious psychological health effects such as mood disorders result from a combination of physical agents and physiological responses to swine odor. It also suggests changing social conditions in rural neighborhoods may be a factor affecting responses. Other research (Thu and Durrenberger, 1994) supports Schiffman's suggestion that rural social issues play a role.

This study addresses a gap in research through a control approach to assessing interrelated issues of health, quality of life, and mental health of residents living in the vicinity of a large-scale swine confinement facility. The primary purpose of the study was to test a methodology for assessing neighbor health and quality of life issues, provide preliminary data to identify salient neighbor health and life quality problems, and generate hypotheses for further research.

Methodology

This study is based on a comparative control methodology. Data on physical health status, mental health, and quality of life were collected via personal interviews of neighbors of a large-scale swine production facility and from a random sample of rural residents who do not live near any livestock. Results from the two groups were compared to identify salient differences.

Survey Instrument

A questionnaire was developed to elicit data via personal interviews on physical health status, mental health, quality of life, and standard sociodemographics. An initial section was designed to collect basic background information, including demographics, employment, residential history, and previous occupational exposures. The second section elicited symptoms indicative of health status. Health status questions were drawn from earlier health assessment studies of swine confinement workers (Donham, 1990). They consisted of an initial set of open-ended questions concerning health problems, frequency ratings of 18 symptoms, and a series of health history and current health status questions.

To assess psychological health, mental health questions were developed in consultation with Professor Susan Schiffman, a medical psychologist at Duke University. In her research (Schiffman et al., 1995), Schiffman collected data on mood states between swine operation neighbors and controls utilizing a standardized mood profile scale (McNair and Lorr, 1992). To complement her findings, we included psychological scales to collect data on depression (Zung, 1965) and anxiety (state-trait anxiety inventory from Steer et al., 1993).

A third section included open-ended questions to solicit qualitative information on neighborhood social issues. For the case sample, questions were designed to elicit information on issues such as how well and how long neighbors knew the owners and operators of the swine facility and the nature of their relationship. Both case and control participants responded to a question on the characteristics of a "good neighbor".

Sample Selection and Procedures

A large-scale swine confinement operation was selected as the study site based on its scale and because we knew certain neighbors had expressed environmental and health concerns. The selected swine operation is one of the largest in Iowa, with approximately 4,000 sows in a farrowing operation consisting of six confinement units, an office building, and a two-stage outdoor waste lagoon about five acres in size. The entire operation is situated on an estimated 35 acres of land.

The 27 neighbors living within two miles were identified from plat maps as potential participants. Each household was sent a letter of introduction, a project summary, an invitation to participate, and a stamped return postcard. Of the 27 households contacted, 18 returned the postcard indicating an interest in participating (67% participation rate). Follow-up phone calls were made to each of the 18 interested households to schedule personal health assessment interviews. Of the 18 interested households, 10 households met the selection criterion of living closer to the large-scale swine operation than other livestock operations. Nine of these with 19 participants completed all aspects of the study. Multiple dwellers within a single household were interviewed independently from each other.

A control sample of rural residents not living near any livestock operation was selected. County level data from the 1992 Agricultural Census were used to locate areas of minimal livestock production. A county different from the case sample site was selected and all rural zip code areas within the county were checked to identify areas with the lowest population of livestock. All rural residents (n = 188) within the selected zip code area who owned a telephone were selected from a telephone data base. Letters of introduction were sent to all residents, including a project summary, an invitation to participate, and a stamped return postcard. Included in the letter was an additional screening caveat that prospective participants must not live within a mile of any type of livestock operation greater than 50 head.

Of the 188 letters sent, 14 were returned undeliverable by the Post Office, 24 postcards were returned declining participation, and 11 postcards were returned indicating they met the selection criteria and were interested in participating. All interested participants were contacted by phone to schedule interviews in their

Table 1. Demographic comparison of case and control samples

	Gender		Marital Status		Age	Education		Occupation	
	Men	Women	Marr.	Single	Mean	H.S.	> H.S.	Farmer	Nonfarmer
Case sample	10	8	14	4	47	10	8	9	9
Control sample	11	7	14	4	47	9	9	8	10

homes at their convenience. We requested that as many members of the household as possible participate. A total of 21 interviews were conducted in 11 households. However, data from two households in which three interviews were conducted had to be eliminated because of a failure to meet our selection criteria. Consequently, the control sample consisted of 18 personal interviews across nine rural households. Neither the control or case sample participants were provided financial or other incentives to participate.

The principle author and a co-author were the primary interviewers. Both are trained in qualitative and quantitative data collection methods utilizing ethnographic and personal interview techniques from social anthropology and the social sciences (Weller and Romney, 1988). The interviewers have 12 years combined experience in data collection specific to agriculture.

All data from the interviews were coded and entered into a Paradox database. Quantitative analyses were performed using a SAS statistical package*. Qualitative data were analyzed based on a combination of results from the quantitative analysis and interviewer notes on the questionnaires.

Results

As evidenced in table 1, there was little difference in gender, marital status, age, or educational level between the two samples. In addition, all respondents were white and there was a comparable proportion of farmers and nonfarmers in our sample populations. It is unlikely that the findings are biased by demographic differences between the sample and control populations.

Physical Health Symptoms

Results of the frequency of physical symptoms are presented in figure 1. The study population reported higher frequencies of 14 out of the 18 symptoms than the control population. There was no connection between the frequency of reported physical symptoms and distance from the swine facility. Results indicate a pattern of four interconnected clusters of symptoms that include respiratory problems, nausea and weakness, headaches and plugged ears, and irritation of eyes, nose, and throat. This constellation of symptoms matched those reported by participants in response to an open-ended question posed earlier in the interview. Skin rash, muscle aches, and fever were reported more frequently among the control group, while hearing problems were reported at an identical frequency by both groups.

Table 2 presents the results of analyses assessing the significance in differences between the reported symptoms from neighbors of the swine facility and the control population. The constellation of 14 symptoms reported more frequently by the study group showed composite mean frequency scores of 21 for the study population and 15 for the control. The first line of table 2 labeled "All Symptoms" presents the

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* SAS Institute Inc., Release 6.03., 1988, Cary, N.C.

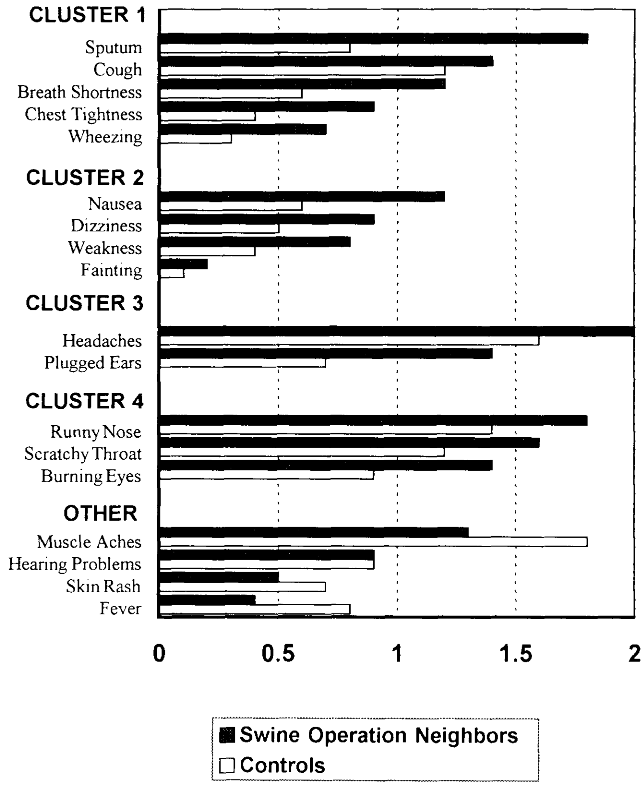

Figure 1–Frequency of physical symptoms experienced by rural resident (comparison of mean scores, 0 = Never, 4 = Very Often).

results of a Wilcoxon Test (Chi Sq = 2.3; P = 0.13) indicating this difference warrants attention but is not conclusive.

More significant is the trend among clusters of symptoms. Within the range of symptoms reported more frequently by the study sample, four clusters of related symptoms deserve particular attention. These clusters of symptoms have been recognized previously in swine facility workers (Donham, 1995). They represent toxic or inflammatory effects on different segments of the respiratory tract.

The first cluster is a combination of five symptoms indicative of inflammation of the bronchi and bronchioles, or chronic bronchitis and hyperreactive airways: sputum, cough, breath shortness, wheezing, and chest tightness. A variety of standardized survey instruments include this cluster of symptoms: the American Thoracic Society,

Table 2. Physical symptom clusters: A comparison of swine facility neighbors and rural controls

Physical Symptom Cluster	T Value	Significance Level
All symptoms combined	2.30	0.13
Cluster 1: Respiratory symptoms	2.12	0.02
Cluster 2: Nausea, weakness, dizziness and fainting	1.83	0.04
Cluster 3: Headaches and plugged ears	1.67	0.06
Cluster 4: Burning eyes, runny nose and throat	1.18	0.12

the British Medical Research Council, and the Agricultural Dust Exposure Assessment. A one-tailed t-test was conducted to determine whether the study population reported experiencing this combination of symptoms more frequently than the control sample. As presented in Cluster 1 of table 2, results indicate that residents living in the vicinity of the large-scale operation do report experiencing significantly higher rates of symptoms associated with chronic bronchitis and hyperreactive airways ($T = 2.12$; $P = 0.02$; 26.7 degrees of freedom). This type of bronchitis is almost invariably associated with environmental exposures, e.g., air pollution, chronic agricultural dust exposure, and long-term cigarette smoking.

A second cluster of related symptoms was examined that included: nausea, weakness, dizziness, and fainting. Previous research among swine workers reveal this group of symptoms is fairly common (Donham, 1993). A one-tailed t-test was again conducted to determine whether the study population reported experiencing this combination of symptoms more frequently than the control sample. As presented in Cluster 2 of table 2, results indicate that residents living in the vicinity of the large-scale operation do report experiencing significantly higher rates of nausea, weakness, dizziness, and fainting ($T = 1.83$; $P = 0.04$; 24.5 degrees of freedom). Research among swine confinement workers suggests that long-term exposure to less than acutely toxic levels of endotoxin and hydrogen sulfide merit investigation in conjunction with these symptoms (Auger et al., 1994).

A third combination of symptoms, headaches and plugged ears, is another frequently observed among swine confinement workers. Once again, a one-tailed t-test was conducted to determine whether the study population reported experiencing this combination of symptoms more frequently than the control sample. As presented in Cluster 3 of table 2, results indicate that residents living in the vicinity of the large-scale swine operation report experiencing higher rates of headaches and plugged ears, though the difference is marginally less significant than the first two clusters ($T = 1.67$; $P = 0.06$; 24.5 degrees of freedom). The physiological explanation for these symptoms among swine confinement workers is that they are often associated with chronic sinusitis. Symptoms of chronic sinusitis are seen in nearly a quarter of active swine producers (Donham, 1993).

A final cluster of symptoms was examined that included: burning eyes, runny nose, and scratchy throat. The one-tailed t-test was replicated to compare the study and control sample. As presented in Cluster 4 of table 2, results indicate that the higher rates of these reported symptoms among neighboring residents of the large-scale operation warrant notice but the difference is less clear ($T = 1.18$; $P = 0.12$; 33 degrees of freedom). Among interior swine confinement workers, these symptoms are associated with a condition called mucous membrane irritation. Irritant gases and particulates inside swine confinement buildings are thought to affect the mucous membranes of the eyes and upper airways, resulting in the symptoms reported.

Differences in reported physical health symptoms between the study and control population are present. More notable than individual symptoms or clusters of symptoms, is the overall trend of interrelated symptom clusters reported more frequently among neighbors of the swine facility than the control sample. The constellation of symptoms reported in excess by neighbors is consistent with, but less severe and frequent, compared to symptoms of workers in swine confinement facilities. A companion article to this article reveals that ammonia, dust, and endotoxin are present in the air downwind from large swine facilities. However, these levels are much lower than those previously associated with any known illness (Reynolds et al., in press). This raises the question as to whether low levels may be associated with reported symptoms.

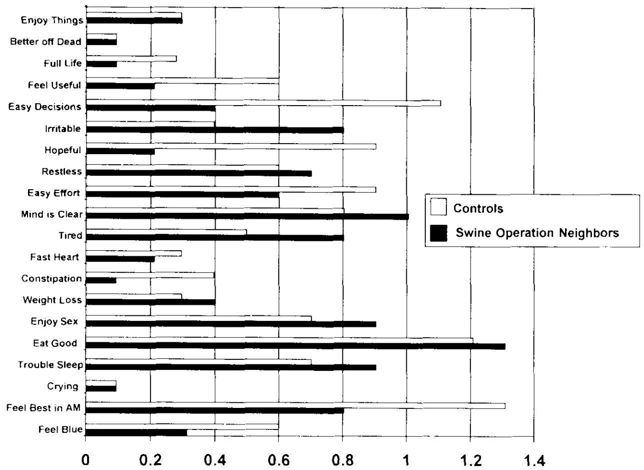

Figure 2–Frequency of depression symptoms experienced by rural residents.

Psychological Symptoms

Research in North Carolina (Schiffman et al., 1995) reported that persons living near large-scale swine operations exhibited significantly higher rates of mood disorders than did matched control participants as measured by a Profile of Mood States (POMS) scale. Neighbors living near large swine facilities experienced higher rates of tension, anger, fatigue, and confusion. Schiffman discusses how molecules responsible for odors can potentially result in physical responses linked to mood alterations. She also suggests that odor may play a role in suppressing immune system responses via physical connections between the olfactory and immune systems. The psychological scales we used measured depression and anxiety as a comparative supplement to Schiffman's research.

The depression scale is based on the work of Zung (1964) and is derived from established research utilizing factor analyses to derive the most common set of underlying characteristics that predict depression in a clinical setting. Participants in our pilot study were administered 20 questions from the Self-Rating Depression Scale (SDS) derived from this clinical work. The comparative results of mean scores of individual items are presented in figure 2.

Little difference in depressive symptoms exists between the study and control populations. Following Zung's (1964) methodology, a depression index was created by totaling the raw scores of participants and dividing them by the total possible score†. The composite mean depression index for case study participants totaled 0.37 compared with 0.40 for the controls and were not significantly different (Chi Sq = 0.35; P = 0.55). These scores compare with a mean depression index of 0.74 in Zung's clinically admitted population of depressed patients. Zung's control, or "normal" population, scored 0.33. Thus our study population is well within the range of Zung's control population, exhibiting very little depressive symptomology.

† Comparison of Mean Scores, 0 = Never or little, 3 = Most of the time. A value of one was added to each response value listed in table 2, i.e., 0 = 1, 1 = 2, 2 = 3, and 3 = 4, in order to make the index results comparable to other research.

An anxiety scale was administered based on the Beck Anxiety Inventory (BAI) developed by Beck and Steer (Steer et al., 1993). The scale is derived from analyses of in-patients exhibiting a set of symptoms distinct from other mental disorders in a clinical setting. Participants in our pilot study were administered 21 questions from the BAI derived from this clinical work. The comparative results of mean scores of individual items are presented in figure 3.

Little difference in anxiety symptoms exists between the study and control populations. Following the methodology of Steer et al. (1993), an anxiety index was created for each case by totaling the raw scores of participants and dividing it by the total possible score. The composite mean anxiety indexes for case study and control participants were virtually identical: 0.11. These scores compare with a mean anxiety score of 0.29 in Steer and coworkers' population of 250 clinically admitted patients categorized as "moderately anxious". Our study population does not appear to be suffering from anxiety related psychological symptoms. Moreover, no significant differences were found in anxiety between the study participants and the control population.

Conclusion

Evidence indicates that neighbors of the large-scale swine operation in our study reported experiencing increased rates of a number of interrelated symptoms, including headaches, respiratory problems, eye irritation, nausea, weakness, and chest tightness. The pattern of differential symptomology rates between the study and control samples suggest further study is warranted. There is little evidence to suggest that neighbors of the large-scale swine operation suffer higher rates of anxiety or depression.

Further study is needed to test the hypothesis that neighbors of large-scale swine operations experience higher rates of physical symptoms comparable to the types of symptoms experienced by interior confinement workers. A larger population-based study is needed that includes neighbors of a cross-section of various sizes and types of swine and other livestock operations. Such a study should continue to use personal interviews as the basis of health assessments. A central issue in these investigations is

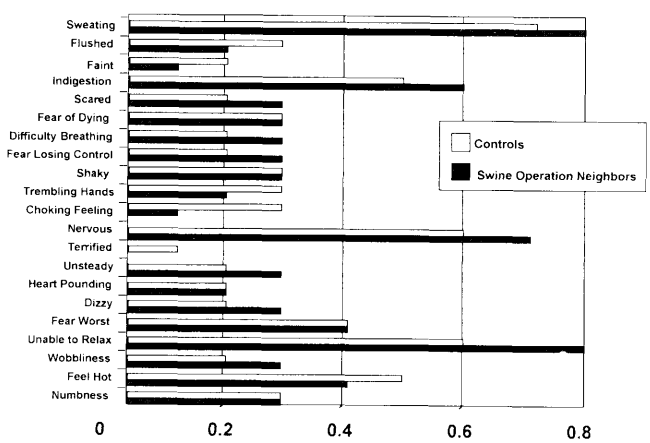

Figure 3–Frequency of anxiety symptoms experienced by rural residents.

the reliability and quality of data. Personal interviews by trained and experienced interviewers in the homes of rural residents provide a comfortable setting for participants to discuss issues in a forthright and open manner. A report based on a 1985 National Science Foundation conference on data collection points to natural settings as providing the best opportunity for collecting reliable interview data (Bernard et al., 1986). Validity of data collection is related to a host of factors, including the extent of open exchange between interviewers and persons being interviewed.

Neighbors did not appear to be concocting evidence of health or psychological problems based on any personal or political agenda. Evidence for the credibility of physical symptom reports comes from the psychological profile data. If participants wanted to concoct evidence it would have been easy for them to report high rates of depression and/or anxiety. Such reporting did not occur. Physical assessments of neighbors would provide clarification of these issues.

Permeating all the responses, regardless of whether respondents had specific health problems, was the underlying view that the owner was creating social and class divisions in the neighborhood and community. Most believed that the construction and presence of the facility violated core rural values of being a good "neighbor". For virtually all respondents, rural "neighborliness" embodies central cultural principles of egalitarian relationships, reciprocal exchange such as helping or sharing in times of need, mutual respect, and being kept informed. The facility's construction and continuing presence was viewed as eroding these cornerstones of agrarian life. Often discussed outside the strictures of the questionnaire, participants voiced concern about such issues as labor turn-over, social chasms emerging between neighbors and between children of neighbors, the influence of the facility's owner on local political and economic decision-making boards, and the ability of residents to have control over their land, homes, families, and quality of life. Clearly the issues confronting rural residents in this study reflect an intertwining of personal, environmental, economic, and social health. Further study should seek to clarify and broaden our understanding of these interrelated issues.

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Appendix — Questionnaire

Date: ______________________________

Interviewer: ________________________

I. Background	Computer Code
1. Name ______________________	ID # __________
2. Address ______________________	
______________________	
______________________	
3. Phone # ______________________	
4. County ______________________	__________
5. Race ______________________	__________
6. Age ______________________	__________
7. Gender ______________________	__________
8. Marital status ______________________	__________
How long? ______________________	__________
9. Occupation ______________________	__________
10. If farming, what kind? ______________________	
11. Off-farm employment? (what and how many hours per week?) ______________________	
12. Highest level of education	__________
13. Annual household income (on- and off-farm income)	__________
14. What proportion of your annual household income comes from farming (%)?	__________
15. What proportion of your annual household income comes from hog production (%)?	__________
16. How many people live at your residence?	__________
17. How long have you lived at this residence?	__________

18. Do any exposures or conditions specific to your neighborhood bother you, or give you health problems?

____

____

____

____

II. Symptoms

19. Please check the frequency with which you experience the following symptoms:

	1 Never	2 Rarely	3 Occasionally	4 Often	5 Very Often
Headache	m	m	m	m	m
Plugged, popping ears	m	m	m	m	m
Hearing problems	m	m	m	m	m
Burning or watering eyes	m	m	m	m	m
Runny nose	m	m	m	m	m
Scratchy throat	m	m	m	m	m
Sputum or phlegm	m	m	m	m	m
Cough	m	m	m	m	m
Fever	m	m	m	m	m
Nausea or vomiting	m	m	m	m	m
Weakness	m	m	m	m	m
Dizziness	m	m	m	m	m
Fainting or blackout	m	m	m	m	m
Shortness of breath	m	m	m	m	m
Wheezing	m	m	m	m	m
Muscle aches and pains	m	m	m	m	m
Skin rash or hives	m	m	m	m	m
Tightness in chest	m	m	m	m	m
*____________________	m	m	m	m	m
*____________________	m	m	m	m	m

*________________________	m	m	m	m	m

* Fill in other symptoms bothering you that are not listed.

20. Please check the following items in terms of the frequency with which they currently apply to you.

	1 Never or a Little of the Time	2 Some of the Time	3 Good Part of the Time	4 Most of the Time
I feel down-hearted and blue	m	m	m	m
Morning is when I feel the best	m	m	m	m
I have crying spells or feel like it	m	m	m	m
I have trouble sleeping at night	m	m	m	m
I eat as much as I used to	m	m	m	m
I still enjoy sex	m	m	m	m
I notice that I am losing weight	m	m	m	m
I have trouble with constipation	m	m	m	m
My heart beats faster than usual	m	m	m	m
I get tired for no reason	m	m	m	m
My mind if as clear as it used to be	m	m	m	m
I find it easy to do the things I used to	m	m	m	m
I am restless and can't keep still	m	m	m	m
I feel hopeful about the future	m	m	m	m
I am more irritable than usual	m	m	m	m
I find it easy to make decisions	m	m	m	m
I feel that I am useful and needed	m	m	m	m
My life is pretty full	m	m	m	m
I feel that others would be better off if I were dead	m	m	m	m
I still enjoy the things I used to do	m	m	m	m

21. Please check the following items in terms of the frequency with which they currently apply to you.

	0 Not at All	1 Sometimes	2 Frequently	3 Almost Constantly
Numbness	m	m	m	m
Feeling hot	m	m	m	m
Wobbliness	m	m	m	m
Unable to relax	m	m	m	m
Fear of the worst	m	m	m	m
Dizzy	m	m	m	m
Heart pounding	m	m	m	m
Unsteady	m	m	m	m
Terrified	m	m	m	m
Nervous	m	m	m	m
Feelings of choking	m	m	m	m
Hands trembling	m	m	m	m
Shaky	m	m	m	m
Fear of losing control	m	m	m	m
Difficulty breathing	m	m	m	m
Fear of dying	m	m	m	m
Scared	m	m	m	m
Indigestion	m	m	m	m
Faint	m	m	m	m
Face flushed	m	m	m	m
Sweating	m	m	m	m

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The Effect of Environmental Odors Emanating From Commercial Swine Operations on the Mood of Nearby Residents

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ABSTRACT: The effect of environmental odors emanating from large-scale hog operations on the mood of nearby residents was determined using the POMS (Profile of Mood States). The scores for six POMS factors and the TMD (total mood disturbance score) for 44 experimental subjects were compared to those of 44 control subjects who were matched according to gender, race, age, and years of education. The results indicated a significant difference between control and experimental subjects for all six POMS factors and the TMD. Persons living near the intensive swine operations who experienced the odors reported significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects as measured by the POMS. Persons exposed to the odors also had more total mood disturbance than controls as determined by their ratings on the POMS. Both innate physiological responses and learned responses may play a role in the impairment of mood found here.

KEY WORDS: Odors, Mood, Pollution, Swine, Psychological effects, Brain-immune connections.

INTRODUCTION

Odors have always been associated with livestock and poultry production [24,55,72,78,79,86,88]. However, odors have recently become a major challenge for the livestock industry due to the present trend toward intensive livestock operations in which large numbers of animals are confined on small areas of land [8,19,51,69,120,122–124,127]. Environmental odors can have a considerable impact upon a population's general well-being, affecting both physiological and psychological status [93,103,128]. Miner [70] concluded that unpleasant odors can affect well-being by "eliciting unpleasant sensations, triggering possible harmful reflexes, modifying olfactory function and other physiological reactions." He also reported that annoyance and depression can result from exposure to unpleasant odors along with nausea, vomiting, headache, shallow breathing, coughing, sleep disturbances, and loss of appetite. Odorous compounds associated with livestock production that are at low concentrations but above odor thresholds are still likely to generate complaints [18,52].

Neutra et al. [77] studied people living near hazardous waste sites, and found that those complaining of odors had a higher number of symptoms than those who did not complain, regardless of proximity to the site. Shusterman [103] reviewed several studies [e.g., 4,37,47,95–97] in which there was a direct relationship between nontoxicological odors and symptomatology. In a variety of settings (municipal, agricultural, and industrial) where airborne toxicants were negligible and odors had been complained about, there was a strong relationship between reported symptoms and odor exposure.

The sources of the odors from swine operations include ventilation air released from swine buildings, waste storage and handling systems including lagoons, and land application of manure to fertilize fields [15]. The odors are produced by a mixture of fresh and decomposing feces, urine, and spilled feed. The more objectionable odors appear to result from anaerobic microbial decomposition of the feces [90]. A broad range of compounds has been identified in livestock manure including volatile organic acids, alcohols, aldehydes, amines, fixed gases, carbonyls, esters, sulfides, disulfides, mercaptans, and nitrogen heterocycles [30,70,71,73,104]. It is likely that the mixture of compounds rather than a single component contributes to the mood changes measured here.

A variety of techniques for reducing odor have been evaluated, but overall the results have been disappointing [123]. Aerobic treatment has been found to be the most effective method to date for deodorizing pig slurry [2,9,11,54,105–107,127]. Odorous compounds can be carried in a plume, and the concentration of these compounds in the plume may not be significantly reduced at distances of 750–1500 feet or more downwind from a source [36]. Dispersion models have been developed to predict the peak and mean concentrations of odors and environmental air pollutants at various distances from the source [20,36,46,80], and complaint patterns at a variety of distances from an odor source have been studied [21].

The purpose of the present study was to use a well-standardized scale to quantify objectively the moods of people living near large-scale hog operations who are exposed to odors. The Profile

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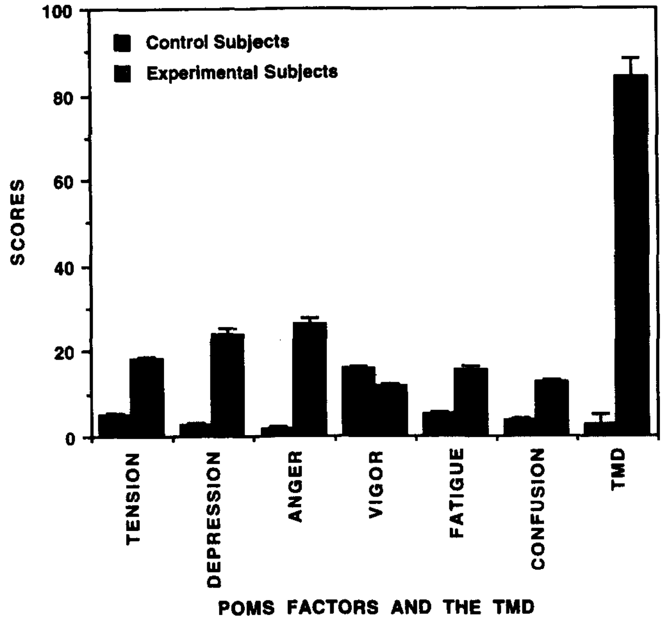

FIG. 1. Mean POMS scores of each factor and the total mood disturbance score (TMD) for experimental and control subjects.

of Mood States questionnaire [65,66] was used to assess mood in persons living near swine operations and in control subjects. This scale has been used extensively in many situations including previous studies that evaluated the effect of pleasant odors on mood [98,99]. The study of mood in persons exposed to odors is important because negative mood has been found to play a role in immunity [16,81,111,125] and can potentially affect subsequent disease.

METHOD

Subjects

Forty-four experimental (persons living near hog operations) and 44 control subjects participated in the study; all of the subjects were residents of North Carolina. The subjects in the two groups (control and experimental) were matched according to gender, race, age, and years of education. Twenty-six subjects in each group were female, and 18 subjects were male. The mean age of the experimental group was 52.0 ± 13.4 years, and the mean age of the control group was 51.7 ± 8.3 years. The experimental group had an average of 12.8 ± 3.3 years of education, and the control group had an average of 13.0 ± 3.1 years of education. The majority of subjects in both groups were employed as skilled laborers. The groups were also matched for the number of chronic illnesses that they had experienced; 14 subjects in each group suffered from allergies. The experimental group lived an average of 5.3 ± 6.5 years near hog operations, with a maximum of 27 years and a minimum of 8 months.

Materials

Subjects in both groups signed a consent form and filled out a general information questionnaire that asked demographic, medical, and dietary information. Mood ratings were obtained from all subjects by filling out Profile of Mood States questionnaires (POMS). The POMS was chosen to measure the impact of the hog odors on mood because it has been shown to be sensitive to transient mood shifts [65,66]. There are 65 adjectives/feelings on the POMS, most of which may be grouped into one of six factors: tension/anxiety, depression/dejection, anger/hostility, vigor/activity, fatigue/inertia, and confusion/bewilderment. Each feeling is rated on a scale from 0 (not at all) to 4 (extremely). The feelings for each factor were added together, according to the POMS manual, to get a total score for that factor. The totals for each factor were then added together, with the vigor/activity factor weighted negatively, to derive a total mood disturbance score (TMD).

Procedure

At the beginning of the study, all subjects filled out the consent form as well as the general information questionnaire. Experimental subjects were asked to complete one POMS questionnaire per day on 4 days when the hog odor could be smelled. The 4 days did not have to be consecutive, and subjects had as long as needed to complete all four POMS questionnaires. Control subjects were asked to complete one POMS per day for 2 days. All subjects were asked to complete the POMS based upon how they recently had been feeling, including at that particular time.

RESULTS

Figure 1 shows the means and standard errors for the experimental group vs. the control group for all POMS factors and the TMD. An analysis of variance was performed to determine if there were any main effects or interactions between group (control or experimental) and gender for each POMS factor and the TMD. Subjects were nested within group and gender. Table 1 gives the results of the analysis. There was a significant difference (at $p < 0.0001$ level) between the control group and the experimental group for all of the POMS factors as well as the TMD. The experimental group had significantly worse scores than the control group for every factor and the TMD. There was a significant main effect of gender for the anger factor, $p < 0.01$, and a significant gender × group interaction for the confusion factor, $p < 0.005$. Males had significantly higher (worse) anger scores than the females. For the confusion factor, scores for experimental males were significantly higher than those for experimental females and control males and females; scores for ex-

TABLE 1

RESULTS OF THE ANALYSIS OF VARIANCE

Effect	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Total Mood Disturbance Score
Group	*	*	*	*	*	*	*
Gender			*				
Group × gender						*	
Subject (group, gender)	*	*	*	*	*	*	*

* Significant at $\alpha = 0.05$ level.

perimental females were significantly higher than those of control males and females. Only scores for control males and control females were not significantly different from each other.

DISCUSSION

The main finding of this study is that persons living near the swine operations who experienced the odors had significantly more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects as measured by the Profile of Mood States (POMS). In addition, persons exposed to the odors also had more total mood disturbance than controls as determined by their ratings on the POMS. These findings are consistent with previous studies in which odors of varying hedonic properties have been found to affect mood [7,32,93,98,99,103,128]. In other settings, odors have also been reported to affect cognitive performance [57,62] and physiological responses including heart rate and electroencephalographic patterns [56,58–61,64].

Possible Causes of Altered Mood

A variety of factors may play a role in the altered mood of residents who are exposed to odors from nearby swine operations. These factors include: a) the unpleasantness of the sensory quality of the odor; b) the intermittent nature of the stimulus; c) learned aversions to the odor; d) potential neural stimulation of immune responses via direct neural connections between odor centers in the brain and lymphoid tissue; e) direct physical effects from molecules in the plume including nasal and respiratory irritation; f) possible chemosensory disorders; and g) unpleasant thoughts associated with the odor.

At moderate to high odor intensities, most persons rate the quality of the odor from the swine operations as unpleasant. The odor is not only perceived while breathing outdoor air but can also be perceived within the homes of nearby residents due to air circulation through open windows and air conditioning systems. The odorant molecules can be absorbed by clothing, curtains, and building materials which act as a sink; the molecules are then released slowly over a period of time from textiles and other materials after the plume has passed the house increasing the temporal exposure to the odor. The intermittent nature of the odors may also be a factor in the mood of persons living near swine operations. Studies of noise have shown that intermittent stimuli produce more arousal and are more likely to affect performance negatively than constant noise [22]. This is due in part to feelings of lack of control over the timing of unwanted transient stimuli. Differences in responses to irregular noise and predictable noise are not only found in humans but in animals as well [27].

Learning (via conditioning) may also play a role in the psychological and physical effects from odors. Conditioned aversions to odors are well-documented in the scientific literature [31,38,44,67,75,119]. Aversive conditioning can occur if environmental odors are associated with an irritant or other toxic chemicals such as pesticides [103]. In addition, conditioned alterations in immune responses using chemosensory (smell and taste) stimuli provide strong evidence for functional relationships between chemosensory centers in the brain and the immune system [1]. Both conditioned immunosuppression and immunoenhancement have been reported using chemosensory stimuli as the conditioned stimulus [1,31,42,43,109,110].

There is a potential for unpleasant odors to influence physical health without involvement of learning or conditioning due to the direct anatomical connections between the olfactory system and the immune system. Brain structures broadly involved in smell [12,35,39,49,82–85,101,112,114–116] can modulate immune responses, especially via the integrated circuitry of the limbic cortex, limbic forebrain, hypothalamus, and brain stem [13,25,26,48,50,76,92,118]. These studies provide an anatomical basis for the possibility that sensory stimulation of the limbic forebrain, hypothalamus, and other odor projection areas of the brain can directly alter immune status. The links between the brain and the immune system are bidirectional [108] so that immune responses can also affect odor centers in the brain [10,94].

Components in the odorous plume may also have direct physical effects on the body. Some of the odorant molecules implicated in malodor from hog farms can cause nasal and respiratory irritation [15,23,29,70,103]. Nasal irritation has been shown to elevate adrenalin [3] which may contribute to feelings of anger and tension. The volatile organic compounds (VOCs) responsible for odors may also be absorbed directly by the body (into the bloodstream and fat stores) via gas exchange in the lungs. Many VOCs that are inhaled into the lungs are known to reach blood and adipose tissue [4,6,53,63,126]. Persons who have absorbed odorants through the lungs can sometimes smell the odor for hours after exposure due to slow release of the odorants from the bloodstream into expired air activating the olfactory receptors. Volatile organic compounds are well known to be eliminated in breath after exposure [89,121], and methods for measuring VOCs in breath have been described [87,89,117]. It is also theoretically possible for some compounds in the plume to be transmitted to the brain via olfactory neurons because a range of agents have been found to reach the brain through the nasal route [28,33,45,74,91,102]. Endotoxin, a component of bacteria, found in the swine house air environment [29], may also be present in the plume. Persons with olfactory dysfunction caused by factors unrelated to swine odor such as concurrent medical conditions, drugs they are taking, or pesticide exposure [100], may find the odor even more objectionable due to their abnormal smell functioning.

Finally, odors may alter mood because they are associated with unpleasant thoughts. Some persons consider the smell from hog farms a taboo odor, which they should not have to endure. For other persons, the odors generate environmental concerns, fear of loss of use and value of property, or a conviction that odors interfere with their enjoyment of life and property. Livestock odors may also be considered inappropriate in certain environments. Odor complaints have been reported to be most frequent among new, large, or recently expanded facilities that are located near existing residences or shopping areas [70,113]. Part of the motivation for odor complaints may be the increased awareness of other environmental agents, such as tobacco smoke, which is malodorous and is considered dangerous to one's health.

Lack of Legislation to Monitor Odor Levels

Odors are not regulated by the Clean Air Act because they are generally regarded as nontoxic [15]. In addition, nonfederal legislation for controlling odors from swine operations is imprecise or lacking in many states. For example, North Carolina Administrative Code Title 15A-02D.0522(c) specifies that "a person shall not cause, allow, or permit any plant to be operated without employing suitable measures for the control of odorous emissions including wet scrubbers, incinerators, or such other devices as approved by the Commission." This regulation is subjective because it gives no provision for either emission standards or ambient air standards. Under this regulation, it appears that as long as a plant has suitable control devices, it is lawful for them to emit offensive odors. In addition, it is unclear what type of operation is to be considered a plant. In contrast, Connecticut's laws on odor emissions set specific standards, as shown in Table

TABLE 2

ACCEPTANCE LIMITS FOR ODORS (FROM 17)

Chemical	ppm by Volume
Acetaldehyde	0.21
Acetic acid	1.0
Acetone	100.0
Acrolein	0.21*
Acrylonitrile	21.4*
Allyl chloride	0.47
Amine, dimethyl	0.047
Amine, monomethyl	0.021
Amine, trimethyl	0.00021
Ammonia	46.8*
Aniline	1.0
Benzene	4.68
Benzyl chloride	0.047
Benzyl sulfide	0.0021
Bromine	0.047
Butyric acid	0.001
Carbon disulfide	0.21
Carbon tetrachloride (chlorination of CS_2)	21.4*
Carbon tetrachloride (chlorination of CH_4)	100.0*
Chloral	0.047
Chlorine	0.314
Dimethylacetamide	46.8*
Dimethylformamide	100.0*
Dimethyl sulfide	0.001
Diphenyl ether	0.1
Diphenyl sulfide	0.0047
Ethanol (synthetic)	10.0
Ethyl acrylate	0.00047
Ethyl mercaptan	0.001
Formaldehyde	1.0
Hydrochloric acid gas	10.0*
Hydrogen sulfide gas	0.00047
Methanol	100.0
Methyl chloride	(above 10 ppm)
Methylene chloride	214.0*
Methyl ethyl ketone	10.0
Methyl isobutyl ketone	0.47
Methyl mercaptan	0.0021
Methyl methacrylate	0.21
Monochlorobenzene	0.21
Monomethylamine	0.021
Nitrobenzene	0.0047
Paracresol	0.001
Paraxylene	0.47
Perchloroethylene	4.68
Phenol	0.047
Phosgene	1.0*
Phosphine	0.021
Pyridine	0.021
Styrene (inhibited)	0.1
Styrene (uninhibited)	0.047
Sulfur dichloride	0.001
Sulfur dioxide	0.47
Toluene (from coke)	4.68
Toluene (from petroleum)	2.14
Toluene diisocyanate	2.14*
Trichloroethylene	21.4

* Exceeds the Threshold Limit Value adopted by the American conference of Industrial Hygienists for 1971.

2 [17]. Similarly, in the Netherlands, regulations are based on accurate records of manure production and bookkeeping, and violations are considered a criminal offense [14].

Regulations need to be established in all 50 states because animal wastes contain high levels of volatile organic compounds that can produce strong odors. The annual production of animal manure in the US in 1987 was estimated at 1.5 billion tons per year, which is enough to apply one ton per acre on each of the 1.9 billion acres of the continental US [14].

Persons exposed to high levels of odor from agricultural sources generally use nuisance laws to protect their rights. However, there are many caveats in nuisance laws that consider a) which party was there first; b) the character of the neighborhood; c) the reasonableness of the use of the land; and d) the nature and degree of the interference [40]. In addition, most states have right-to-farm statutes that supersede nuisance laws in some circumstances [40]. Strong support against nuisance suits involving agriculture is not specific to the United States but is found in the laws of many countries [5]. Suits against agricultural activities based on odor nuisance are harder to prove than those based on water pollution [68]. In addition, nuisance claims fall under state laws, while suits on water pollution are most frequently filed in federal courts.

Conclusion

Odors from swine operations have a significant negative impact on mood of nearby residents. Methods must be found to lower the concentrations of compounds responsible for the odors so that swine operations do not affect the emotional lives of residents in the local vicinities. This may involve legislation that sets standards for odor. In addition, technological solutions must be found to reduce the concentrations of the offending compounds.

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Malodor as a Trigger of Stress and Negative Mood in Neighbors of Industrial Hog Operations

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Objectives. We evaluated malodor and air pollutants near industrial hog operations as environmental stressors and negative mood triggers.

Methods. We collected data from 101 nonsmoking adults in 16 neighborhoods within 1.5 miles of at least 1 industrial hog operation in eastern North Carolina. Participants rated malodor intensity, stress, and mood for 2 weeks while air pollutants were monitored.

Results. Reported malodor was associated with stress and 4 mood states; odds ratios (ORs) for a 1-unit change on the 0-to-8 odor scale ranged from 1.31 (95% confidence interval [CI]=1.16, 1.50) to 1.81 (95% CI=1.63, 2.00). ORs for stress and feeling nervous or anxious were 1.18 (95% CI=1.08, 1.30) and 1.12 (95% CI=1.03, 1.22), respectively, for a 1 ppb change in hydrogen sulfide and 1.06 (95% CI=1.00, 1.11) and 1.10 (95% CI=1.03, 1.17), respectively, for a 1 $\mu g/m^3$ change in semivolatile particulate matter less than 10 μm in aerodynamic diameter (PM_{10}).

Conclusions. Hog odor, hydrogen sulfide, and semivolatile PM_{10} are related to stress and negative mood in disproportionately low-income communities near industrial hog operations in eastern North Carolina. Malodor should be considered in studies of health impacts of environmental injustice. (*Am J Public Health.* 2009;99:S610–S615. doi:10.2105/AJPH.2008.148924)

Odor, noise, heat, and crowding are environmental stressors[1] that may affect physical and mental health. Malodor is reported in neighborhoods near hazardous waste facilities, petroleum refineries, certain industrial facilities, and confined animal feeding operations; people in these areas may report sensations of irritation, respiratory problems and other physical health symptoms, interference with activities of daily living, and concerns about chronic diseases and property values.[1–37] Because polluting facilities are disproportionately located in low-income communities and communities of color,[38,39] malodor is an important aspect of environmental injustice that threatens physical, mental, and social well-being.[40]

Several studies have evaluated relationships among malodor, negative mood, and reduced quality of life in neighbors of industrial hog operations. Schiffman et al.[26] found that a small sample of neighbors of industrial hog operations reported more tension, depression, anger, fatigue, and confusion, and less vigor, compared with an unexposed rural sample. Bullers[4] found higher mean scores on a short form of the Center for Epidemiologic Studies Depression Scale (CES-D) in neighbors of industrial hog operations than in control participants (2.24 vs 1.84). Wing and Wolf[36] assessed effects on quality of life, determined by asking how often neighbors of hog operations could open windows or go outside during nice weather. By that metric, neighbors reported greatly reduced quality of life relative to other demographically comparable rural residents.

The Community Health Effects of Industrial Hog Operations (CHEIHO) study was a collaborative community-based participatory research project conducted in the predominantly low-income African American communities of rural eastern North Carolina where industrial hog operations are disproportionately located.[35] The purpose of this study was to evaluate longitudinal relationships among malodor, airborne emissions, stress, and negative mood. We hypothesized that malodor from industrial hog operations is an environmental stressor that may also negatively affect mood.

METHODS

We have previously described the CHEIHO study, including details of its community-based design and its links to education and organizing for environmental justice.[41] Research on health effects in neighbors of industrial hog operations is community-based at its origin. Community-based organizations brought the issue to the attention of researchers at the School of Public Health at the University of North Carolina and have continued as partners in all research that has been conducted. In the CHEIHO study, members of community-based organizations participated as advisors in the study design and design of study instruments. They were integrally involved in the recruitment and training of study participants. Indeed, community organizers were essential to the recruitment and retention of study participants in predominantly African American communities with historic distrust of researchers and research institutions.[42]

Study Participants

Eligible participants in the CHEIHO study were nonsmoking adults who lived within 1.5 miles of at least 1 industrial hog operation and were willing to collect data twice daily for approximately 2 weeks. Between September 2003 and September 2005, participants collected data on odor, stress, mood, physical health symptoms, blood pressure, immune function, and lung function; outcomes analyzed in this study are described in more detail in the paragraphs that follow.

At a central location in each neighborhood, research staff set up a monitoring trailer to collect data on hydrogen sulfide (H_2S; MDA Scientific Single Point Monitor, Honeywell Analytics Inc North America, Lincolnshire, IL), particulate matter less than 10 μm in aerodynamic diameter (PM_{10}) and semivolatile PM_{10} (Tapered Element Oscillating Microbalance Series 1400a Ambient Particulate Monitor with a Series 8500 Filter Dynamics Measurement

System, Thermo Fisher Scientific, Waltham, MA), and weather (Vantage Pro Weather Station, Davis Instruments, Hayward, CA, and Young Model 05103VM-42 Wind Monitor, R.M. Young Company, Traverse City, MI).

Selection of the particular pollutants to be monitored was based on previous work that has documented emissions of both H_2S (a product of the anaerobic decomposition of hog waste) and particulate matter from feed, dried feces, skin cells, hair, and bioaerosols, at confinement buildings and waste lagoons.[6,43] Furthermore, we found that H_2S and PM_{10} were related to reported malodor in the CHEIHO study; H_2S was associated with reported malodor in models that adjusted for the study's longitudinal design, as was PM_{10} during times when wind speed was greater than 6.75 miles per hour.[44]

The average distance from the monitoring platform to the nearest industrial hog operation in each neighborhood was 0.51 miles; the minimum distance to the nearest industrial hog operation was 0.20 miles and the maximum distance to the nearest industrial hog operation was 1.42 miles. In 2 of the 16 neighborhoods, the platform was located within 2 miles of 1 industrial hog operation; in the other 14 neighborhoods, however, the platform was located within 2 miles of at least 3 industrial hog operations (maximum of 16 industrial hog operations). We therefore calculated, for each neighborhood, the average distance between the platform and the industrial hog operations within 2 miles of the monitoring platform. The average distance across all neighborhoods was 1.10 miles, with a range by neighborhood from 0.56 miles to 1.50 miles. In contrast, the average distance between participant households and the monitoring platform across 15 of the 16 neighborhoods was 0.20 miles, with a range by neighborhood from 0.03 miles to 0.36 miles.

In 1 neighborhood, the average distance between participant households and the platform was 0.95 miles. In this and 3 other neighborhoods where participant homes were more geographically dispersed, we deployed additional H_2S monitors at homes farthest from the platform. All of the data on particulate matter, however, were collected at the platform and assigned to all participants in the neighborhood.

Participants attended a 3-hour training session during which they learned to complete the required data collection activities. They selected a morning time and an evening time at which they would collect data (for example, 6:00 AM and 6:00 PM). In addition, participants completed an assessment of coping style using the John Henryism Active Coping scale[45,46] and an assessment of threshold odor sensitivity using butanol standards.[47]

At the preselected, twice-daily times, participants spent 10 minutes outdoors at home and then returned indoors to rate any odor present during that 10-minute period on a 9-point scale ranging from 0 (no odor) to 8 (very strong odor). Hourly average H_2S, PM_{10}, and semivolatile PM_{10} values were calculated for the hour immediately preceding the odor rating. Following the odor rating, they responded to 5 mood state questions: "How do you feel now: (a) stressed or annoyed?, (b) nervous or anxious?, (c) gloomy, blue, or unhappy?, (d) angry, grouchy, or bad-tempered?, (e) confused or unable to concentrate?" They rated these mood questions on a 9-point scale ranging from 0 (not at all) to 8 (extremely). The "stressed or annoyed?" question was an ad-hoc single-item measure,[48,49] and the remaining 4 questions came from the Profile of Mood States instrument,[26,50] specifically, from the Tension–Anxiety, Depression–Dejection, Anger–Hostility, and Confusion–Bewilderment subscales. (The Fatigue–Inertia and Vigor–Activity subscales were not used.)

Statistical Analyses

We used logistic mixed models to evaluate malodor, H_2S, PM_{10}, and semivolatile PM_{10} as predictors of reported stress and negative mood (NLMIXED procedure in SAS version 9.1.3, Cary, NC). We used 2-level (within person and between person) mixed models to take into account the correlated structure of longitudinal data for individuals. The stress and mood variables were recoded as binary; for stressed or annoyed and nervous or anxious, 0 and 1 on the original scale were coded as 0 and 2 to 8 on the original scale were coded as 1. For the remaining 3 mood variables, 0 on the original scale was also coded as 0 and 1 to 8 on the original scale were coded as 1. These coding decisions were based on the distribution of the data such that approximately 90% of the records for each outcome variable were coded as 0 and approximately 10% were coded as 1. We included all predictor variables as linear terms. We conducted all analyses with records for which the ratings of malodor, stress, and mood, and the airborne emissions data, were not missing.

Random intercepts were included in the mixed logistic models to capture the variation between participants in baseline (average) levels of stress and negative mood. Models included the following time-dependent covariates: time of day (morning vs evening), study day (1 to ≥14), and study week (first vs second). For analyses of odor as a predictor of stress and mood, the models also included whether participants reported a cold, flu, or stomach virus at any time during data collection (yes or no). We hypothesized that illness could affect a participant's ability to smell or perception of odor and negative mood. We did not consider time-independent confounders, such as age or gender, because their relationship with exposure and outcome did not vary over time. A sample logistic mixed model follows.

Level 1 (time, within person):

$$(1)\ \text{Logit}\,(\Pr[\text{Stress}_{ij} = 1]) = b_{0j} + b_{1j}(\text{odor}) + b_{2j}(\text{time of day}),$$

where $\Pr[\text{Stress}_{ij}=1]$ is the probability that stress reported by person j at timepoint i equaled 1, b_{0j} is the person-specific intercept, b_{1j} is the effect of the time-dependent odor rating, and b_{2j} is the effect of time of day (morning vs evening).

Level 2 (between person):

$$(2)\ b_{0j} = \gamma_{00} + \gamma_{01}(\textit{person}_j) + \mu_{0j};\ \mu_{0j} \sim N(0, \tau_{00}),$$

where b_{0j} is the person-specific intercept, γ_{00} is the mean of the person-specific intercepts (i.e., fixed intercept), $\gamma_{01}(\text{person}_j)$ is the contribution to the overall mean from person j, and μ_{0j} is the residual between-person variation in the intercept.

We also evaluated several potential modifiers. For analyses of H_2S as a predictor of stress and negative mood, we considered modification by wind speed (low [≤0.57 mph], medium [0.58 mph–6.75 mph], and high [>6.75 mph]) because of previous work that suggested modification of the relationship between H_2S and reported malodor by wind speed.[44] Based on previous research,[3,29,30,37] we considered age, dichotomized at the median (≤53.7 years vs >53.7 years), and coping style, dichotomized at the median, (John Henryism Active Coping scale score <52 vs ≥52)[46,47] as potential modifiers of any association between reported odor and stress. We also considered threshold odor sensitivity (low or moderate [<320 ppm] vs high [≥320 ppm]) as a potential modifier of the relationships between odor, stress, and mood to evaluate whether more-sensitive individuals responded differently than less-sensitive ones.

RESULTS

There were 2895 records from 101 individuals in 16 neighborhoods. Complete data on reported odor, stress, and mood were available for 2666 records. Of the 2666 records with complete odor, stress, and mood data from study participants, 78 records were missing data on H_2S and 741 records were missing data on PM_{10} because of monitoring equipment malfunction.

Demographics

Table 1 presents demographic information about study participants. The median age was 53.7 years; age ranged from 19.2 years to 89.5 years. Approximately two thirds of the participants were female, and approximately 85% were African American. Seventy-five percent of participants reported that they grew up around livestock. Six neighborhoods were within 2 miles of 1 to 4 industrial hog operations, 4 were within 2 miles of 5 to 9 industrial hog operations, and 6 were within 2 miles of 10 or more industrial hog operations. Average H_2S values in the 16 neighborhoods ranged from less than 0.01 ppb to 1.5 ppb, and the highest measured H_2S values ranged from 2 ppb to 90 ppb. Average PM_{10} values ranged from 10.8 μg per cubic meter (μg/m^3) to 28.7 μg/m^3, and average semivolatile PM_{10} values ranged from –3.2 μg/m^3 (negative values occurred because of measurement imprecision at very low concentrations) to 9.2 μg/m^3.[44]

TABLE 1—Participant Characteristics: Community Health Effects of Industrial Hog Operations Study, Eastern North Carolina, 2003–2005

	No. of Records	No. of Participants
Age		
>53.7 y	1377	50
≤53.7 y	1289	51
Gender		
Female	1737	66
Male	929	35
Race		
Black	2167	85
Non-Black[a]	499	16
Grew up around livestock		
Yes	1998	76
No	591	22
Missing	77	3
Total	2666	101

[a]Fifteen White participants and 1 Latino participant.

The distribution of twice-daily odor ratings during the preselected 10-minute exposure times is presented in Table 2. Of the 2666 odor ratings recorded after participants spent 10 minutes outdoors, approximately 50% equaled zero. An additional 30% were low (a rating of 1 or 2) on the 9-point scale. Approximately 20% were 3 or higher, and 1% of the data were in each of the 2 highest categories. Most of the ratings of stress and mood state also equaled zero. For "stressed or annoyed," 81% of reports were zero; 87% were zero for "nervous or anxious," 88% for "gloomy, blue, or unhappy," 93% for "angry, grouchy, or bad-tempered," and 95% for "confused or unable to concentrate" (Table 2).

Mixed Models

Table 3 presents parameter estimates, standard errors, *t* values, odds ratios (ORs), and 95% confidence intervals (CIs) for H_2S, PM_{10}, semivolatile PM_{10}, and reported malodor as predictors of binary stress and negative mood. Variables considered as time-dependent confounders produced little change in the magnitude of the parameter estimates for the independent variables. However, we adjusted all models for time of day (morning vs evening) because time is an important predictor of odor. Reporting stress or annoyance was strongly associated with increasing levels of H_2S; the OR for a 1 ppb change in H_2S was 1.18 (95%CI=1.08, 1.30). Hydrogen sulfide was also strongly associated with feeling nervous or anxious (OR=1.12; 95% CI=1.03, 1.22). Hydrogen sulfide did not appear to be associated with the other 3 mood state variables, and wind speed did not modify any of the relationships between H_2S and stress or mood.

We found that PM_{10} did not appear to be associated with stress or negative mood, with the exception of a marginal association with feeling confused or unable to concentrate (Table 3). Semivolatile PM_{10} was most strongly associated with feeling stressed or annoyed and nervous or anxious. Associated ORs for a 1 μg/m^3 increase in semivolatile PM_{10} were small (1.06 and 1.10, respectively), though ORs associated with a 10 μg/m^3 increase, for example, were 1.73 and 2.59, respectively. Semivolatile PM_{10} appeared to be only marginally associated with feeling gloomy, angry, or confused or unable to concentrate.

Table 3 also presents parameter estimates, standard errors, *t* values, ORs, and 95% CIs for reported malodor as a predictor of binary stress and negative mood. All parameter estimates were large relative to their standard errors. The ratio of the odds of reporting stress for a 1-unit increase in reported odor on a 0-to-8 scale was 1.81 (95% CI=1.63, 2.00). Consequently, a 4-unit change on the odor scale (from odor=0 to odor=4, for example) yielded an OR of 10.6. Odds ratios for feeling nervous, gloomy, angry, and unable to concentrate, associated with a 1-unit change in odor, were 1.60 (95% CI=1.41, 1.81); 1.43 (95% CI=1.25, 1.63); 1.52 (95% CI=1.37, 1.70) and 1.31 (95% CI=1.16, 1.50), respectively.

Coping, but not age, appeared to modify the relationship between reported odor and stress. The parameter estimate for participants who scored below the median on the John Henryism Active Coping scale was 0.45 (standard error [SE]=0.07), whereas the parameter estimate for participants who scored above the median was 0.73 (SE=0.08). Threshold odor sensitivity did not appear to modify the associations between reported malodor and stress or negative mood.

DISCUSSION

We used a longitudinal design to evaluate relationships between malodor from industrial hog operations, H_2S, PM_{10}, semivolatile PM_{10}, and the stress and negative mood reported by neighboring residents. We found that ratings of

TABLE 2—Number and Percentage of Records and Number of Participants in Each Category of the Odor, Stress, and Mood Variable Ratings: Community Health Effects of Industrial Hog Operations Study, Eastern North Carolina, 2003–2005

	Twice-Daily Odor Rating		Stressed or Annoyed		Nervous or Anxious		Gloomy, Blue, or Unhappy		Angry, Grouchy, or Bad-Tempered		Confused or Unable to Concentrate	
Rating	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants	No. of Records (%)	No. of Participants
0	1374 (51.5)	88	2162 (81.1)	98	2314 (86.8)	100	2337 (87.7)	98	2479 (93.0)	99	2529 (94.9)	100
1	472 (17.7)	82	290 (10.9)	60	217 (8.1)	40	198 (7.4)	44	109 (4.1)	40	96 (3.6)	24
2	273 (10.2)	72	95 (3.6)	39	80 (3.0)	24	42 (1.6)	20	22 (0.8)	11	20 (0.8)	9
3	196 (7.4)	68	50 (1.9)	20	34 (1.3)	12	45 (1.7)	13	10 (0.4)	7	10 (0.4)	4
4	123 (4.6)	47	14 (0.5)	10	10 (0.4)	3	12 (0.5)	6	6 (0.2)	5	7 (0.3)	2
5	73 (2.7)	39	22 (0.8)	13	8 (0.3)	6	13 (0.5)	6	17 (0.6)	9	3 (0.1)	3
6	108 (4.1)	40	19 (0.7)	10	1 (<0.1)	1	8 (0.3)	4	10 (0.4)	4	1 (<0.1)	1
7	22 (0.8)	12	6 (0.2)	4	1 (<0.1)	1	6 (0.2)	3	5 (0.2)	3	0 (0.0)	0
8	25 (0.9)	12	8 (0.3)	6	1 (<0.1)	1	5 (0.2)	3	8 (0.3)	3	0 (0.0)	0
Total	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101	2666 (100.0)	101

feeling stressed or annoyed, nervous or anxious, gloomy or unhappy, angry or grouchy, and confused or unable to concentrate increased with ratings of malodor. Of the 5 outcome variables, odor was most strongly related to feeling stressed or annoyed. Active coping appeared to modify the relationship between odor and stress or annoyance, with those with higher John Henryism scores more affected by malodor. Hydrogen sulfide appeared to be associated with feeling stressed or annoyed and nervous or anxious but not with the other 3 mood variables. We found that PM_{10} was not associated with the outcome variables, with the exception of a marginal association with feeling confused or unable to concentrate. Semivolatile PM_{10}, however, appeared to be associated with feeling stressed or annoyed and nervous or anxious and only marginally associated with the remaining 3 mood variables.

Though we are not aware of other work that has sought to link airborne emissions to reported stress and negative mood, there is a consistent literature documenting the effect of malodor on annoyance, both in laboratories[1,37,51–53] and other settings.[3,29,30] Several authors have also considered coping style as a potential effect modifier.[1,3,29,30,37] In field studies of annoyance response to industrial odors, people with higher scores for problem-oriented coping, or action-oriented coping, tended to report more annoyance following odor exposure than did people with lower scores.[3,29,30,37] In a laboratory study, however, Asmus and Bell did not find coping style to be an effect modifier.[1]

We found a stronger relationship between odor and stress in participants with high scores on the John Henryism Active Coping scale. Our findings are consistent with odor studies by Steinheider and Winneke,[29] Winneke et al.,[37] Sucker et al.,[30] and Both et al.[3] The John Henryism Active Coping scale was developed by Sherman James in studies conducted among African Americans in eastern North Carolina[46] and, therefore, may be especially appropriate in the context of the present investigation. It measured "the degree to which [Black Americans] felt they could control their environment through hard work and determination."[46(p259)] James hypothesized a poorer health outcome (higher blood pressure) in men who scored high on the scale but lacked the resources to control their environments.[46] Consistent with our a priori hypothesis, it appears that study participants who perceived that they had more control over their environment found an unpredictable and uncontrollable malodor more stressful than those who perceived they had less control.

Strengths and Limitations

The longitudinal design was a particular strength of this research. There were approximately 28 repeated measures for each participant. In the analyses, each participant served as her or his own control. Perceptions of stress and adverse mood vary between people, and we were able to statistically model the between-person variation in such perceptions. Physical measures of pollution are an additional strength of this research; previous studies have relied entirely on self-reported measures of exposure and outcome. We did, however, measure only several constituents of a chemically complex odor plume that includes, potentially, hundreds of volatile organic compounds.[23]

A further design limitation was the contemporaneous assessment of both exposure and outcome for the analyses of odor as a predictor of stress and negative mood. Because both exposure and outcome were assessed by self-report, it is difficult to determine how the assessment of one affected the assessment of the other. Participants spent 10 minutes outdoors before returning indoors to complete the required data collection activities; they rated the intensity of any malodor present and then rated stress and mood. Rating the odor while stressed or annoyed for reasons unrelated to odor may have induced a higher rating than the participant would have rated in the absence of feeling stressed or annoyed. Though the results of the analyses of odor and stress or mood must be interpreted in light of this design limitation, odor as a marker of exposure is important because it captures information on numerous other pollutants with odorant properties that we were unable to explicitly measure in this study. Furthermore, it permits consideration of the mixture of chemicals emitted from industrial hog

TABLE 3—Logistic Mixed Model Results for Associations Between Hydrogen Sulfide, PM_{10}, Semivolatile PM_{10}, Odor, Stress, and Negative Mood: Community Health Effects of Industrial Hog Operations Study, Eastern North Carolina, 2003–2005

Main Exposure and Outcome Variable	b	SE	*t*	OR (95% CI)
Hydrogen sulfide (ppb)				
Stressed or annoyed	0.17	0.048	3.54	1.18 (1.08, 1.30)
Nervous or anxious	0.11	0.044	2.55	1.12 (1.03, 1.22)
Gloomy, blue, or unhappy	0.012	0.063	0.18	1.01 (0.89, 1.15)
Angry, grouchy, or bad-tempered	0.039	0.047	0.84	1.04 (0.95, 1.14)
Confused or unable to concentrate	–0.074	0.12	–0.63	0.93 (0.73, 1.17)
PM_{10} ($\mu g/m^3$)				
Stressed or annoyed	0.00065	0.0051	0.13	1.00 (0.99, 1.01)
Nervous or anxious	0.0029	0.0052	0.57	1.00 (0.99, 1.01)
Gloomy, blue, or unhappy	0.012	0.010	1.11	1.01 (0.99, 1.03)
Angry, grouchy, or bad-tempered	0.0035	0.0057	0.61	1.00 (0.99, 1.01)
Confused or unable to concentrate	0.010	0.0070	1.43	1.01 (1.00, 1.02)
Semivolatile PM_{10} ($\mu g/m^3$)				
Stressed or annoyed	0.055	0.025	2.15	1.06 (1.00, 1.11)
Nervous or anxious	0.095	0.033	2.91	1.10 (1.03, 1.17)
Gloomy, blue, or unhappy	0.058	0.043	1.35	1.06 (0.97, 1.16)
Angry, grouchy, or bad-tempered	0.027	0.026	1.05	1.03 (0.98, 1.08)
Confused or unable to concentrate	0.043	0.036	1.22	1.04 (0.97, 1.12)
Twice daily odor rating (0–8)				
Stressed or annoyed	0.59	0.051	11.50	1.81 (1.63, 2.00)
Nervous or anxious	0.47	0.064	7.37	1.60 (1.41, 1.81)
Gloomy, blue, or unhappy	0.36	0.067	5.35	1.43 (1.25, 1.63)
Angry, grouchy, or bad-tempered	0.42	0.055	7.70	1.52 (1.37, 1.70)
Confused or unable to concentrate	0.27	0.065	4.20	1.31 (1.16, 1.50)

Note. OR = odds radio; CI = confidence interval; PM_{10} = particulate matter less than 10 μm in aerodynamic diameter. Adjusted for time of day, morning versus evening.

operations as opposed to its individual constituent parts.

Conclusions

In a community-based, longitudinal study of neighbors of industrial hog operations, we observed associations among malodor, several airborne emissions, stress, and negative mood. Specifically, we observed increased reporting of stress and negative mood in response to increasing malodor. Additionally, increases in H_2S and semivolatile PM_{10}, both odorous in nature, were associated with reported stress and 1 or more mood variables. Our findings complement a large literature on malodor as an environmental stressor. Malodor and concomitant airborne emissions do appear to trigger stress and negative mood in nearby residents unwillingly exposed at home.

It is important to contextualize the effect of malodor on the lives of nearby residents. People who cannot afford air conditioning, clothes dryers, membership at a gym, and entertaining in restaurants depend on opening their windows for ventilation, drying their clothes outside, exercising in their yards, and entertaining family and friends in and around their homes. In ethnographic interviews, neighbors of industrial hog operations report that they refrain from gardening, walking, chores, and having cookouts with family and friends because of hog odor, and they report interruption of their sleep because of hog odor inside their homes.[54] This is significant, because physical activity, social support, and sleep are important for health. Industrial hog operations in North Carolina are located disproportionately in low income, African American communities[35] that have limited financial resources to prevent the influx of polluting industries as well as to manage the impacts of uncontrollable environmental malodors on physical and mental health. Recognizing that health is a state of well-being, and not merely the absence of disease,[40] public health and environmental professionals should consider the impacts of environmental malodor and its potential role in magnifying health disparities. ■

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Contributors

R. Avery Horton had primary responsibility for the study, completed the analyses, and wrote the first draft. S. Wing actively provided consultation throughout all phases of the research. S.W. Marshall provided statistical expertise in the design and analysis of data. K.A. Brownley consulted in the design phase and in the interpretation and contextualization of the results. All authors contributed to the writing of the article.

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Human Participant Protection

This study was approved annually by the institutional review board of the University of North Carolina at Chapel Hill. All study participants provided informed consent.

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Intensive Livestock Operations, Health, and Quality of Life among Eastern North Carolina Residents

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People who live near industrial swine operations have reported decreased health and quality of life. To investigate these issues, we surveyed residents of three rural communities, one in the vicinity of an approximately 6,000-head hog operation, one in the vicinity of two intensive cattle operations, and a third rural agricultural area without livestock operations that use liquid waste management systems. Trained interviewers obtained information about health symptoms and reduced quality of life during the previous 6 months. We completed 155 interviews, with a refusal rate of 14%. Community differences in the mean number of episodes were compared with adjustment for age, sex, smoking, and employment status. The average number of episodes of many symptoms was similar in the three communities; however, certain respiratory and gastrointestinal problems and mucous membrane irritation were elevated among residents in the vicinity of the hog operation. Residents in the vicinity of the hog operation reported increased occurrences of headaches, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes as compared to residents of the community with no intensive livestock operations. Quality of life, as indicated by the number of times residents could not open their windows or go outside even in nice weather, was similar in the control and the community in the vicinity of the cattle operation but greatly reduced among residents near the hog operation. Respiratory and mucous membrane effects were consistent with the results of studies of occupational exposures among swine confinement-house workers and previous findings for neighbors of intensive swine operations. Long-term physical and mental health impacts could not be investigated in this study. *Key words*: African Americans, agricultural health, air pollution, epidemiology, respiratory conditions, rural health. *Environ Health Perspect* 108:233–238 (2000). [Online 8 February 2000]
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Industrial hog production has grown rapidly in North Carolina since the early 1980s. Once characterized by relatively small independently owned farms scattered across the state, hog production in North Carolina is now concentrated in the coastal plain region, under the domain of large corporate growers, and dominated by large-scale intensive operations (*1,2*). Persons who live near large hog operations have reported reduced quality of life as well as health problems related to airborne emissions from animal confinement houses, open waste lagoons, and spray fields (*3–8*). Airborne emissions include hydrogen sulfide, ammonia, dusts, endotoxins, and complex mixtures of volatile organic compounds. Health effects from environmental exposures could occur through inflammatory, immunologic, irritant, neurochemical, and psychophysiologic mechanisms (*5*).

In contrast to the many studies of occupational exposures of swine confinement-house workers (*9–25*), only a few field studies have investigated the health effects of lower level environmental exposures. In a study of residents near hog facilities in North Carolina, Schiffman et al. (*26*) reported that persons exposed to odors from intensive hog operations experienced "more tension, more depression, more anger, more fatigue, and more confusion" than a group of unexposed persons. A study in Iowa (*7*) compared physical and mental health symptoms among people residing within a 2-mile radius of a 4,000-head swine operation and a control group in an area with no intensive livestock operation. Those who lived in the vicinity of the intensive hog operation reported higher frequencies of 14 of 18 physical health symptoms, especially respiratory symptoms. The Iowa study did not find an excess of mental health symptoms but, in contrast to the North Carolina study (*26*), it was not designed to evaluate symptoms at the time that odors were present.

The present study addressed a number of issues raised by previous research. Unlike studies of volunteers, the sample was drawn systematically from defined populations. To increase the levels of participation and prevent exclusions based on literacy or the ability to participate in a longer study, we did not ask participants to keep a diary or respond to questions at the times that airborne emissions from livestock operations were noticeable. Instead, we asked questions about the number of times that participants experienced the symptoms of interest during the previous 6 months. Because mood disturbance and mental health effects may be acute responses to the presence of odors, we focused on physical health and quality of life rather than on short-term mood changes. We achieved high levels of participation in the study by establishing cooperative relationships with local community based organizations in planning and conducting the research.

This study compared health symptoms in residents of three North Carolina communities, one in the vicinity of an intensive hog operation, one in the vicinity of two intensive cattle operations, and a third in a rural agricultural area where no livestock operations used liquid waste management systems. Although the primary motivation for the study came from an interest in airborne emissions from swine operations, the inclusion of people residing near cattle operations afforded an opportunity to examine possible health effects from a different kind of livestock, and also offered a second comparison community that may share other features common to communities with intensive livestock production.

Materials and Methods

Selection of communities. The North Carolina Division of Water Quality (Raleigh, NC) maintains a database on intensive livestock operations that use liquid waste management systems (*27*). Information on livestock operations included in the database as of January 1998 was merged with 1990 U.S. Census block group data (U.S. Census Bureau, Suitland, MD). Data for block groups, which average approximately 500 households, included information on population size, race, and poverty levels. Maps of the eastern part of North Carolina

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were prepared showing the locations of livestock operations, towns, roads, and churches. Community consultants experienced with the hog industry and the health concerns of community members met with university researchers to review the maps and choose potential study sites. Our goal was to choose three areas with similar economic and demographic characteristics where residents would be willing to participate in an interview and where existing community based organizations would be interested in working with researchers. We sought livestock areas with 80–100 households within a 2-mile radius of the livestock facility so that we would be able to obtain approximately 50 participants in each area.

The hog and cattle study areas were defined by a < 2-mile radius around the operations and each study area was contained within a single census block group. The hog operation was a feeder-to-finish facility with a head capacity of approximately 6,000, a steady-state live weight of approximately 800,000 pounds, and one lagoon. The cattle community contained two neighboring dairy operations with a combined head capacity of approximately 300, live weight of approximately 200,000 pounds, and two lagoons. The area with no intensive livestock operations extended across two block groups. Parts of two block groups were included to ensure that eligible households were at least 2 miles away from any livestock operation using a liquid waste management system. The median annual family income of the census block groups from which the study areas were chosen ranged from approximately $17,000–23,000 and the populations were between 65 and 90% African American.

All habitable dwellings in the study areas were enumerated. The location of each dwelling was noted on an enlarged area map and was assigned a unique study number. Information on street or road location and the type of dwelling was entered into a computerized database.

Questionnaire. A structured questionnaire was developed based on previous research findings and on discussions with community members who had experienced exposures from intensive livestock operations. In addition to symptoms identified by previous studies or community residents as possibly related to airborne emissions from livestock operations, we included symptoms that we did not believe would be related to airborne emissions to evaluate the possibility that residents of exposed communities might report excesses of all types of symptoms because of negative feelings about intensive livestock operations. The questionnaire was designed to obtain information about the frequency of occurrence of each symptom over the 6 months preceding the interview. Possible responses were never; rarely (once or twice over the past 6 months); sometimes (1–3 times per month); often (1 per week); and very often (twice a week or more over the past 6 months). After all of the structured questions had been asked, respondents were asked about aspects of the environment that may have affected their own health or the health of others in the household. Interviewers took notes to summarize the types of responses. At the end of the interview, participants were asked their age, occupation, household size, source of drinking water, and whether they or others in the household smoked tobacco. The interviewers recorded race, sex, and whether anyone other than the participant and interviewer were present during the interview.

Household interviews. Adults 18 years of age or older with no serious speech or mental impairment who lived in the current residence for 6 months or longer were eligible to respond to the questionnaire. The households of dairy operators who lived beside the cattle facility were excluded to avoid the complication of occupational exposures; the household of the swine facility operator was not within the 2-mile enumeration area of the facility. Interviews were conducted on Fridays and Saturdays in January and February 1999 by university-based staff. Interviewers were accompanied by a community consultant, a local resident recruited from the membership of the community based organization. The community consultant introduced the interviewer to the prospective respondent, explained the purpose and importance of the survey, and encouraged each person to participate. Interviewers were trained to administer the survey instrument systematically and uniformly to all respondents. The participant interview was conducted in a location of the participant's choosing. The questionnaire required less than 15 min to complete. The community consultant was not present for the interview unless the participant specifically asked the consultant to remain.

One adult from each household was invited to participate in the survey. Preference was given to the first person to answer the door if

Table 1. Characteristics of study households, listed by type of livestock operation.

	Livestock operation			
Characteristic	None	Cattle	Hogs	Total
Inhabited houses	104	116	92	312
Households ineligible[a]	5	2	3	10
Not home	29	44	19	92
Rescheduled or not contacted	5	14	10	29
Completed interviews	50	50	55	155
Refused	15	6	5	26
Refusal rate[b]	23.1%	10.7%	8.3%	14.4%

[a]Not living in the house for 6 months; difficulty understanding survey questions. [b]Refusal rate = completed interviews/completed interviews + refusals.

Table 2. Characteristics of respondents.

	Livestock operation, no. (%)			
Characteristic	None	Cattle	Hogs	Total
Age				
19–44 years	19 (38)	13 (26)	23 (42)	55 (36)
45–64 years	19 (38)	19 (38)	20 (36)	58 (37)
65–90 years	12 (24)	18 (36)	12 (22)	42 (27)
Race/ethnicity				
African American	45 (90)	49 (98)	48 (87)	142 (92)
White	5 (10)	1 (2)	6 (11)	12 (8)
Latino	0 (0)	0 (0)	1 (2)	1 (1)
Sex				
Female	31 (62)	33 (66)	36 (65)	100 (65)
Male	19 (38)	17 (34)	19 (35)	55 (35)
Smoking				
Yes	14 (28)	13 (26)	7 (13)	34 (22)
No	36 (72)	37 (74)	48 (87)	121 (78)
Employed outside of the home				
Yes	26 (52)	15 (30)	34 (62)	75 (48)
No	24 (48)	34 (68)	21 (38)	79 (51)
Not completed	0 (0)	1 (2)	0 (0)	1 (1)
Number in household				
1	12 (24)	8 (16)	3 (5)	23 (15)
2	21 (42)	21 (42)	20 (37)	62 (40)
3–4	12 (24)	15 (30)	15 (27)	42 (27)
5–12	5 (10)	6 (12)	17 (31)	28 (18)
Total respondents (*n*)	50 (100)	50 (100)	55 (100)	155 (100)

the person was over 18 years old and lived in the household. Those who declined to participate because the time was inconvenient were offered alternative times and the visit was rescheduled. If no one was at home, the information was recorded on the tracking form. These households were visited a second time. Households were visited sequentially using the enumeration map in approximate order of distance from the intensive livestock operation until a minimum sample size of 50 was reached. Informed consent was requested verbally by the trained interviewer.

Statistical methods. Differences in symptoms among the three communities were evaluated by comparing the average number of episodes experienced over the last 6 months for each symptom. The number of episodes over the 6 months preceding the interview was scored according to the instructions given to respondents for responding to the frequency of symptoms. A response of "never" corresponded to 0 episodes. A response of "occasionally" corresponded to two episodes. "Sometimes" corresponded to 12 episodes (2/month), "often" corresponded to 26 episodes (1/week), and "very often" corresponded to 52 episodes (2/week). Adjusted mean differences in the numbers of episodes were calculated using linear regression to control for sex, age (19–44, 45–64, or 65–90 years), respondent's smoking status (yes or no), and employment outside the home (yes or no). These variables were considered potential confounders because they may be associated with exposure to airborne emissions and experience or reporting of symptoms. Because the five response categories for the number of episodes were highly skewed, regression models were also run with the dependent variable coded as the square root of the number of episodes and as 0–4.

The ratio of the β-coefficient (adjusted mean difference in number of episodes) to its SE yields a *t*-value. Larger absolute values of *t* indicate that the livestock variable is more important for statistically predicting numbers of symptom episodes. Significance tests are not presented because exposures were not randomized in this observational study; however, *t*-values > 1.66 would produce a significant one-tailed test of the hypothesis that average numbers of symptoms are greater in the livestock than in the control community at $p < 0.05$. Values > 1.98 would produce a significant two-tailed test at $p < 0.05$.

Table 3. Number and percent of respondents reporting 12 or more episodes, and mean number of episodes.

	Livestock operation					
	None		Cattle		Hogs	
Symptom	No. (%)[a]	Mean[b]	No. (%)[a]	Mean[b]	No. (%)[a]	Mean[b]
Total respondents	50 (100.0)	–	50 (100.0)	–	55 (100.0)	–
Upper respiratory/sinus						
Headache	16 (32.0)	7.8	18 (36.0)	9.4	34 (61.8)	15.5
Stuffy nose/sinuses	14 (28.0)	7.2	17 (34.0)	8.8	24 (44.4)	10.2
Runny nose	8 (16.0)	3.9	10 (20.0)	5.4	16 (29.1)	8.5
Burning nose/sinuses	11 (22.0)	4.1	9 (18.0)	3.4	14 (25.5)	6.7
Sore throat	2 (4.0)	0.9	6 (12.0)	2.5	9 (16.4)	4.7
Plugged/popping ears	10 (20.0)	5.5	11 (22.0)	5.2	11 (20.0)	4.6
Scratchy throat	6 (12.0)	2.2	10 (20.4)	3.8	10 (18.2)	4.4
Lower respiratory						
Mucus/phlegm	14 (28.0)	5.9	14 (28.6)	7.2	16 (29.1)	8.5
Excessive coughing	5 (10.0)	1.8	6 (12.0)	3.7	12 (21.8)	6.3
Shortness of breath	12 (24.0)	7.0	13 (26.0)	6.1	11 (20.0)	5.5
Tightness in chest	6 (12.0)	3.0	9 (18.0)	4.9	11 (20.0)	3.9
Wheezing	8 (16.0)	4.4	7 (14.0)	3.7	9 (16.4)	3.6
Strange breathing sounds	10 (20.0)	5.2	5 (10.2)	3.0	6 (10.9)	2.3
Gastrointestinal						
Heartburn	10 (20.4)	5.2	10 (20.0)	8.1	17 (30.9)	7.1
Nausea/vomiting	7 (14.0)	3.0	7 (14.0)	4.8	15 (27.3)	5.9
No appetite	8 (16.0)	2.8	8 (16.3)	4.1	12 (21.8)	5.5
Diarrhea	2 (4.0)	1.7	4 (8.2)	1.3	10 (18.2)	4.3
Skin/eye irritation						
Burning eyes	8 (16.0)	3.8	5 (10.0)	3.4	19 (35.2)	9.4
Tearing eyes	16 (32.0)	9.5	14 (28.0)	8.7	20 (36.4)	9.3
Dry/scaly skin	10 (20.0)	4.4	11 (22.0)	7.1	12 (21.8)	7.1
Skin rash or irritation	4 (8.0)	1.6	4 (8.0)	2.0	8 (14.6)	4.0
Skin redness	1 (2.0)	1.2	0 (0.0)	0.1	4 (7.3)	1.3
Miscellaneous						
Joint/muscle pain	24 (48.0)	16.1	26 (52.0)	17.2	28 (50.9)	16.7
Unexplainably tired	19 (38.0)	12.8	19 (38.0)	10.5	23 (41.8)	13.7
Blurred vision	15 (30.0)	8.8	9 (18.0)	5.4	16 (29.6)	9.7
Dizzy/faint	11 (22.0)	5.5	10 (20.0)	5.3	12 (21.8)	4.1
Hearing problems	7 (14.0)	7.4	5 (10.0)	2.0	6 (10.9)	2.7
Chest pain	10 (20.0)	3.4	6 (12.0)	1.6	6 (10.9)	2.7
Fever/chills	5 (10.0)	2.3	2 (4.0)	1.2	5 (9.3)	1.9
Fainted	0 (0.0)	0.04	0 (0.0)	0.04	1 (1.9)	1.0
Quality of life						
Can't open windows	7 (14.3)	3.2	4 (8.2)	1.8	31 (57.4)	18.5
Can't go outside	5 (10.0)	2.1	3 (6.0)	1.2	30 (55.6)	15.4

[a]Number and percentage of respondents answering sometimes (1–3 times/month), often (1/week), and very often (≥ 2 times/week over the past 6 months). [b]Average number of episodes per person over 6 months.

Results

Table 1 shows the numbers of households enumerated and surveyed. Enumerated households were within 2 miles of an intensive livestock operation in the cattle and hog communities. In the control area, enumerated households were > 2 miles from an intensive livestock operation in the control area. Approximately 100 households were enumerated in each area. Fifty interviews were completed in the cattle and control communities, and 55 interviews were completed in the hog community. The refusal rate was 23.1% in the control community, 10.7% in the cattle community, and 8.3% in the hog community.

Characteristics of the respondents are shown in Table 2. The cattle community had the largest proportion of respondents older than 65 years of age. All three communities were predominantly African American. Approximately two-thirds of the participants were female. The proportion of respondents who reported smoking tobacco was lower in the hog community than in the other two communities, whereas the proportion employed outside of the home was higher. None of the study participants reported that they worked in the livestock industry. Household size was largest in the hog community.

Responses to the symptom questions in the three communities are shown in Table 3. The symptoms were categorized in six groups: upper respiratory and sinus, lower respiratory, gastrointestinal, skin and eye irritation, miscellaneous, and quality of life. For each community we tallied the number of persons who answered "sometimes," "often," or "very often" corresponding to ≥ 12 episodes during the 6-month period. Table 3 also shows the percentage of "sometimes" or more often and the average number of episodes for the 6 months.

Most of the percentages in Table 3 are < 50; the majority of participants responded "never" or "occasionally" to most of the symptom questions. Among the upper respiratory and sinus conditions, the percentage of respondents reporting ≥ 12 episodes was the largest in the hog community except for plugged ears and scratchy throats. Percentages were generally intermediate in the cattle community. The percentage of respondents reporting ≥ 12 episodes was generally smaller for lower respiratory, gastrointestinal, and skin or eye irritation symptoms. Percentages were the highest in the hog community for all four gastrointestinal symptoms. In all three communities, more than one-third of the participants reported experiencing joint or muscle pain and unexplained tiredness ≥ 12 times. By far the biggest differences between the communities were seen in the quality-of-life questions. Over half of the respondents in the hog community, as compared to less than one-fifth in the other two communities, reported not being able to open windows or go outside, even in nice weather, ≥ 12 times over the last 6 months.

Table 4 presents the results of the linear regression showing differences between the average number of episodes in each livestock community as compared to the community with no intensive livestock. Table 4 shows the difference in the mean number of episodes adjusted for sex, age, smoking, and work outside the home; the SE of the β-coefficient; and the *t*-value, which is the ratio of the β-coefficient to its SE (see "Statistical Methods"). The adjusted mean differences for the cattle community were generally small, with lower mean scores (negative β-coefficients and *t*-values) for many symptoms in the cattle as compared to the control community. Only episodes of excessive coughing and heartburn occurred on average > 2 times more in the cattle than in the control community ($\beta > 2$), and the *t*-values for these differences were only approximately 1.0. All of the symptoms in the miscellaneous category appeared less frequently in the cattle than in the control community. Hearing problems showed the largest difference in adjusted mean episodes, although this is based on a small number of people in the higher categories (Table 3).

In contrast, there were many mean differences of more than two episodes for the hog as compared to the control community. The average number of episodes was the most consistently elevated for upper respiratory and sinus conditions, gastrointestinal conditions, and skin or eye irritation. *t*-Values for headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes showed that residence in the hog community was an important predictor of these physical health symptoms. In contrast, none of the miscellaneous symptoms showed important excesses in the hog community.

Responses to the quality-of-life questions were very different in the control and cattle communities as compared to the hog community. The adjusted number of episodes during which participants could not open windows or go outside even in nice weather differed little for the cattle and control communities, whereas excesses of approximately 13–15 episodes were seen in the hog as compared to the control communities. *t*-Values for these β-coefficients were large.

To evaluate the sensitivity of the regression results to the coding of the dependent variable, the models shown in Table 4 were rerun using values of the square root of the number of episodes and as 0, 1, 2, 3, and 4. *t*-Values for differences between the hog community and the control community were larger in these models. The *t*-value for nausea/vomiting was 1.61 with the original metric, 2.68 using the square root of the number of episodes, and 2.88 with a coding of 0–4. To consider whether elevated gastrointestinal symptoms in the hog community might be related to well contamination, the models shown in Table 4 were rerun for the four gastrointestinal symptoms including a variable for well versus municipal water supply. The coefficients for well water were small and had little influence on the estimates of differences between livestock and control communities.

Responses to open-ended questions about how the environment around the home affected the life or health of the respondent or members of her household are shown in Tables 5 and 6. Responses that were given by two or more persons in the study are shown. Most participants from the control and cattle communities had little to report in response to these open-ended questions, although eight participants in the cattle community mentioned livestock odor. In contrast, livestock odor was noted as a problem for many residents of the hog community and for members of the residents' households.

Discussion

To our knowledge this is the first population-based study of physical health symptoms and

Table 4. Linear regression results: average number of episodes in two livestock communities as compared to a community with no intensive livestock.

	Livestock operation					
	Cattle			Hogs		
Symptom	β[a]	SE[b]	*t*-Value	β[a]	SE[b]	*t*-Value
Upper respiratory/sinus						
Headache	1.57	3.02	0.52	7.62	2.94	2.60
Stuffy nose/sinuses	1.33	2.86	0.47	2.97	2.79	1.06
Runny nose	1.26	2.44	0.52	5.18	2.37	2.18
Burning nose/sinuses	-0.42	2.19	-0.19	1.99	2.13	0.93
Sore throat	1.71	1.52	1.12	3.64	1.48	2.45
Plugged/popping ears	-1.07	2.28	-0.47	-0.79	2.22	-0.35
Scratchy throat	1.63	1.49	1.09	2.09	1.45	1.44
Lower respiratory						
Mucus/phlegm	0.56	2.65	0.21	3.91	2.57	1.52
Excessive coughing	2.15	2.06	1.04	4.74	2.01	2.36
Shortness of breath	-1.62	2.66	-0.61	-0.74	2.59	-0.29
Tightness in chest	1.45	2.08	0.70	1.37	2.02	0.68
Wheezing	-0.63	2.05	-0.31	-0.50	1.99	-0.25
Strange breathing sounds	-2.31	2.16	-1.07	-2.57	2.09	-1.23
Gastrointestinal						
Heartburn	2.35	2.86	0.82	1.94	2.78	0.70
Nausea/vomiting	1.15	2.20	0.52	3.46	2.15	1.61
No appetite	0.92	2.02	0.46	3.03	1.96	1.55
Diarrhea	-0.92	1.44	-0.64	2.96	1.39	2.13
Skin/eye irritation						
Burning eyes	-1.39	2.47	-0.56	5.58	2.42	2.31
Tearing eyes	-1.70	3.24	-0.52	0.64	3.16	0.20
Dry/scaly skin	1.85	2.81	0.66	2.67	2.74	0.98
Skin rash or irritation	0.54	1.72	0.31	2.28	1.67	1.36
Skin redness	-1.25	1.01	-1.23	0.12	0.99	0.12
Miscellaneous						
Joint/muscle pain	-0.22	4.03	-0.06	1.22	3.93	0.31
Unexplainably tired	-3.43	3.78	-0.91	0.76	3.68	0.21
Blurred vision	-4.67	3.14	-1.49	1.25	3.07	0.41
Dizzy/faint	-1.22	2.17	-0.56	-1.32	2.11	-0.63
Hearing problems	-6.44	2.50	-2.57	-3.58	2.44	-1.47
Chest pain	-2.30	1.32	-1.74	-0.35	1.29	-0.27
Fever/chills	-1.32	1.04	-1.27	-0.39	1.02	-0.38
Fainted	-0.18	0.86	-0.20	1.02	0.84	1.21
Quality of life						
Can't open windows	-1.33	2.88	-0.46	14.74	2.80	5.26
Can't go outside	-0.79	2.38	-0.33	12.73	2.32	5.47

[a]Difference in the average number of episodes between communities with and without livestock operations, adjusted for sex, age, smoking, and work outside of the home. [b]Of the β-coefficient.

quality of life among community residents in North Carolina that focused on the possible health effects of airborne emissions from intensive livestock operations. The study sample was drawn from areas of the state with a majority of African American residents who have low median income. This was not unexpected because intensive hog operations in North Carolina are located disproportionately in poor and nonwhite areas (*27*). Despite the legacy of distrust of biomedical research in the African American community (*28*), refusal rates were low because of the participation of community based organizations in introducing researchers to participants. The preponderance of women in the study reflects, in part, who was at home and who answered the door when approached by the community consultant and interviewer.

A number of symptoms previously reported as elevated among persons occupationally exposed in swine confinement houses were elevated among the residents of the hog community as compared to the community with no livestock operations. In particular, headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes were reported more frequently in the hog community. Members of the cattle community did not report similar elevations, nor did they report reduced quality of life. The quality of life measures (not opening of windows and not going outside even in nice weather) showed a large excess in the hog community.

As in all studies, measurement problems and differences between the communities other than the exposure of interest could have influenced the results. Recall bias is an issue in any survey. We were particularly concerned that residents living in proximity to a hog operation might report a greater number of symptoms because of negative feelings about the effect of the operation on their lives and their community. Therefore, we were careful to present the study as a rural health survey, not as a livestock and health study, and we did not include any questions in the survey that referred to hogs, livestock, or odors. During debriefings after the field work, interviewers reported that some respondents did not understand that questions about the environment referred to problems including odor. Such misunderstandings would have led to an underestimate of the impact of livestock operations on health and quality of life.

It is possible that residents of the hog community could have reported more symptoms because of their feelings about the negative impact of the hog operation on their community. However, if this had occurred, we would have expected excess reports for most symptoms. In fact, the eight symptoms in the miscellaneous category, none of which were expected to be related to exposure to airborne emissions, occurred with about the same frequency in the hog and control communities (Table 4). This suggests that there was not a tendency for over-reporting among residents of the hog community. Negative feelings might also have been evident in the open-ended questions, when respondents had the opportunity to report concerns beyond the environmental health and quality-of-life issues addressed in the structured questionnaire. As shown in Table 6, two persons in the hog community expressed concerns about property values.

Other circumstances of the survey may have led to an underestimate of the impact of swine operations on health of area residents. Perhaps most important, we studied an area with only one intensive hog operation. We would have expected to see larger effects in areas of the state with larger and more numerous operations and consequently heavier airborne emissions. Differences between the livestock and control communities may also have been reduced because of exposures to agricultural chemicals and dusts from row cropping in the control community.

Levels of emissions and weather conditions at the time interviewers were in the field may also have influenced the findings. With one exception, interviewers did not notice an odor from the hog operation while conducting the interviews. If interviews had been conducted when odors were strong, respondents may have reported a greater frequency of health symptoms.

The lack of environmental exposure monitoring data is also a concern in this study. We assumed that if persons resided within 2 miles of the hog operations, they were exposed to the emissions. We were not able to distinguish higher or lower exposure levels within the community. Exposure differences could occur because of differences in distance, direction, elevation, physical barriers, the amount of time spent at home, the amount of time spent outdoors, and the availability of air conditioning and filters in the home. Quantitative evaluation of exposure differences between individuals would increase the ability of an epidemiologic study to identify health effects of airborne emissions.

Similarly, clinical or biologic measures of outcome would strengthen information about relationships between environmental exposures to emissions from livestock operations and health. Future studies could be designed to obtain information on respiratory and immune function and standardized clinical evaluation of physical and mental health conditions. Such studies could evaluate possible mechanisms linking environmental exposures and health.

This study was not able to evaluate specific populations that may be more susceptible to health impacts of environmental exposures. These groups include children, asthmatics, and older persons with compromised pulmonary or cardiovascular function. Future studies should evaluate whether these subgroups are more sensitive to airborne emissions from intensive livestock operations. We were also unable to evaluate the acute impact of odors on mental health or the long-term impacts of reduced quality of life on mental, physical, or community health.

This study supports previous research suggesting that community members experience health problems due to airborne emissions from intensive swine operations (*7*). In North Carolina there are approximately 2,500 intensive hog operations, and they are located disproportionately in areas that are poor and nonwhite (*27*). The public health

Table 5. Problems that affect respondents' own life or health.[a]

Problem	Livestock operation None	Cattle	Hogs
Livestock odor	0	8	25
Livestock odor (limits adult recreation)	0	0	14
Livestock odor (respiratory symptoms)	0	0	6
Livestock odor (can't open windows)	0	0	4
Livestock effluent (contaminated well)	0	0	4
Livestock odor (try not to breathe)	0	0	3
Livestock odor (nausea)	0	0	3
Livestock operation (flies and insects)	0	0	3
Crop sprayers (dust or noise)	1	0	2

[a]Respondents were asked, "Has the environment around your house affected your life and health?"

Table 6. Problems that affect family members' life or health.[a]

Problem	Livestock operation None	Cattle	Hogs
Livestock odor	0	0	18
Livestock odor (limits child recreation)	0	0	10
Livestock odor (limits adult recreation)	0	1	4
Livestock odor (try not to breathe)	0	0	4
Livestock odor (respiratory symptoms)	0	0	4
Respiratory ailments	3	0	3
Complaints of skin symptoms	1	0	2
Livestock effluent (contaminated well)	0	0	2
Livestock odor (decreases property value)	0	0	2

[a]Respondents were asked, "Has the environment around your house affected the life or health of other members of your household?"

and environmental injustice implications of this geographical pattern extend beyond the physiologic impact of airborne emissions to issues of well-water contamination (*29*) and the negative impact of noxious odors (*8*) on community economic development (*30,31*). Populations in these areas may be at greater risk of health impacts due to high disease rates (*32,33*), low income (*27*), and poor housing conditions. Future research could provide a better understanding of the health effects of intensive livestock operations by combining individual exposure assessment, physiologic measures, clinical evaluation of physical and mental health, and follow-up of exposed communities.

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Environmental Stressors, Perceived Control, and Health: The Case of Residents Near Large-Scale Hog Farms in Eastern North Carolina

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This study first explores the physical and psychological health effects of residence near industrial hog farms. The study compares differences in specific health symptoms, psychological distress, and perceived control between a group of 48 nearby residents and a control group ($n = 34$) with no exposure to hog farms. The process through which nearby residence affects psychological distress is then explored by examining for mediating effects of either physical health symptoms or perceived control. Findings suggest that nearby residence is associated with increases in 12 of the 22 reported physical symptoms. Most of these significantly different symptoms are related to respiratory, sinus, and nausea problems. Nearby residence is also associated with increased psychological distress and decreased perceptions of control. Nearby residence appears to affect psychological distress by increasing physical health symptoms. Although nearby residents report significantly lower perceived control, perceived control does not play a significant role in the process through which nearby residence affects psychological distress.

KEY WORDS: agricultural pollution; health; psychological distress; perceived control.

BACKGROUND

Hog Farms

Industrial or corporate agricultural operations have largely replaced family farms throughout the U.S. In keeping with this trend, eastern North

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Carolina has experienced a dramatic increase in large-scale hog growing operations over the past 15 years. As opposed to smaller family-owned and operated hog farms, these corporate operations typically hold tens of thousands of animals in fully enclosed "hog houses." Industrial hog farms also differ from traditional family farms in that they have a separation of ownership, management, and labor. Rarely do these owners or employees live in the immediate vicinity of the operation. These operations tend to draw non-local capital and they have a non-family corporate structure in which family labor plays little, if any, role (Thu *et al.*, 1997, p. 13). They have replaced the smaller hog farms in a rural area that has suffered from a steady decline in viable family farms over the past few decades.

Hopeful that this large-scale hog industry would alleviate some of the area's economic problems, local leaders and state government encouraged the growth of industrial hog farms with protective legislation and tax breaks (Furseth, 1997). The subsequent growth in these operations has made North Carolina the second largest producer of hogs in the country, and has made hogs the state's largest agricultural commodity. Others, however see this growth as an economic boost for the corporate owners at the expense of small-scale farmers and local residents. There is evidence that the introduction of large-scale hog farming precipitated the demise of the smaller family farms in the area (Edwards and Ladd, 2000).

There has been growing opposition to this industry from local grassroots activist groups comprised mostly of nearby residents, who have protested against negative impacts of these operations on their families and property, including noxious odor, health threats from the hog waste, decreased property values, interference with enjoyment of their homes and property, local environmental impacts, and community divisions. Most of their health concerns stem from the waste management practices used in these operations. The hog waste (liquid and solid) is stored in large open pits, or "lagoons" with typical capacities of several million gallons. Aside from the odor, nearby residents are concerned that these lagoons are leaking into the groundwater and contaminating drinking wells. There are further complaints that when overloads from these lagoons are sprayed on nearby fields (a common and legal practice) the effluent drifts onto neighboring property and runoff from saturated fields further contaminates adjoining property. These fears were heightened by highly publicized incidents of lagoon breaches, which polluted local waterways causing large-scale fish kills (Okun, 1997).

The hog industry countered that the situation was no different than generally accepted farming practices in rural areas. Although these operations produced substantially more waste than traditional farms (a 10,000 hog operation can produce as much waste as a town of 25,000 people

[Edwards and Ladd, 2000]), waste disposal practices were still generally accepted under regulations that applied to the smaller family farms that were prevalent at the time the regulations were written. Furthermore, alternative waste handling options were expensive and the technology was still in experimental stages. The hog industry was under no legal obligation to make changes in their practices to accommodate nearby residents and the lagoon systems remained.

The hog industry at this time held considerable economic and political power in the region, whereas the opposing nearby residents were mainly lower- to middle-class families with limited resources.[2] The divisiveness of the issue dominated local politics and eventually drew national attention and the support of regional and national environmental groups. The struggle was characterized by the opponents of the industry as one in which lower- and middle-class rural residents felt that their health, rights, property values, and environment were being harmed by a powerful industry that used political and economic influence to increase profits and circumvent ethical and legal practices. The conflict was generally characterized by the hog industry as a groundless attack against family farms, instigated by external environmental agitators.

Environmental Stressors and Health

The literature concerning the effects of environmental stressors on health covers both the direct effects of toxins, noise, crowding, disasters, etc., on physical health as well as the indirect effects of chronic stressors, such as noxious odors, polluted drinking water, noise, and smog on psychological distress. The most helpful theoretical model concerning the effects of environmental stressors on health includes two components; an explanation of the physiological adaptations to stress and a model of individual appraisals of the stressfulness of the situation (see Rice, 1992, for an overview of this literature). The first component, which draws on Hans Selye's (1956) Stress Adaptation Syndrome model, describes how individuals react to stressors with a physiological response that compromises the immune system over time. This model explains how psychological distress can compromise health. Research on the effects of industrial pollution on health have found that even when chronic stressors show no direct effect on physical health the resulting stress process does compromise individuals' ability to cope with additional stressors (Evans *et al.*, 1987).

[2]Evidence from environmental justice research has also found that large-scale hog operations are disproportionately concentrated in African American communities (Edwards and Ladd, 2000; Wing *et al.*, 1996).

The second component derives from Richard Lazarus' Cognitive-Transactional theory (Lazurus and Launier, 1978), which suggests that there is a cognitive factor in the stress process in which individuals interpret the meaning or seriousness of the stressor. This model introduces a component of individual-level appraisal of the stressors, which affects the degree of psychological distress. With respect to noxious odors, the cognitive associations between the odor and the known source can lead to heightened distress: the knowledge that the air you are breathing is polluted from hog feces may increase your aversion to the odor. In addition, any beliefs regarding the harmfulness of the odor can exacerbate the psychological distress. The belief that an odor contains contaminants that are detrimental to one's health is far more distressing than a similarly aversive but harmless odor. Past research has shown that individual appraisals of the toxicity of environmental stressors do affect the level of symptom reporting (Luginaah *et al.*, 2002).

Perceived Control

"Perceived control" is a psycho-social construct that describes generalized beliefs about one's ability to effect desired outcomes and avoid undesired outcomes. Individuals who feel that they can readily influence their circumstances or environments have high perceived control whereas those who believe that their lives are largely directed by external forces or influences have low perceived control.

In the past three decades perceived control and the related constructs of self-efficacy (Bandura, 1977), mastery (Pearlin and Schooler, 1978), and locus of control (Rotter, 1966), have received a great deal of attention in both sociological and psychological research. This research has established that low levels of perceived control are associated with several indicators of physical and psychological illness, whereas high levels of perceived control are associated with various indicators of physical and psychological well-being (for overviews see Alloy *et al.*, 1993; Gecas, 1989; Mirowsky and Ross, 1989; Thompson, 1993; Wallston and Wallston, 1978; Wheaton, 1980).

Although early research on this construct assumed that perceived control was a developmentally acquired personality characteristic, current research suggests that perceived control is determined, in large part, by current socioeconomic status (SES) and circumstances (Bullers, 1994, 1996). By reflecting one's access to resources and opportunities within a stratified society, perceived control is often a relatively accurate assessment of an individual's actual ability to control life circumstances and to respond to stressful events. Several studies confirm that those with lower SES report lower perceived control than those in more privileged social positions

(Aneshensel, 1992; Gecas, 1989; Gecas and Schwalbe, 1983; Kohn, 1989; Mirowsky and Ross, 1989; Ross *et al.*, 1990; Thoits, 1987; Turner and Noh, 1983).

The conflicts between the hog industry and nearby residents reflect a situation in which individuals with relatively scarce resources feel that their circumstances are being controlled largely by a powerful external agent—the hog industry. The effects of nearby residence on individual perceptions of control may be directly affected by lack of control in the specifics of the hog farm pollution. First, the actual lack of control over the odor and the intermittent nature of the odor may both lead to decreased perceptions of control. The lack of control over one's own property with respect to environmental degradation, property values, and use and enjoyment may also decrease generalized perceptions of control. If so, these residents would report lower perceptions of control than similar individuals who did not have negative experiences with nearby hog farms. Decreases in perceived control could then lead to physical or psychological health problems among nearby residents. This would reflect a mediating relationship in which the association between nearby residence and poor health is due, at least in part, to decreased perceptions of control.

Health and Industrial Hog Farms

Some residents are concerned about the negative impact of industrial hog operations on their physical and mental health. The most evident concern is that the dust and gasses associated with the odor are causing respiratory, sinus, and nausea problems. Evidence from previous studies finds that nearby residents of these operations do indeed have higher rates of these types of symptoms. Thu *et al.* (1997) find higher rates of respiratory and nausea symptom clusters among nearby residents than for a matched control group, and Wing and Wolf (1999) find that residents of nearby hog operations report significantly higher rates of headache, runny nose, sore throat, excessive coughing, and diarrhea than does a control group.

Another health concern involves the contamination of local drinking water supplies from leakage of waste lagoons and runoff from spray fields. Possible contaminants from hog waste include increased nitrate levels. Methempglobinemia (blue baby syndrome), a rare but potentially life threatening condition for infants, can be caused by nitrates and there is evidence that nitrates have caused cancer in laboratory rats (for a review, see Okun, 1997). However, the health effects of current well water nitrate levels on humans have not been established so there are no specific health symptoms to look for that would clearly indicate elevated nitrate levels.

Other possible contaminants include the bacteria, viruses, and protozoa associated with untreated waste. There has been no conclusive evidence that these pathogens have leached into the groundwater from functioning hog lagoons in the area but the threat of such contamination increases with flooding and lagoon breaches that flush the untreated waste into local waterways. Spread of such contaminants is the main reason that non-farm waste of this scale would be required to go through carefully monitored sewage treatment.

Because of the methodological difficulties involved in linking physiological health problems directly to hog waste, many studies have looked at the effects of nearby residence on psychological distress. Although Thu *et al.* (1997) found no associations between nearby residence and either anxiety or depression with a sample of 18 respondents, Schiffman *et al.* (1995) found significant effects of odor on the mental health of nearby residents. In Schiffman *et al.*'s study, residents reported significantly more tension, depression, anger, fatigue, and confusion than control subjects. Schiffman *et al.* suggest that the effects of odor on mood may operate through various processes including unpleasantness of the smell, intermittent nature of odor, learned aversions to the odor, neural stimulation of immune responses, direct physical effects, chemosensory disorders, and unpleasant thoughts associated with the odor. Their results indicate that nearby residence can have a negative impact on mood, but the specific causal pathways have not been determined.

Although psychological distress itself is clearly a health problem, an exploration of the process through which nearby residence affects psychological distress may reveal specific factors that contribute to the distress. Two mediating factors that may be involved in the process through which nearby residence affects psychological distress are 1) any physical symptoms associated with nearby residence, and 2) perceived control. Although both physical and psychological health may be compromised directly by hog operations, a portion of the psychological distress may stem from the physical health problems themselves. This would reflect a mediating relationship in which industrial hog operations increased psychological distress by increasing physical health symptoms. The discomfort, physical and social limitations, and unknown cause and course of the symptoms would be likely to affect psychological distress.

Perceived control may also mediate the relationships between nearby residence and distress, as well as the relationship between physical symptoms and distress. In the former case nearby residents would have lowered perceptions of control over their environment, with respect to the political, economic, and health aspects of the hog farms, which would lead to increased psychological distress. In the latter, the actual health symptoms associated with the hog farms, and their attendant physical and social limitations, could decrease perceptions of control, exacerbating the distress process.

One further issue covered in the literature on pollution and health concerns the responsiveness of the medical community to the pollution-related health symptoms. As stated in Wilson (1994), many doctors who practice in poor rural areas that suffer from industrial pollutants may be reluctant to link symptoms to a specific industry because employees of that industry may comprise the bulk of their practice, as well as the political and economic power in the community. The lack of medical response to harmful industries may further lower perceptions of control among those afflicted.

HYPOTHESES

This study will use a quasi-experimental design to establish any differences in physical health symptoms, psychological distress, and perceived control between the nearby residents group and a matched control group who have had no prolonged exposure to hog farms. Analyses will then be conducted to explore the processes through which nearby residence may affect psychological distress. First, the extent to which nearby residence affects psychological distress by increasing physical health symptoms associated with hog farms will be explored. Next the extent to which nearby residence and physical symptoms affect psychological distress by decreasing perceived control will be examined.

It is hypothesized that respiratory and allergy-like symptoms will be higher among the nearby residence group. It is also expected that the nearby residents will report lower levels of perceived control and higher levels of psychological distress than the control group. It is hypothesized that physical health symptoms will mediate the relationship between nearby residence and perceived control, and that perceived control will mediate, to some extent, the effects of nearby residence and physical health symptoms on psychological distress.

METHODS

Research Setting

Experimental group interviews were conducted in 1999 among residents of a rural area in the coastal plain of North Carolina. This is a sparsely populated rural agricultural county with a relatively stable population of just under 50,000 residents. Most residents are in the low- to middle-income categories. This county is the second largest hog-producing county in the US. Virtually all of the family-run hog farms in this area have been replaced by industrial hog farm operations. The control group interviews were conducted among residents of another predominantly rural coastal plain county. Although County statistics of the control county show higher SES and more urbanization, respondents were recruited from the western part of the county, which is very comparable to the experimental group county (with the exception of the industrial hog farm presence).

Sample

The sample consisted of two groups. The first group was a snowball sample of respondents who lived near industrial hog farms and had been identified by local grass-roots activists as individuals who were distressed about the effects of the nearby hog farms. Ten of the nearby residents were interviewed in their homes by trained interviewers in February of 1998. The remaining 38 nearby residents were interviewed by telephone by trained interviewers in the Fall of 1998 and the Spring of 1999. The interviews lasted anywhere from 15 min to an hour. These respondents were very willing to participate in the study and were not compensated for their participation.

The control group was recruited with flyers in local businesses in an area that had no industrial hog farm operations. This control community was similar to the hog farming community in that it was mostly rural with a town center of similar size to the town center nearest the hog farm group. All control group respondents confirmed that they had no personal experience with industrial hog farms. Control respondents were paid $7.50 to participate, and were interviewed by telephone by a trained interviewer in the Spring of 1999.

The original study plan also called for a sample of industrial hog farm employees and industry representatives to be interviewed. This group was extremely reluctant to interview. Given that the industry had received bad press in the past, they were wary of speaking to any non-industry representatives who might be able to use the interview data in an unfavorable portrayal of the industry. Efforts to gather psychological distress data from this group were dropped entirely when ensuing natural disasters (hurricane and flooding) caused devastating hardship for residents of southeastern North Carolina, including most contract hog farmers in the region.

The final sample consisted of 48 individuals in the nearby resident group and 34 individuals in the control group. The analytic method used here is a quasi-experimental design. This type of research design is used when random assignment and traditional isolation and control techniques are not feasible. The political, social, and environmental characteristics being studied here do not allow for traditional experimental manipulation. However, validity issues stemming from non-random assignment have been addressed by including a control group matched to the experimental group on characteristics relevant to this study.

The lack of random sample selection does limit the interpretation of results to the sample being studied. Again, the feasibility of collecting a random sample is likely to be compromised, given the political, social, and environmental issues surrounding this topic. A low response rate from a random selection design may result in a biased sample. Given these methodological limitations, the quasi-experimental design used here offers a reasonably valid test of the processes involved in the physical and psychological health effects of these respondents. (For further discussion of the validity and reliability issues involved in quasi-experimental designs see Cook and Campbell, 1986.)

Variables

Perceived control was measured using a short form of Pearlin's Mastery scale (Pearlin and Schooler, 1978). The version of the scale used here consists of four statements: I can do just about anything I really set my mind to; I often feel helpless in dealing with the problems of life; What happens to me in the future mostly depends on me; and, I can do little to change many of the important things in my life. Respondents indicate how strongly they agree or disagree with the statements by choosing responses ranging from "strongly agree (4)," to "strongly disagree (1)." The second and fourth statements in this scale are reverse coded. The responses are then summed and divided by four, creating a final mastery score that ranges from 1 to 4, with 1 indicating low perceived control and 4 indicating high perceived control. For this sample, coefficient alpha is .71, indicating a reliable scale.

Psychological distress is measured with seven items from the CES-D depression scale (Devins and Orme, 1985). This is a widely used measure, which is recommended for epidemiological studies relating depressive symptoms to psycho-social constructs, rather than for diagnoses of clinical depression. The seven-item short form was used here because of space constraints but the short scale does not appear to compromise its performance. Research using the full scale finds alpha reliability scores ranging from 84 to 89 (Devins and Orme, 1985), whereas the reliability coefficient for the short form used here was 0.87. The items in this scale ask how often in the past month the respondent had a poor appetite, was tired, worn out and didn't enjoy anything, felt depressed, felt unhappy about the way their life was going, felt discouraged and worried about their future, felt lonely, and how often the respondent felt tense, nervous, or on edge. Responses to these items were chosen from four frequency indicators ranging from “most of the time (4)” to “never (1).” Responses from these items were summed and divided by 7, resulting in a final depression score that ranges from 1 to 4, with 4 indicating high distress and 1 indicating low distress.

Individual physical health symptoms are measured with an item asking “Next, I would like to know how often, if ever, you experienced various health symptoms in the past year. Please state whether you experienced the following symptoms daily, a few times per week, a few times per month, a few times per year, or never in the past year.” These response categories were repeated as often as necessary for each of the following symptoms; headache, plugged or popping ears, hearing problems, burning or watery eyes, runny nose, scratchy throat, sputum or phlegm, cough, fever, asthma, bronchitis, nausea or vomiting, weakness, dizziness, fainting or blackout, shortness of breath, wheezing, muscle aches and pains, skin rash or hives, tightness in chest, fatigue, and diarrhea. Responses were re-coded in units of approximate occurrences per month as follows; daily (30), a few times per week (12), a few times per month (3), a few times per year (0.25), never in the past year (0).

Symptoms is a single interval level variable, which sums the count of individual physical health symptoms that were experienced a few times per month or more. This measure includes only those 12 symptoms that were found to differ significantly between the nearby residents and the control group.

Age was measured in years and *education* was measured in years of formal education completed. *Household income* was measured with grouped responses as follows: 0–10,000, 11,000–20,000, 21,000–30,000, 31,000–40,000, 41,000–50,000, 51,000–60,000, 61,000–70,000, 71,000–80,000, 81,000 and over. This variable was coded in dollars using category mid-points.

Analyses

Correlations between psychological distress and each of the health symptoms will be explored, as well as correlations between the perceived control variable and each of the health symptoms. Then, differences between the two groups in the 22 physical health symptoms will be analyzed with independent sample *t*-tests. Group differences in psychological distress and perceived control will also be analyzed with independent sample *t*-tests.

Preliminary analyses will use multiple regression to explore the effects of demographic characteristics of age, household income, education, and sex on both perceived control and psychological distress (this sample was predominantly white and there was not enough diversity for a meaningful analysis of racial effects). These demographic variables will be included as control variables in subsequent regression analyses.

The mediating effects of symptoms and perceived control in the relationship between nearby residence and psychological distress will be analyzed with a set of three regression models. The first model will regress psychological distress on nearby residence, controlling for demographic factors. The second model will retain all independent variables in the first model but will also include the "symptoms" as an independent variable. A reduction in the effects of nearby residence on psychological distress, along with significant effects of symptoms on distress will indicate that some of the effects of group membership on distress are mediated through physical health symptoms.

The final regression model will explore the mediating effects of perceived control in the relationships between nearby residence and psychological distress, as well as in the relationship between physical health symptoms and psychological distress. This model will be similar to the second model with the addition of perceived control as an independent variable. Again, significant effects of perceived control along with decreases in the effects of nearby residence or symptoms will indicate that perceived control mediates those relationships.

RESULTS

The two groups, nearby residents and the control group, were well-matched on socioeconomic characteristics. There were no significant differences between the two groups with respect to household income ($t = 1.96$) or education ($t = -0.888$). There were five African Americans and two respondents reporting "mixed race" in the control group whereas all of the respondents in the experimental group were "white." Sixty-three percent of nearby residents are female whereas 85% of the control group were female. The nearby resident group was somewhat older than the control group—the mean age of nearby residents was 57 years and mean age for the control group was 42 years. These demographic characteristics will be controlled for in subsequent regression analyses.

Independent sample *t*-tests show statistically significant differences between the nearby resident group and the control group for 11 of the 22 physical illness symptoms. The significantly different symptoms include watery eyes, runny nose, scratchy throat, sputum, cough, popping ears, nausea and vomiting, dizziness, shortness of breath, and wheezing and chest tightness. These symptoms generally reflect respiratory, sinus and nausea symptoms. The 10 non-significant symptoms include fever, muscle pain,

Table I. Pearson's Correlations Coefficients of Symptoms With Psychological Distress and Perceived Control, and *t*-Test for Residence/Control Group Differences

Symptom	Perceived control (r)	Psychological distress (r)	Resident/control t-test
Hearing problems	—	0.288*	—
Burning or watery eyes	−0.482**	—	5.224**
Runny nose	−0.293**	0.291**	6.161**
Scratchy throat	−0.382**	0.297**	5.241**
Sputum or phlegm	−0.300**	0.368**	6.252**
Cough	−0.265**	0.225*	5.429**
Fever	—	—	—
Asthma	—	—	—
Headache	0.303**	0.298**	—
Plugged or popping ears	−0.334**	0.270*	2.297**
Bronchitis	—	—	—
Nausea or vomiting	−3.91**	0.316**	2.836**
Weakness	—	0.247*	—
Dizziness	−0.500**	0.293**	2.282**
Fainting or blackout	—	—	—
Shortness of breath	−3.57**	0.319**	3.864**
Wheezing	—	—	2.383**
Muscle aches and pains	—	0.343*	—
Skin rash or hives	−0.524**	—	—
Tightness in chest	—	0.411**	2.161**
Fatigue	—	0.329**	—
Diarrhea	—	—	—

*Sig. <0.05, **Sig. <0.01.

hearing problems, weakness, rash, fever, headache, bronchitis, fainting, etc. (see Table I). *T*-tests also reveal significant group differences in both perceived control and psychological distress, with the nearby residents reporting lower perceived control and higher levels of distress than did the control group (Table II).

With the exceptions of wheezing and chest tightness, all symptoms that differed between the two groups were correlated with lower perceptions of control. With the exceptions of wheezing and watery eyes, all symptoms that differed between groups were also correlated with psychological distress. Two-thirds of the symptoms similarly affected perceived control and psychological distress, whereas seven symptoms affected either one or the other (Table I).

Table II. Resident/Control *t*-Test Comparisons of Perceived Control and Psychological Distress

	Resident mean	Control mean	t
Perceived control	2.908	3.515	−4.336**
Psychological distress	2.244	1.838	2.769**

**Sig. <0.01.

Table III. Regression of Psychological Distress on Nearby Residence, Physical Symptoms, and Perceived Control

	Mode I		Mode II		Mode III	
	Beta	(se)	Beta	(se)	Beta	(se)
(Constant)		(568)**		(0.527)**		(0.718)**
Household income	−0.039	(0.043)	−0.014	(0.040)	−0.012	(0.040)
Education	−0.131	(0.044)	−0.169	(0.041)	−0.171	(0.041)
Sex	−0.157	(0.198)	−0.145	(0.184)	−0.145	(0.185)
Nearby residence	0.276	(0.185)*	−0.090	(0.230)	−0.095	(0.234)
Symptoms	—		0.510	(0.032)**	0.500	(0.034)**
Perceived control	—		—		−0.029	(0.131)

Note. $N = 80$.
* Sig. <0.05, ** Sig. <0.01.

The first mediation model shows that nearby residence does have a significant effect on psychological distress (Table III), controlling for the demographic variables of household income, education, and sex. Model II shows that the distress associated with nearby residence is due to individuals' physical health symptoms. Contrary to the hypothesized relationships, Model III indicates no mediation effects of perceived control. In fact, perceived control does not appear to significantly affect psychological distress.

DISCUSSION AND CONCLUSION

The results found here confirm those of earlier studies regarding the effects of nearby hog farm residence on physical and mental health symptoms. This study shows that respiratory and nausea-type symptoms appear to be higher among these nearby residents than among matched controls. Such symptoms are consistent with results from studies of exposure responses to noxious odors, dust, and gasses found in large-scale hog operations (Wing and Wolf, 1999).

These results also indicate that nearby residents have higher levels of psychological distress than do controls. Although results from previous studies were inconsistent regarding mental health effects, the psychological distress effects found here were significant. This is expected given the sample used here was self selected as having negative effects. Most importantly though, the effects of nearby residents on psychological distress found here were completely due to the physical health symptoms. In other words, these nearby residents had increased distress because of increased physical health symptoms. Unless physical and mental health effects are modeled separately, the direct effects of nearby residence on psychological distress may be hidden by the direct effects of physical health symptoms.

Surprisingly, perceived control did not mediate any of the effects of nearby residence on distress, nor did it mediate the effects of physical health symptoms on distress. Perceived control does not appear to play a role in the process through which nearby residence affects physical or mental health. Rather, the process seems to consist of direct effects of physical symptoms on psychological distress.

On the other hand, nearby residence and physical health symptoms both had similar effects on psychological distress and perceived control. These findings suggest that distress and control are affected by similar factors, but that they differ in their outcomes. Perceived control may represent a more cognitive aspect of nearby residence whereas distress represents an affective component. It may be that perceived control would, in turn, affect more cognitive outcomes associated with nearby residence. For example, perceptions of control may affect whether an individual chooses to engage in activism, or it may determine how likely individuals are to lodge complaints about the situation (Zimmerman and Rappaport, 1988).

One note of caution in interpreting these results is that this study did not use a random sample and so generalizations cannot be made about all nearby residents. As discussed earlier, a random sample of nearby residents would be difficult to obtain because of difficulties in demarcating a similarly affected area, as well as the likelihood of getting a very poor response rate to questions on an issue that is so politicized and socially divisive in this area. However, the quasi-experimental design used here does address validity issues with a matched control group. Results from the design used in this study along with previous studies using other designs show a consistent emerging pattern regarding the health effects of industrial hog farms (Schiffman *et al.*, 1985; Thu *et al.*, 1997; Wing and Wolf, 1999).

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THE CONCENTRATION OF SWINE PRODUCTION

Effects on Swine Health, Productivity, Human Health, and the Environment

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The sustainability of a livestock industry depends on a host of factors, most especially economic and political factors; however, the health and productivity of the livestock, the health of those doing the work, the health of the host communities, and the environment are integral parts of the sustainability picture.[35] Outside of agriculture, whole industries have changed drastically or disappeared as the result of uncontrolled occupational or environmental hazards. Examples include the luminescent watch dial manufacturers (radium paint–induced lung cancer) and the fire-proof fabric industry (asbestos-induced fibrosis and cancer). An industry is no more healthy than its workers and the environment it creates.[105] As the swine production industry becomes increasingly concentrated, it is more subject to the concerns of regulatory agencies and the general public regarding worker, environmental, and community health. As veterinarians' roles are expanding to help sustain the modern livestock industry, there is a need for them to understand the impacts of livestock concentration on occupational and environmental health, swine health and productivity, and community health. Veterinary consultants should have the knowledge to incorporate this information into economic assessment and management models and should recommend appropriate preventive and control actions.[102]

The livestock industry is vital to the US economy, especially the

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rural economy. For example, in Iowa, the pork industry generates $258 per pig produced, and Iowa raises 24 million pigs per year, for over $6 billion dollars of economic activity.[58] Beef, dairy, and poultry offer similar economic inputs in other areas of the country. The livestock industry also provides jobs for over 2 million Americans.

Public concerns relative to adverse consequences of livestock production have been increasingly voiced since the late 1960s. It was not until the early 1990s that this public concern began to dramatically heighten. This increase came about as the result of the nationwide ripple effect of the rapid industrialization of the swine industry in North Carolina in the late 1980s and early 1990s.[105] In response to the public outcry, a national conference was held in 1994 that included the systematic collection of citizen and producer concerns. The conference was entitled "Livestock Production for Sustainable Rural Communities" (October 28–30, 1994, Kansas City, MO). This activity was preparatory to a conference designed to summarize current scientific knowledge in specific response to the previously identified public concerns. This conference was held on June 29–30, 1995, in Des Moines, Iowa, and entitled "Understanding the Impacts of Large-Scale Swine Production—Proceedings from an Interdisciplinary Scientific Workshop."[106] This article relies on this publication for its framework and structure. Furthermore, this article is supported by the Union of Concerned Scientists, who provided a "white paper" on the subject. A review is included of recent literature, particularly for the swine, human, and community health effects of air and water contamination. Information from several subsequent relevant conferences has been integrated into this report, including (1) "Manure Management in Harmony with Environment and Society, Soil and Water Conservation Society," February 10–12, 1998, Ames, Iowa; (2) "The Confinement Animal Feeding Operation Workshop," The National Center for Environmental Health, Centers for Disease Control and Prevention, June 23–24, 1998, Washington, DC; (3) "Animal Feeding Operations and Current Water Issues, Impacts, and Solutions—A Conference for the Future," National Ground Water Association, November 4–5, 1998, St. Louis, Missouri; (4) "1996 National Poultry Waste Management Symposium," October 21–23, Harrisburg, Pennsylvania; and (5) "Manure Matters—Safe and Effective Ways to Plan for and Use Manure and its By-Products," September 22, 1998, Ames, Iowa.

This article concentrates not only on swine health but also on the individual and community health consequences of large-scale livestock operations. In addition to the physical health of livestock and workers, the social and economic concerns of individuals and communities are considered. Regarding human health, the broad definition of *health* used by the World Health Organization (WHO), and the one used here, states that *health* is "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity."[118]

There is growing international and national concern regarding livestock feeding operations and the health and welfare of the livestock, workers, environment, and community. As livestock production becomes more like other industries in management, structure, and concentration, it gains more public attention and requires greater accountability. Furthermore, concentration increases the probability of waste production outstripping the capacity of natural ecosystems to incorporate and recycle the wastes in a balanced manner.[43] This concentration of the industry has led to serious social, mental, economic, and physical health stresses in many communities. The magnitude of the problem is highlighted by the following facts:

- Nationwide, there is 130 times more animal waste produced yearly than human waste.
- Animal waste is not treated like human waste before it is returned to the environment.[43] The concern comes from 450,000 confined animal feeding operations (CAFOs) in the United States. The largest of these (about 10,000) have greater than 1000 animal units (AU). One AU is defined by the Environmental Protection Agency (EPA) as one beef cow, four pigs, 55 kg of turkeys, or 100 kg of hens.

The potential for air and water pollution is present and growing because of the concentration of production into fewer large-scale units, not the increase in total numbers of animals. In this article, the scientific literature is reviewed relative to swine health, worker health, and environmental impacts of air and water emissions on community and worker health.

SWINE HEALTH AND PRODUCTIVITY

Air Contaminants Inside Swine Buildings

Assessments of the environment inside swine buildings have been conducted by a number of researchers, starting back in the early 1970s.[3, 4, 9, 12, 16, 17, 50, 54] The contaminants can be divided into gases, particulates, bioaerosols, and toxic microbial by-products. There are approximately 160 different gases (Table 1) that may be emitted from anaerobic swine waste.[80] The primary or so-called *fixed gases* include ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), and hydrogen sulfide (H_2S). If the wastes are stored for a lengthy period of time under the building in a pit deeper than 3 ft (creating an anaerobic environment), there is a potential to have all of these gases in the atmosphere of the building; however, if the wastes are removed frequently (i.e., at least weekly) by way of gutter flush, scraper, pull plug, or other system, then H_2S, CH_4, CO_2, and the various other anaerobic gases should not be a problem in the building. Even if manure is not stored under the building, there could be high concentrations of NH_3 (up to 40% of the total in the air) from degradation of wastes on top of the flooring before reaching the pit.[31] There are additional sources of gases in buildings. These include

Table 1. VOLATILE COMPOUNDS ASSOCIATED WITH PIG WASTES

Ethanol	Ethanal	Ammonia
1-Propanol	Propanal	Methylamine
2-Propanol	Butanal	Ethylamine
1-Butanol	Pentanal	Trimethylamine
2-Butanol	Hexanal	Triethylamine
2-Methyl-l-propanol	Heptanal	
3-Methyl-l-butanol	Octanal	Carbonsulphide
2-Ethoxy-l-propanol	Decanal	Hydrogen sulphide
2-Methyl-2-pentanol	2-Methyl-l-propanal	Methanethiol
2,3-Butanediol	Ethylacetate	Dimethylsulphide
		Dimethyldisulphide
3-Hydroxy 2-butanone	Methanaoic acid	Dimethyltrisulphide
Propanone	Ethanaoic acid	Diethyldisulphide
2-Butanone	Propanoic acid	Propanethiol
3-Pentanone	Butanoic acid	Butanethiol
Cyclopentane	2-Methylpropanoic acid	Dipropldisulphide
1-Octanone	Pentaoic acid	2-Methylthiophene
2,3-Butanidione	3-Methylbutanoic acid	Propylprop-l-enyldisulphide
	Hexanoic acid	2,4-Dimethylthiophene
Phenol	4-Methylpentanoic acid	2-Methylfuran
4-Methylphenol	Heptanoic acid	
4-Ethylphenol	Octanoic acid	
Toluene	Nonanoic acid	
Xylene	Phenylacetic acid	
Indone	2-Phenylpropanoic acid	
Benzaldehyde		
Benzanoic acid		
Methylphthalene		
Indole		
Skatole		
Acetphenone		
o-Aminoacetophenone		
Aneline		

Data from Proceedings, Understanding the Impacts of Large-Scale Swine Production, Des Moines, IA, June 29–30, 1995. Iowa City, IA, The University of Iowa Printing Service, 1996, p 51.

the animals themselves (CO_2) and fossil fuel–burning heating systems (CO_2 and CO).

Dust, or particulates, come from two primary sources: pigs and feed. The main particulate component from the pigs is dried fecal material.[34] Fecal material becomes smeared over the flooring, pens, and pigs. When it dries, it becomes aerosolized by movement of the pigs and air currents. This dust is very fine, and up to 40% is inhalable. It is also highly contaminated with microbes and toxic microbial by-products such as endotoxin and glucans.[34] This fecal dust makes up a larger portion of the dust in farrowing and nursery buildings compared to finishing buildings, where feed dust predominates.

The atmosphere in swine buildings is highly contaminated with bacteria, fungi, and yeasts.[16] Whereas the levels of microbes in a home (or other relatively clean environment) would seldom reach more than 1000 organisms per cubic meter of air, swine building air is often 100 to 10,000 times more concentrated with organisms.[63] The bacteria are gram negative and gram positive and largely of fecal orgin. Rarely does one find pathogens in the air, because they generally are less viable and much fewer in number relative to the nonpathogens and saprophytes. The yeast and fungi are also very concentrated and have been well characterized. They seem to be of similar portions to what might be found in the outdoors but, like bacteria, are concentrated by a factor of 100 to 10,000.

In recent years, researchers have become increasingly concerned about endotoxin as a part of the contaminants inside livestock buildings.[95] Endotoxin is a component of the cell wall of gram-negative bacteria. It is a highly inflammatory substance and is believed to be a major agent in respiratory disease for workers and perhaps pigs. An additional microbial by-product has been found, glucans, which is a component of the cell wall of certain fungi, yeasts, and bacteria. This agent is also an inflammatory substance and seems to work in conjunction with endotoxin. The exact interaction of these two substances has not yet been defined.

Table 2 demonstrates the range, typical level found, and recommended maximum limits for swine health for several common contaminants. These limits were based on a study of 28 swine farms, where production records and heath status were monitored relative to the environments in which the animals were raised.

Acute Environmental Swine Health Problems

There are several environmental situations in intensive swine housing that may result in acute death of livestock. These include (1) acute H poisoning, (2) asphyxiation with CO_2, (3) carbon monoxide poisoning, and (4) heat stress. These are listed in order of their frequency of occurrence.

Table 2. COMMON AIR CONTAMINANTS INSIDE SWINE BUILDINGS: RANGES AND RECOMMENDED LIMITS FOR HEALTH

Contaminant	Typical Range	Typical Mean Winter Concentrations	Maximum Concentration for Swine Health	Maximum Concentration for Human Health
Total dust (mg/m^3)	2–7	4	3.7	2.5
Respirable dust (mg/m^3)	0.2–0.7	0.5	0.23	0.23
Endotoxin Units	150–1000	200	150	100
CO_2 (ppm)	2500–5500	4000	1500	1500
NH_3 (ppm)	5–20	10	11	7
Total microbes (cfu/m^3)	100,000–10,000,000	1,500,000	430,000	430,000

Data from references 22, 31, and 34.

Hydrogen Sulfide Poisoning

Acute H_2S poisoning typically occurs while emptying or otherwise agitating a deep pit situated over a slatted floor. H_2S is produced by anaerobic digestion of liquid swine manure. This highly toxic gas is stored in the liquid slurry similar to CO_2 in a carbonated beverage. The gas comes off very slowly, until agitation. Then, according to Lewis' law of gas diffusion between a liquid and gas phase, increasing the surface area by agitation rapidly accelerates diffusion of the gas out of the liquid manure.[36] A typical history is that the pit is pumped with a chopper agitator pump or a circulating pump, or back-flushed from a manure wagon, while pigs are in the buildings. The ventilation may be on in full; however, when the pigs are observed, they may be laying down; frothy, bloody foam coming from their mouths; and many apparently unconscious. All the pigs in the building may be dead or near death. Postmortem examination shows pulmonary edema, blood-tinged froth in the trachea and bronchi, and perhaps a greenish tinge to the viscera. Laboratory confirmation is by way of a positive blood sulfhemoglobin. The toxic effects of H_2S include tissue irritation and generally cellular poisoning by decoupling oxidative phosphorylation, with predilection for the central nervous system, causing sudden unconsciousness and respiratory failure. At levels of up to 500 ppm, the gas is generally an irritative problem on short-term exposures and may not cause death; however, there may be some respiratory damage that may retard growth and productivity. This author observed one case in which surviving pigs from an H_2S exposure were rejected at slaughter because of suspected tuberculosis. This abnormality was in fact bullous emphysema from lung parenchyma damage by the H_2S exposure; however, the usual cases are massive death losses, which might include every pig in a given building.

Prediction of an H_2S toxicity event is difficult. One survey of 50 swine operations in the Midwest revealed that 50% of the pits had the potential to create an acute toxic atmosphere inside the buildings, even with the exhaust ventilation system at full power.[36, 37] The pH of the pit can help predict the potential of a toxic event. The pKa of H_2S between its ionic and gaseous phase is 7; the more acid the slurry, the more H_2S gas is available to diffuse to the air when agitated. A pH of 7 or lower indicates a more potentially critical situation. Another potential predictor of toxic situations is the amount of sulfate in the water source, because this provides more sulfur that can be reduced to H_2S by anaerobic bacteria. Sulfate concentrations higher than 250 ppm should be considered a potential problem.

Prevention is by precaution. Slow agitation and careful observation of the pigs from outside the building is the key. At any signs of restlessness or stress on the pigs, agitation should be ceased immediately. The ideal situation would be to remotely monitor the gas levels while agitating, using one of several direct-reading devices available on the market.

In critical pits, the addition of slacked lime (not field lime) to raise the pH may help to prevent a toxic atmosphere; however, as the pH is raised, more NH_3 is available to come from the pit, because the pKa of NH_3 is much lower than that of H_2S. If high water-source sulfate levels are a problem, a new well may have to be dug, or remodeling the waste system to remove wastes from the buildings or changing to an aerobic system may be required.

Carbon Dioxide Asphyxiation

There are certain situations when there is an essential ventilation failure limiting fresh air brought into the buildings. In a fully loaded, completely enclosed grower or finishing unit, the CO_2 level can rapidly raise and, along with depletion of oxygen, create an asphyxiate atmosphere in as little as 6 hours. The most obvious situation is a power failure, with ventilation completely down; however, there are other situations in which there may not be a power failure and there is still ineffectual ventilation, as in the following two exemplary situations that this author has observed. The first was in a typical exhaust-ventilated building, in which the exhaust fans were located on the north side of the building. A winter storm developed overnight, with strong north winds. The building had variable-speed fans, and because of the cold temperature, the fans were operating very slowly and could not function with the strong wind pressure, essentially creating a nonventilated building. All of the pigs in this growing unit were found dead at 7:00 AM; they were observed to be healthy at 9:00 PM the night before. A building's sole exhaust fans should never be located on the side of the building of the prevailing winter winds. Furthermore, minimum ventilation fans should never be variable speed, because they lose their power rapidly to work against static pressure as the revolutions per minute decrease.

A third situation causing an asphyxiate environment observed by this author is failure of a recirculating ventilation system. These systems are designed to keep air in circulation in the building and, by a system of baffles, to let in fresh air according to indoor temperature or humidity. In this instance, the inlet baffle became inoperable, and no fresh air was coming into the building. The result was that 200 pigs died overnight, and the power never failed.

Carbon Monoxide Poisoning

There are two syndromes observed with CO toxicity in swine: a low-concentration chronic exposure and an acute high-level exposure.[10, 11] The first syndrome is most often seen in farrowing barns where propane-fueled infrared litter heaters are used. The air vents in these heaters easily become blocked with dust, creating inefficient combustion. This can create levels of CO of up to 800 ppm in the immediate vicinity of the heaters, and from 150 to 250 ppm in the building. This is not high enough to create an acute clinical situation in adult pigs, but it does affect the fetuses in the pregnant sow and may result in small, weak, and slow-growing litters, perhaps with weaning of only three to six pigs. The sows may never show any clinical illness. The second syndrome is massive herd abortion and perhaps some deaths in sows. A typical history is that sows are brought into the farrowing barn 3 days before the due date. Unexpectedly, the operator finds that all the sows in the building have aborted, and perhaps a few of the sows have died also. This situation can be caused by a malfunctioning space heater (e.g., cracked heat exchanger or plugged flue) or a ventilation failure in connection with fossil fuel–burning heaters in operation. The level of CO may reach 500 to 1500 ppm in these instances.

Diagnosis in these instances is by history and inspection for proper functioning of the heating and ventilation systems. Air measurement of CO with electronic instruments or diffusion tubes can be helpful; however, by the time the veterinarian is called to the farm, the ventilation or heater malfunction may have been restored, and the air levels of CO may be normal. One can take blood samples from exposed pigs, seal the tube, and have it tested for carboxyhemoglobin. This can be done at most hospitals having surgery units or at other reference laboratories. The carboxyhemoglobin molecule is fairly stable, and if the samples are taken within 4 hours of the event, the results may be helpful.[25] For the chronic low-exposure syndrome, the carboxyhemoglobin level in sows may be 15% to 20%. In the acute high-level exposure situation, sow carboxyhemoglobin levels may be 30% to 60%, and heart blood from aborted fetuses may be even higher.

Heat Stress

Ventilation failures in the summer are more likely to create a lethal heat stress situation before an asphyxiate atmosphere develops. The heat and humidity rise rapidly in hot weather in fully stocked and enclosed buildings when the ventilation fails. In a fully loaded grower or finishing unit, a critical heat stress environment can develop in a matter of 2 to 4 hours, and whole buildings of pigs may be lost.

Chronic Environmental Swine Health and Production Problem

There are relatively few scientific studies regarding chronic health and production problems related to the indoor swine environment. This type of research is very difficult; because there are so many variables, it is almost impossible to carry out a well-controlled study.

One study that provided good data was conducted on 28 swine farms in Sweden.[22] The environment was monitored in all buildings for total and respirable dust, endotoxin, microbes, NH_3, CO_2, and H_2S. These data were compared to excellent production and slaughter check records, maintained by a centralized veterinary preventive health program. There were significant associations with higher levels of environmental exposures to decreased production parameters and increased pathology on slaughter checks. In farrowing and nursery operations, the following significant correlations were found:

- Bioaerosols (microbes in the air) were related to lowered feed efficiency, decreased growth rate, and excess mortality.
- Excess total and respirable dust was related to lowered growth in the nursery from weaning to 25 kg body weight.
- Excess NH_3 was related to lowered average number of pigs weaned.

Environmental contaminants were related to health and production in the finishing barn in the following associations:

- Excess bioaerosols were related to excess pneumonia and abscesses.
- Excess dust and endotoxin were associated with liver ascarid scars.
- Excess NH_3 was associated with excess arthritis, porcine stress syndrome, muscle lesions, abscesses, and liver ascarid scars.

Other studies showed associations of poor environment to nasal turbinate atrophy.[26] Laboratory animal studies showed a relation to exposure and pleuritis, pneumonia, and death loss.[29] Exposure-response studies were conducted to establish exposure limits for swine to help reduce the environmental component of disease and productivity inside livestock buildings. Although there are not enough data to put an economic cost on excess environmental exposures, there are strong indications that close attention should be paid to the environment, including regular monitoring of air quality and implementation of management and engineering procedures to ensure that exposures are below the recommended limits in Table 2.

HUMAN HEALTH ISSUES

Worker Health Issues

Agricultural production has historically been an occupation with notable health and safety hazards. Magnus, in the 1500s, and Ramazzini, at the turn of the 18th century, wrote about the health hazards of agricultural workers.[68] The German physician Preuschen[86] was one of the first to report on this subject. He reported that workers in confined livestock facilities had significantly increased physiologic demand on their respiratory tracts compared to other farmers. In the late 1950s and early 1960s, poultry production became consolidated and moved to intensive, confined housing systems. A decade later, swine production came "indoors" in the United States. This led to the first description of health hazards to people working in swine facilities in 1977.[33] This early study revealed that over 60% of veterinarians working in these facilities experienced one or more respiratory health symptoms. This report led to more than 25 subsequent studies in the United States, Canada, Sweden, Denmark, the Netherlands, Germany, and England.[21] In addition to respiratory illnesses, other occupational health problems have been documented, including traumatic injuries, noise-induced hearing loss, needle sticks, hydrogen sulfide and carbon monoxide poisonings, and infectious diseases.[49, 69]

Further industrialization of livestock production will cause more independent producers to leave the industry or to become quasi-employees of large-scale producers as contract growers. Furthermore, many minority workers are becoming employees of larger producers, raising legal issues of undocumented workers and Occupational Safety and Health Administration (OSHA) jurisdiction on farms. In the past, OSHA has been restricted in agriculture because of a law that restricts enforcement on farms with less than 10 employees. Many of the large corporations now employ hundreds of workers, meaning more workers spend longer hours in animal confinement buildings. This will likely lead to increased exposure and greater risk of adverse health effects.

The worker health component of this article is intended to characterize the range of occupational health hazards associated with large-scale livestock production and to suggest ways to reduce the associated morbidity and mortality. Gaps in the understanding of these hazards are also identified, and ways to fill those gaps are suggested.

Overview of Worker Health Concerns

Table 3 lists major categories of occupational hazards and further classifies diseases or health outcomes within those categories. The order does not necessarily relate to incidence, prevalence, or severity. One can further describe inhalation exposure and respiratory disease by region of the respiratory tract affected and various disease conditions. Symptoms and specific agents for each disease are seen in Table 4.

There are common health risks among all intensive livestock production operations. By far, the vast majority of the research in this area has been with swine production. This report deals largely with swine operations. Poultry, dairy, beef, and other production is dealt with on a comparative basis where applicable.

The principal health risks for swine workers (Table 3) result from a wide range of exposures. Chemical, biologic (noninfectious), and infectious hazards have received the majority of research attention; however, noise, trauma, fires, explosions, electrocutions, thermal stress, poisonings, and drownings are all important causes of morbidity and mortality.[49] Often overlooked are emotional stress, chronic pain, and fatigue, which can lead to significant impairment and put the worker at additional risk. Most of these are readily understood, and established preventive measures are available but often are not implemented.

Table 3. MAJOR HAZARD CATEGORIES IN SWINE PRODUCTION

Hazards	Subcategories	Examples
Chemical hazards	Asphyxiation	Carbon monoxide
	Lung injury	Ammonia, hydrogen sulfide
	Contact dermatitis	Allergic, irritant
	Poisonings	Pesticides, fuels, cleaning agents
	Intoxication	Solvents, substance abuse
	Immunomodulation	Adjuvants: biocides, phytotoxins
		Immunosuppressants: pesticides
Biologic hazards	Microorganisms	Pathogenic
		Non-pathogenic
	Organic dust	Bacterial toxins: endotoxins, exotoxins, enterotoxins
		Fungal toxins: mycotoxins, glucans
		Phytotoxins
		Inflammatory agents
	Aeroallergens	Arachnid detritus
		Animal proteins
		Allergenic fungi
Infectious hazards	Zoonotic	*Streptococcus suis*
	Antibiotic resistance	Salmonella
	Emerging pathogens	Hepatitis E
Biomechanical stress	Trauma	Animal bites
		Falls
		Needle sticks
		Punctures, lacerations, abrasions, burns
		Crushing injuries
		Repetitive trauma
	Noise	Noise-induced hearing loss
Thermal stress	Heat stress	
	Cold stress	
Emotional stress	Occupational	Suicide
	Marital	Depression
	Financial	Anxiety
Drowning		Lagoons
		Pits
		Farm ponds
Fires/explosions	Chemical	Methane in pits
	Electrical	Ignited building
	Welding	Ignited building
	Organic material	Grain, grain dust
Electrocution		Faulty wiring
		Water associated
Chronic pain	Biomechanical stress	Arthralgia
	Arthritis	Myalgia
	Myalgia	
Fatigue	Sleep deprivation	Planting, harvesting
	Chronic fatigue syndrome	Chronic endotoxin exposure

Data from Proceedings, Understanding the Impacts of Large-Scale Swine Production. Des Moines, IA, June 29–30, 1995. Iowa City, IA, The University of Iowa Printing Service, 1996, p 156

Table 4. RESPIRATORY DISEASES ASSOCIATED WITH SWINE PRODUCTION

Upper Airway Disease
Sinusitis
Irritant rhinitis
Allergic rhinitis
Pharyngitis
Lower Airway Disease
Organic dust toxic syndrome
Occupational asthma
Nonallergic asthma, hyperresponsive airways disease, or reactive airways disease syndrome
Allergic asthma (IgE mediated)
Acute subacute bronchitis
Chronic bronchitis
Chronic obstructive pulmonary disease
Interstitial Disease
Alveolitis
Chronic interstitial infiltrate
Pulmonary edema

Data from Proceedings, Understanding the Impacts of Large-Scale Swine Production. Des Moines, IA, June 29–30, 1995. Iowa City, IA, The University of Iowa Printing Service, 1996, p 158.

Respiratory Diseases Overview

Respiratory exposures lead to the most common health hazard among swine farmers and others working in CAFOs. Lung diseases from the multitude of exposures have been difficult to characterize, in part because they are often not discreet conditions and there is considerable overlap in symptoms. For example, there are confined-space entry hazards (areas that are not vented and may trap toxic gases) in swine farming, with H_2S a principal hazard.[2, 8, 28] Other lung injuries result from less acutely toxic exposures and lead to nonfatal acute lung insults that may result in chronic declines in lung function.[8, 13–15, 38] Respiratory problems associated with this environment are listed in Table 4 by upper respiratory tract, airway, interstitial, and mixed airway and interstitial lung diseases. Classic (allergy diseases, IgE or IgG-mediated) asthma or farmers' lung diseases appear to be uncommon in livestock workers. The pathogenesis is primarily acute to chronic inflammation.

Upper Respiratory Tract Disease

Bronchitis is the most common complaint of workers, affecting as many as 70% of exposed persons. This is an inflammatory-induced irritation of the airways. Acute or subacute bronchitis is a dry cough associated with exposure to the swine facility. It occurs for usually less than a year and will typically dissipate within a year with decreased exposure; however, it may lead to chronic bronchitis, a condition with chronic cough and phlegm production that occurs at least 3 weeks out of the month for 2 or more years. This condition affects about 25%

of swine producers who work in confinement buildings. It may be accompanied by occupational asthma.

Frequent upper respiratory tract problems include sinusitis and rhinitis. Several studies have referred to these collectively as mucus membrane irritation (MMI).[94, 95] MMI may be attributable to the combination of bioaerosol, endotoxin, and ammonia exposures.[27, 34]

Sinusitis is often chronic in confinement workers. They complain of a continual or frequent cold that they "just cannot shake." They complain of a stuffy head, difficulty in breathing through the nose, headache, and "popping ears." These symptoms are a result of a noninfectious inflammation and swelling of the mucus membranes of the sinus cavities in the head and the eustachian tubes leading to the middle ear. These symptoms are often accompanied by an irritant rhinitis (nasal passages) and pharyngitis (sore throat).

Allergic rhinitis (also called *hay fever*) has rarely been attributed to confinement exposures. These persons have a specific allergy to some component of the swine environment. These symptoms may be similar to irritant rhinitis, except that they usually begin after only brief exposure to the environment and may be accompanied by itchy, watery eyes and, possibly, acute chest tightness (allergic asthma).

A condition reminiscent of byssinosis (a condition of workers exposed to cotton dust) is apparent with swine workers. This condition is characterized by acute onset of chest tightness, wheezing, cough, and perhaps fever on return to work from 2 or more days of work absence (Monday-morning response). The condition wanes through the week, only to recur on return to work following another absence (weekend). It occurs following chronic exposure of weeks to months and is not a specific allergic illness (IgE-mediated). This condition was documented in 11% of workers in a population-based study of Iowa swine confinement workers.[30] Byssinosis is often associated with chronic bronchitis and includes chronic airway obstruction with progressive decline in pulmonary function.

A nonallergic occupational asthma also occurs in about 25% of swine producers. The symptoms include periodic airway obstruction, chest tightness, wheezing, and dyspnea. This condition also takes months to years to develop. Workers with existent asthma may experience severe asthma on first exposure to swine confinement facilities. These workers usually select themselves out early in their employment. Occupational asthma of swine workers is associated with prolonged (usually 6 or more years) exposure to the work environment. The primary cause is chronic inflammation. Rarely have there been documented allergic (IgE-mediated) causes for swine workers' asthma. This condition (especially in combination with bronchitis) may lead to chronic obstructive pulmonary disease, which is a permanent, possibly disabling condition.

Organic dust toxic syndrome (ODTS), another condition of swine workers, results in a spectrum of flu-like symptoms with headache, joint and muscle pain, fever, fatigue and weakness, and irritation of the airways and the cells lining the small sacs of the lung. ODTS may be mistaken clinically for acute farmer's lung disease (FLD), because they have nearly identical acute symptoms (e.g., the delayed onset of severe influenza following exposure); however, FLD is rare. It is caused by a certain type of allergic condition (hypersensitivity pneumonitis) seen in a variety of farming operations but has not been documented in swine workers.[94] Agricultural exposure assessment studies established that airborne thermophilic organisms most commonly associated with FLD (*Saccharopolyspora rectivirgula, Thermoactinomyces vulgaris, T. saccharii*) are present in significantly lower concentrations in swine barns than in dairy barns.[63] Because swine farmers are exposed to higher levels of inflammatory agents, such as endotoxins and ammonia, these may alter the processing of inhaled bioaerosols. On the other hand, 33%[30] of swine producers have reported episodes of ODTS, that is, an influenza-like illness following exposure to a higher than usual dust load (e.g., moving and sorting hogs). It is marked by headache, fatigue, muscle aches and pains, fever, low work or exercise tolerance, and possibly a pulmonary infiltrate.

An as yet unnamed chronic or subacute condition (possibly a chronic form of ODTS) seen in swine workers is marked by chronic fatigue, dyspnea, and possibly persistent mild pulmonary infiltrates[3]; however, there is one animal study that provides evidence for persistent pulmonary infiltrates associated with chronic exposure to intensive swine housing.[29]

Acute respiratory distress syndrome (ARDS) or pulmonary edema can result in swine workers who experience acute or chronic exposure to H_2S. There have been at least 19 acute deaths of workers resulting from sudden H_2S exposure of above 500 ppm secondary to liquid manure agitation. These people collapse rapidly and stop breathing within only a few breaths at this high exposure. Severe pulmonary edema and death may result. Longer-term, lower exposure may lead to ARDS at an unpredictable time during or following an accumulative or multiple exposure period.[288]

It is recognized that several of these conditions may occur in an individual swine worker and that they may occur at the same time. It is common for an individual worker to simultaneously have signs and symptoms of occupational asthma and bronchitis and episodes of ODTS. This produces an interrelated group of conditions (a syndrome) of illness caused by exposure to the swine building environment (illustrated in Fig. 1).

Potential for End-Stage Lung Disease

It is likely that some of the lung problems experienced by swine workers do cause irreversible damage, because there are progressive declines in lung function over time in some of these workers.[40, 97] One study in Canada indicated that about 10% of producers left production over a 7-year period because of respiratory illnesses[55]; however, there

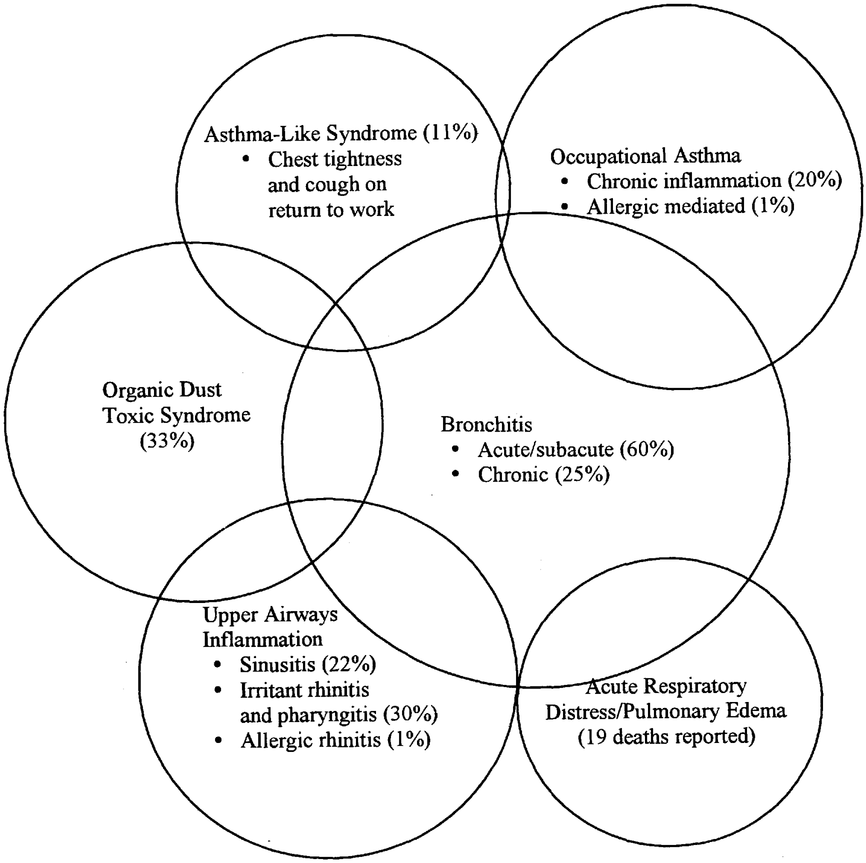

Figure 1. The spectrum of respiratory disease in swine confinement workers. The circles indicate overlapping symptoms and conditions; percentages indicate approximate rates of swine workers who experience these symptoms.

are unpublished anecdotal cases observed by the author in which some acute lung illnesses are probably reversible.

Control of the Occupational Environment

The author believes that worker health risks can be significantly reduced through a comprehensive program of environmental monitoring and environmental control by use of management practices, engineering controls, use of personal protective equipment, and health surveillance; however, such programs are exceedingly rare in today's swine industry. There is little to no exposure monitoring except for research purposes, and routine health assessment in this worker population is rare. Engineering controls are generally implemented if they will benefit hog production but rarely with worker health as the principal motivation. Several research studies are in concordance that maximum exposure levels for worker health are the following concentrations[27, 30, 32, 88]:

2.5 mg/m^2 total dust
0.23 mg/m^3 respirable dust
7 ppm ammonia
100 EU/m^3 endotoxin
10^5 microorganisms/m^3

It is important to recognize that swine workers are a survivor population, meaning that the most severely affected leave the environment early, leaving those who can better tolerate these exposures.

Management practices and engineering controls can significantly reduce exposures to inhaled toxicants. These procedures include frequent facility cleaning (power washing from floor to ceiling at least every 3 weeks); addition of extra fat and a urease inhibitor to the feed; installation of self-cleaning flooring; and improved lagoon operation.[76] Ventilation alone cannot necessarily ensure a healthful environment. The management procedures mentioned above must also be implemented. The ventillation system must be properly engineered and maintained; very often, higher cool-weather exchange ventilation rates are needed, and lower animal density (swine mass per unit of barn volume) is required.

Respirators should not be considered an effective alternative to good management practices and engineering controls. It is very difficult to ensure that exposed personnel wear the right respirator and that it fits properly, functions properly, and is worn at the appropriate times. Respirators are generally not well tolerated by workers, especially for strenuous work in a hot environment. OSHA requires that if respirators are worn to protect workers, they must be worn at all times and be fit, maintained, and stored properly. We recommend use of respirators as an adjunct to management practices and engineering controls, especially for specific tasks that result in higher-than-normal exposures or that have historically caused respiratory problems for the worker.

Special attention should be given to pregnant women who work in swine confinement facilities. The unborn fetus is susceptible to CO and hormonal drugs used in swine (e.g., oxytocin and prostaglandins). Pregnant women working in these facilities may be at increased risk for spontaneous abortion because of exposure to CO, prostaglandins, or oxytocin.[25, 76] A high level of monitoring and exposure control is appropriate for this group of workers.

Noise-induced hearing loss is a problem in this occupation, because the sound pressure level of squealing sows in swine barns routinely exceeds 100 dB. This noise is compounded by that emanating from ventilation equipment and feeding systems. Reduction of noise exposure through engineering is difficult in this setting because animals, rather than machines, are the primary source of the noise. Use of absorptive materials and baffles is impractical because of the need for surfaces to be cleaned with high-pressure spray equipment. The simplest approach to prevention of noise-induced hearing loss in this environment is the proper use of protective devices such as ear muffs, ear plugs, or semi-aural caps. These can provide noise attenuation in excess of 30 dB at frequencies most common in swine barns.

Relationships of the Work Environment to Outdoor Air Quality Around Livestock Environments

Extrapolating occupational health risks from inside swine facilities to community health risks outside swine production is of limited use. Although there is discharge of airborne particulates and vapors from the swine barns to the exterior environment, the aerosols downwind differ considerably in composition and concentration of specific agents. The aerosols disperse, and adsorbed vapors may be stripped from particles. These substances may change because of photochemical reactions. Some substances may be deposited on the ground with rain. Most swine confinement facilities are surrounded by other buildings, row crops, and trees, which can influence dispersion of effluents. All these factors make the indoor exposures vastly different from those outdoors. Odoriferous volatile organics present in the outdoor air in the vicinity of a swine production facility may arise from the lagoon or outdoor manure piles, and particulates and gases may be discharged from the confinement facilities.

Although there is theoretically a definable dose-response relationship for respiratory diseases by individual compound, the exposures inside are unique from those outside. Perhaps equally important is the fact that the exposed populations are quite different in terms of susceptibility factors. Figure 2 illustrates that whereas workers may require a high dose to develop a particular response, the general population, including children, the elderly, asthmatics, and other susceptible individuals, would be expected to develop responses at lower doses.

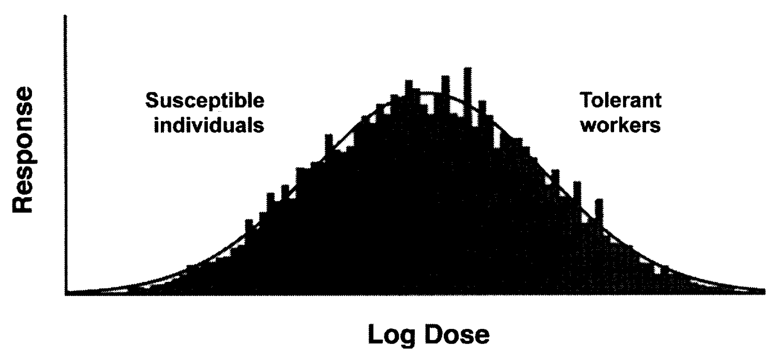

Figure 2. The distribution of responses to toxicants in exposed populations.

Individuals living in the vicinity of CAFOs who have their quality of life and social and economic conditions affected, and who feel that they have no control over their environment, may also be affected at lower doses.

There are many anecdotal reports of neighbors experiencing adverse symptoms[106]; however, there are only three controlled studies to date on this subject.[96, 107, 117] Although an association between symptoms in neighbors and CAFOs has been established, a specific cause-and-effect relationship has not been identified.

Relationships of Increasing Industrialization of Livestock Production to Worker Exposures

In smaller owner-operator swine production facilities, farmers may spend as little as 10 hours per week in the swine facilities, and the rest of their time with crop production and other farm work. In some large operations, full-time workers spend 40 or more hours per week in the facilities. Time spent inside swine barns is likely to increase with movement toward large-scale swine production. If one applies Haber's law of toxicology, the benefits (which may be present with newer facilities) of lower exposure concentrations (C) may be entirely offset by the longer exposure times (T), expressed mathematically as $C_1 \cdot T_1 \cong C_2 \cdot T_2$, where the subscripts denote different facility types.

This author believes that exposures and related occupational risks will increase with proliferating large facilities, mainly because of longer exposure periods. Increased risk does not have to happen if proper controls are implemented. Increased health and environmental surveillance by OSHA will likely increase as large-scale swine production expands. Operations with less than 10 employees are exempted from inspection by OSHA.

For producers who are proactive for worker health, there are potential rewards, including a healthier, more stable work force, lower absenteeism, lower health insurance costs, and reduced worker compensation burden. There is a need for large-scale swine producers to have model surveillance programs that they can implement. Environmental exposure assessments available on a fee-for-service basis through independent parties could help in developing guidelines for these producers based on actual environmental conditions in their facilities. Veterinarians are in an excellent position to provide these services.

A second important potential impact of the proliferation of large-scale swine production facilities is the impact on public health. Important concerns relating to immigration of new social and ethnic classes of workers into a region include the following: the stressing of community resources and social service programs, lack of appropriate immunizations, need for bilingual education and language translation, potential increase in tuberculosis and other transmissible diseases, burdening of the health care system because of uninsured status, and increase in housing needs for housing mental health treatment and law enforcement services. These concerns should be addressed in a broadened assessment of the impact of vertically integrated agricultural systems on public health and social services.

Community Health Issues

Physical Health

Most medically trained persons and the general public have a rather narrow view of health and disease causation. The author uses a broad definition of health as per the 1997 WHO definition (which defines health as the lack of physical, mental, social, and economic illness). When considering the health hazards of residents living in the vicinity of CAFOs, one must look beyond direct toxic explanations, especially when considering air emissions. The reason is that in many environmental cases (e.g., Three Mile Island, Love Canal, and so forth) where there are neighbor health complaints, environmental measurements often cannot explain the symptoms expressed by residents based on standard toxicologic mechanisms.[18] For example, Jacobson[60] reported H_2S levels in the vicinity of CAFOs well under 1 ppm (10 to 100 parts per billion). The threshold limit value (TLV) for occupational health has been set at 10 ppm, or an order of nearly three magnitudes higher. Also, in a study by Reynolds et al,[88] levels of ammonia in the vicinity of swine CAFOs were generally less than 1 ppm, whereas the occupational TLV is 25 ppm. Additional data reported in the same study included levels of endotoxin and dust at concentrations near the lower limits of detection of the instrumentation used (which was around 10 endotoxin units per cubic meter of air and less than 0.5 mg dust per cubic meter of air).

The previous paragraph considers occupational exposure limits, but it is logical that community residents may respond to lower-than-occupational limits. Residents are in the area more than 8 hours per day. Also, some chemicals have toxic effects at much lower levels than occupational limits. For example, several states have limits for H_2S at 20 to 50 parts per billion, nearly three orders of magnitude below the occupational exposure limit.

Kilburn[64] has recently reported on neurobehavioral effects of H_2S gas, which is emitted from many CAFOs with liquid-stored manure. Studying 16 exposed persons (with various durations and concentrations of exposure), he found consistent decreases in the following nine neurologic measurements: balance, reaction time, visual field performance, color discrimination, hearing, cognition, motor speed, verbal recall, and mode states. H_2S is a toxin with several effects, including cell irritation and poisoning of cellular respiration mechanisms, with a predilection for brain cells. His study brings new information to the importance of very low levels of H_2S exposure (20 to 50 parts per billion) such as those around CAFOs and other industrial sites such as refineries.

The physical and mental health concerns of residents near CAFOs are reported in only three studies to date.[96, 107, 117] These were controlled studies of self-reported symptoms, and no attempts were made to document objective correlates of health impairment. Thus et al[107] reported respiratory symptoms (significant relative to controls) almost identical in type and pattern to workers in CAFOs. Schiffman et al[96] reported excessive mood alterations in CAFO neighbors relative to controls. There are numerous instances of similar studies in other environmental settings, including community concerns around paper pulp mills, hazardous waste sites, refineries, and solid waste disposal sites. Most of these studies have not documented objective findings of toxic insult to humans. Some have reported subtle findings such as increased concentrations of urinary catecholamines. Additionally, most of these studies have not shown environmental evidence of known toxic levels of substances in the environment; however, the symptoms data are too strong in these studies to dismiss the plausibility of a real toxic environmental hazard in these difficult situations.

Extratoxic Mechanisms

Meggs[70, 71] has put forth an anatomic and physiologic hypothesis for induction of hypersensitivity to environmental chemicals. Biopsy studies of exposed individuals showed lesions in the nose that include cellular junction lesions, loss of respiratory epithelium, glandular hypoplasia, lymphocytic infiltration, and peripheral nerve fiber infiltration. Meggs[71] thinks that these lesions are related to reactive lower and upper airways disease and dysfunction, sick building syndrome, and multiple chemical sensitivity.

In addition to this literature regarding direct toxic effects, there is also evidence of what might be considered nontoxic effects of emissions. The literature on this most difficult environmental health conundrum has focused on exposure to waste sites, sewage treatment plants, and other large population-based community exposures. Our scientific and regulatory communities have difficulty dealing with this kind of situation, because it is complex, mixing the physical, mental, emotional, and social environments. "Genetic memory" and other very basic limbic-level self-preservation mechanisms may be involved. The following paragraphs review some of the literature regarding adverse health symptoms in the community when there are no objective toxicologic data.

The Somatasization of Adverse Odors

There are two cranial nerves involved in innervating the nasal mucosa; the first cranial nerve (olfactory nerve) and the fifth cranial nerve (trigeminus).[99, 100] The olfactory nerve is primarily responsible for odor detection. The trigeminus nerve, although it has several functions, has many branches that penetrate the oral mucosa and give additional information to an odor sensation, such as irritation and pungency, which trigger protective responses, decreased respiratory rate, rhinitis, tearing, cough, gag reflex, and bronchoconstriction. These responses are indicators that something associated with the odor may be harmful, and our genetic-based "instinctive-protective" mechanisms are telling us to make physiologic changes to meet the impending insult or to get out of the area. Odors can result in symptoms of mucosal irritation and nausea and feelings of "disease."

There are complex physiologic interactions that may explain symptoms of illness associated with odors. In fact, there are five possible mechanisms for nontoxic odor-related symptoms[99, 100]:

1. Innate odor aversions
2. Innate pheromonal phenomena
3. Exacerbation of underlying conditions
4. Aversive conditioning
5. Stress-induced illness

Innate Odor Aversions. As a basic protective mechanism, our body wants to avoid odors that may signify potential harm. For example, odors in "putrefaction" gas (e.g., H_2S, mercaptans, and other sulfur-containing chemicals) are common substances that stimulate a physiologic effect at lower-than-toxic levels. These gases may be associated with spoiled food but are also associated with animal manure, as are many of the odors associated with these innate odor responses.

Pheromonal Phenomena. Pheromonal responses are physiologic reactions that stimulate physiologic responses, especially regarding sexual reproduction. These responses are apparent for insects and many mammals, including humans. Some odors might destroy normal positive pheromone responses, such as those that Schiffman et al[96] reports on concerning impaired sexual function.

Exacerbation of Underlying Conditions. Previous research showed that workers with underlying conditions (asthma, atopy, bronchitis, heart conditions) are more susceptible to the CAFO environment than others.[26] Research by Meggs[70, 71] also lends strength to the theory.

Aversive Conditioning. Some persons previously exposed to high levels of gases that caused toxic effects may respond physiologically to less-than-toxic levels of this substance in future exposures. This conditioned stimulus is probably an innate protective mechanism. This response can also happen with lower-level exposures over a long period of time (acquired odor intolerance).[100]

Stress-Induced Illness. Odor-related stress-induced illness is discussed as a component of environmental stress syndrome by some authors. This phenomenon has been observed around disaster sites such as Three Mile Island.[18] Studies showed that there are increased urinary catecholamines in the affected individuals. They also have feelings of depression and helplessness and a high degree of environmental worry, which is exacerbated by the frequency of detection of the offending odor. Odors can act as a cue for these individuals, stimulating adverse physiologic responses. Long-term stress can be associated with muscle tension and headaches, coronary artery disease, and peptic ulcers.

Summary of Extratoxic Mechanisms

In studies of physical health complaints in communities around CAFOs, it is expected that objective findings of toxicity are difficult to find; however, that does not discount the fact that people experience valid symptoms. The reasons have to do with complex interactions of the brain and somatic systems. First, odors may initiate somatic symptoms based on enervations of the trigeminus nerve. Second, odors may initiate physiologic activity as a response to primordially acquired aversions to toxic substances. These responses may be modulated by the person, as he or she worries about environmental threats, and by the frequency with which odors are experienced. These conditions may be exacerbated by previous toxic exposures to the substances in question, creating a learned response of avoidance where even very subtle exposures are present. Further exacerbation may occur when combined with a feeling that the person has no control over the situation, resulting in "environmental stress." If an individual has an underlying health condition, such as asthma, further complications may be present.

ENVIRONMENTAL HEALTH ISSUES

Water Quality Issues

The EPA reports that 36% of our streams, 39% of our lakes, 38% of our estuaries, and 97% of the Great Lakes shoreline are impaired. Although there are many potential sources of pollution, agriculture is considered the most widespread.[108] The most important potential contaminants of water from CAFOs include microbes, nitrogen, phosphorus, and trace metals.

Water quality issues can be broken down into point source, nonpoint source, surface water contamination, ground water contamination, and land deposition of atmospheric nitrogen. There are complexities in analyzing the effects in each of these sectors. First, the focus of research and control has been on point source concerns. It is easy to discern the source in most point source pollution episodes (e.g., one can visualize a fish kill, and visually and temporarily one can usually identify a cause, such as a broken berm in a lagoon or wastes flowing into a receiving stream). Specific examples of point source pollution include[43]

- North Carolina, 1995, 35 million gallons of animal waste spilled into North Carolina waterways, killing 10 million fish and closing 350,000 acres of coastal wetlands for shellfish harvesting
- Iowa, Minnesota, and Missouri reported that animal spills in-

creased from 20 in 1992 (55,000 fish killed) to over 40 in 1996 (670,000 fish killed)
- North Carolina, 1997, 450,000 fish killed, apparently because of *Pfiesteria piscicida* infection
- Nebraska, 1992–1993, reported seven fish kills (National Center for Environmental Health Workshop, June 23–34, 1998)

Nonpoint source pollution is much more difficult to discern. There are many potential sources of pollution, for example, industry, crop production, and human waste disposal. Differentiating livestock from other sources of pollution is difficult; however, one study estimates that of the 450,000 animal feeding operations (AFOs) in the United States, there are 1000 to 3000 CAFOs that may be contributing to decreased water quality.[108] Additionally, studies have mainly concentrated on local chemical and physical emissions and have paid less attention to watersheds and regional water quality. Furthermore, studies have not concentrated on the biologic integrity of an area, region, or watershed.[59]

Studies of surface and ground water quality are also difficult, because surface and ground waters are not necessarily separate. Certain soil and geographic formations, especially sandy soils, shallow waters, Karst formations (sink holes directly channeled to subsurface waters and prairie pothole formations) provide close association with surface waters. There are some man-made phenomena that provide direct association of surface and ground waters (e.g., abandoned wells and drainage wells, which directly connect surface and ground water).

The risk for surface water contamination from agricultural operations is subject to many variables and considerations. Croplands throughout the United States in nonarid areas have been altered by human engineering to allow rapid drainage of land into surface receiving streams. Tiling, drainage ditches, stream straightening, and removal of wetlands have all contributed to decreasing the normal recharge of our waters, resulting in a higher potential for pollution of receiving streams, which makes surface waters vulnerable to many sources of contamination—industrial, municipal, and agricultural. When CAFOs are inserted into this milieu, with their large quantities and geographically concentrated wastes, the potential for surface water contamination is significantly heightened.

Microbes

There is a definite potential for microbial contamination of ground and surface waters from livestock operations.[7] Organisms that have been associated with animal waste include *Helicobacter pylori*,[66] *Campylobacter* spp, *Salmonella* spp, and *Listeria* spp.[45] Although there may be hundreds of species of organisms found in swine waste, most pathogens do not survive in animal wastes very long because they are not well suited to survive desiccation, sunlight, the rather low pH, the high osmolality, and the high ammonia concentrations in stored swine waste slurry.[36, 337]

For example, *Salmonella* and *Leptospira* organisms were found to survive only 3 days in swine waste.[115] A study of the survivability of *Salmonella* organisms in poultry manure[6] revealed that organisms could live up to 19 days under ideal conditions,[7] that survival of organisms after land application was only a few days, and that survival was retarded by low temperatures, low moisture in soil, low pH, sunlight, and competition with other organisms.

Another concern about microbes is antibiotic resistance, because animals are commonly fed low-level antibiotics as growth promotants or as infectious disease treatments. Humans may acquire resistant zoonotic pathogens directly or may be infected with a nonpathogenic, resistant organism that may then transfer that resistant gene to a pathogen in the gut of an individual by way of conjugation or phage induction.[4, 19, 41, 111]

Although there have been a few documented gastrointestinal (GI) illnesses and leptospirosis cases (from animal to water to person),[46, 47] it is difficult to characterize or quantify the health hazard. Although we know that GI illnesses may be a potential hazard in consuming water contaminated with animal waste, it is difficult to document such relationships. In fact, there were no specific pathogens found associated with GI illnesses in nearly 70% of the cases of waterborne outbreaks in one study[74]; however, another study tracked human and animal cases of *Salmonella* infection and found that 6 of 23 *Salmonella* GI infection cases were animal-related and from occupational exposures.[46]

There are little data relating to infectious hazards of persons living in the area of a CAFO acquiring an infection from contaminated water or air. One study[65] identified 29 different fecal bacterial species growing in lagoons from two CAFOs in Illinois. One ground water sample in the vicinity did contain fecal *Streptococcus* organisms.

Cryptosporidium parvum is a special case. An estimated 400,000 persons in Milwaukee in 1993 contracted a GI illness of *C. parvum* infection from drinking city water.[77] One hundred deaths were attributed to this outbreak. This organism was thought to come from runoff of dairy farms that contaminated city water supply reservoirs. Young ruminants are especially susceptible to this infection and shed the organism in their feces. The filtering component of this system was not capable of removing this organism, and it is resistant to usual municipal water treatments.[92] As few as 30 ingested spores may induce human infection. The usual human infection persists for 4 to 7 days with typical GI symptoms. Ninety-four animal species are susceptible to eight different cryptosporidia species, *C. parvum* being the most common in livestock and humans. Feral birds may act as environmental disseminators of this organism. There are no data at present on CAFOs as sources of human infection with *C. parvum*.[44]

Another special infectious disease case is *Pfiesteria piscicida,* which is the cause of major fish kills in the coastal waters of North Carolina. *P. piscicida* is believed to thrive because of the eutrophication process associated with a high density of CAFOs in North Carolina and along the Atlantic Coast. More recently, *P. piscicida* has been implicated as an agent causing human health problems. Skin irritation, short-term memory loss, and other cognitive impairments are suspected to be caused by *P. piscicida*. The full definition of health concerns related to *P. piscicida* awaits the results of current research.[77]

Microbes do not have to be infectious to cause a health hazard. Many microbes contain toxins (e.g., endotoxin, glucans) that are potent inflammatory substances.[94] These may not cause a health problem from drinking contaminated water, but aerosolized (spray irrigation) animal wastes could produce aerosol exposure to these substances, which could result in asthma-like symptoms, bronchitis, mucus membrane irritation, and organic dust toxic syndrome (a systemic influenza-like illness).

Nitrogen

Nitrogen (N) from livestock wastes becomes available by breakdown of nitrogen-containing amino acids. Nitrogen in the environment is reduced to ammonia and then to nitrates, elemental nitrogen (N_2), and oxides of nitrogen (NO, NO_2, N_2O). There are several fates of the N produced. It may be emitted to the air as ammonia or nitrogen oxides vapor (to be redeposited on land or water elsewhere downwind). Most of the N becomes incorporated in the soil, where it is taken up by plants and incorporated into plant cells. Residual N finds its way to ground or surface water, where it is eventually metabolized by microorganisms. If in excess (along with excess phosphorus), it will cause eutrophication of rivers or lakes, increasing algae blooms or increasing the biologic oxidation demand (a measure of free oxygen available in the water for animal life). Microbes in the water need oxygen to fully use the N. This use reduces the oxygen available for aquatic animals and plants and causes fish kills, increased aquatic weed growth, and decreased aquatic biota generally because sunlight penetration of the water is limited. The amount of N required to create eutrophication is much less than that which causes danger for drinking waters.

It is often difficult to discern if the source of N in water is from animal waste, commercial crop fertilizers, or human waste.[52] Water contamination with animal wastes is difficult to ascertain; however, Ritter and Chirnside[91] surveyed 500 wells, and the nitrate content was significantly increased near large broiler production facilities. Hallberg et al[53] studied the nitrate levels in well water in northeast Iowa and found a threefold increase from 1960 to 1983 in well water nitrates (3 mg/L to 10 mg/L). The area experienced an associated 30% increase in manure application during the same period; however, there was also a 300% increase in inorganic fertilizer use in the region. It is difficult to differentiate the contributions of each source of N to the water contamination.

Acute surface water contamination incidents are more readily documented. The EPA requires each state to report point source pollution incidents ("305b" report), including fish kills.

Human Health Effects

There are two potential primary health effects from excess nitrates in drinking water: (1) methemoglobinemia and (2) cancer risk. To be toxic, Nitrates must be reduced to nitrites either in the environment or the GI tract. The reduction of nitrates to nitrites in mammals is most likely in neonates. Nitrates, when absorbed in the blood, associate with the hemoglobin molecule in red blood cells, forming methemoglobin. If methemoglobin is sufficiently high in concentration, the blood has insufficient capacity to carry oxygen to the body, causing anoxia. The degree of damage is directly related to the amount of hemoglobin saturation and length of time that the poisoning occurs. Symptoms range from weakness to brain damage, to death. Infants are at greatest risk, because they have relatively less overall oxygen-carrying capacity. Blue baby syndrome was coined many years ago for an infant poisoned with nitrate.[75] The methemoglobin is blue to chocolate in color, producing the blue tint to the white infant skin. The levels required to cause these poisonings are quite high (more than 40 mg/L). A second suspected health hazard of nitrates (nitrates) comes from the combination of nitrates with certain amino acids in the gut, forming nitrosamimes.[75] These substances are known carcinogens in several animal or in vivo systems; however, nitrosamimes are also found naturally in plants (e.g., broccoli), so the overall health importance of water-associated nitrosamine consumption is unknown.

Trace Elements

Sodium (Na), potassium (K), copper (Cu), and zinc (Zn) are found in animal manure because they are additives to animal feeds, often at levels higher than the animal is capable of metabolizing. Although there is little known direct toxic health hazard to humans from usual exposure, there are problems with soil fertility degradation or eutrophication and from grazing animal toxicity (mainly Cu). Cu and Zn toxicities for some plants have been studied, and soils with long-term applications of manure may surpass these levels. Although N and Na leach into ground or surface waters to cause excess eutrophication, K, Cu, and Zn are not highly water-soluble and tend to build up in soils. K is a crop nutrient, as are N and phosphorus (P), and may be removed similar to N and P by uptake into plants; however, the others (Cu, Zn, Na) tend to accumulate and are lost mainly by soil erosion, making soil regeneration very difficult.[107]

Phosphorus

Phosphorus (P) is an essential plant nutrient. It is not toxic to humans or animals, but it contributes to eutrophication in fresh or brackish waters and to general environmental degradation.[61] Eutrophication enhances the process whereby aquatic organisms grow, and some may produce neurotoxin.[108, 109] Other researchers have noted effects on drinking waters of the carcinogenic trihalomethanes, which are formed following chlorination of surface waters that have recently experienced algal blooms.

Because P is generally bound to soils, it would rarely reach ground waters unless there are shallow water tables or loose sandy soils, which would allow soil particles to reach the ground water. Phosphorus that is not taken up by plants builds up in soils and may be transposed as sediment-bound P in runoff.[98] Because P in animal manure is present at a high ratio relative to the level of N for optimal plant growth, heavy long-term manure application is crop-limiting because of excessive P build-up, requiring years to decades to return to optimal plant growth levels. The following scenario describes this situation in more detail.

Most livestock operations rely on local soil application of manure, and crops are counted on to incorporate the N, P, and K applied for new plant growth. One problem is that swine manure has excess P relative to N for proper plant use. Plants use N and P at a ratio of one part N to 0.17 parts P. Hog manure is one part N to 0.7 parts P, resulting in P levels at four times the capability of crop uptake. Applying manure according to the N needs of plants causes, in the long term, soil build-up of P, resulting in reduced water infiltration capacity and highly reduced soil fertility.[93] The Netherlands, a small country with high pig production, has over 1 million hectares with excessive P contamination because of concentrated animal manure applications.[113]

Atmospheric Nitrogen

A typical lagoon loses 70% to 80% of the N to the air as ammonia or nitrous oxide (N_2O).[103] Irrigation of wastes results in a 30% to 40% N loss to the air, compared to 10% to 25% for soil application or 0% to 2% for injection. The ammonia comes back to earth in precipitation, which can secondarily contaminate surface water or contaminate native plants and cause overgrowth of undesirable species and acidification of soils. One researcher[5] documented N precipitation and reported increased soil N decreased soil pH in areas of poultry farms. Researchers in the Netherlands have found deposition of N to be 45 kg N/hectare/y, which is 10 times normal background levels. The greatest N deposition is in the high-density livestock region to the south of the country, where the deposition is 50 to 65 kg N/hectare/y.[42, 110] Nitrous oxide, which may form atmospherically from N emissions, is a greenhouse and ozone-depleting gas.

Regional and Ecologic Considerations

The bottom line in containing contaminants is to help ensure that the amount of N, P, K, and other inputs used in a regional ecosystem are balanced by crop use so that excesses do not build up in the soils and leaching and run-off are minimized. When agricultural production was more dispersed and diversified, contamination was minimized. Farming operations of the 1950s and 1960s were relatively diversified between livestock and crops, so that there was a relatively good balance between nutrient output (manure) and nutrient uptake in crops, resulting in a balance of N, P, and K and minimal leaching and runoff. Results from the long-term Big Springs study area in Iowa revealed no ground water contamination before 1930.[53] Three trends emerged since then to disrupt the balance: (1) bringing extra N into the area from the outside in the form of inorganic fertilizer; (2) concentration of livestock populations, resulting in more manure applied to less land area; and (3) specialized or industrial livestock farms that bring extra N into the region from outside in the form of animal feed. This results in concentrating large quantities of nutrients in localized areas, far outstripping what the local vegetation can use. Where animal populations are dispersed and minimal outside inorganic fertilizer is used, pollution potential is low. In regions where animal densities are high, greater proportions of the feed come from other areas, and inorganic fertilizer is used, there is an increasing nitrogen imbalance, resulting in increased risk for pollution. Part of the problem is that regulations tend to focus on individual operations, when in reality, we need plans for larger ecologic regions such as watersheds.[80] There is a need to define the ecologic carrying capacity of a region and to base regulations on that information.

Water Usage

Greater water use is an emerging environmental concern for regions where large livestock facilities are located. This problem is especially important because the largest facilities have been relocating to more arid regions of the country (e.g., western Kansas, the panhandles of Oklahoma and Texas, eastern Colorado, and Utah). Water use can be compartmentalized into animal consumption, cleaning and flushing of lagoons, filling lagoons, and recharging of lagoons. Finishing hogs consume 3 to 5 gal/d. A sow and litter consume 8 gal/d. Water needs for flushing include 15 gal/d per pig, and 35 gal/d per sow and litter.[73] For a large industrial facility (e.g., a 25,000-sow unit), this would translate to over 6 million gallons of water use per day.

Pharmaceuticals

There is a concern that antibiotics, parasiticides, and growth stimulants (or their by-products) may pass in the urine or feces of animals and find their way to soils and water sources through manure application; however, relatively little is known about the fate of veterinary pharmaceuticals after they leave the animal or their environmental impact. Perhaps the primary concern for environmental health is the introduction of antibiotic-resistant organisms. Antibiotics given to animals result in development of resistant organisms in the gut of animals. Some of these organisms may be pathogens, or some resistant nonpathogens may transfer resistance to pathogens. This concern is already realized through organisms passed occupationally and through the food chain. With so little known about the fate and impact of veterinary pharmaceuticals on the environment, scientists and scholars recently convened by the Centers for Disease Control, National Center for Environmental Health (June 23–24, 1998) discussed many issues related to CAFOs and the environment. They indicated that pharmaceuticals were a potential concern, but secondary in importance to nitrogen, volatile organic compounds, and pathogens.

Air Quality Issues

Merkel et al[72] published the first assessment of the content of gases from swine manure, which was subsequently confirmed. O'Neill and Phillips[79] identified 168 different compounds. Some of these substances have a very low odor threshold (e.g., 1 part per billion) that challenges the confidence limits of most modern assessment methods. Table 1 lists primary compounds identified.[91]

The source of gaseous compounds is the degradation of feces and urine and, to a certain extent, wet animal feeds and dead animals. Gaseous emissions can come from animal wastes applied to land directly where ammonia is the main emittant; however, a much larger variety of compounds are emitted from animal wastes stored in liquid phase (a common practice with swine, occasionally beef and dairy, but not poultry) where anaerobic digestion by microbes takes place, leaving a plethora of breakdown products that includes proteins, simple and complex carbohydrates, and fats. The major (so-called *fixed gases*) products of this anaerobic digestion include NH_3, H_2S, CO_2, and CH_4. NH_3 is a by-product of almost any treatment method of animal waste. The other compounds and the additional 160 or so "trace compounds" come primarily from the storage and anaerobic decomposition of manure in lagoons or other liquid storage systems. The emitted compounds can be grouped into the following classes of chemicals: mercaptans, sulfides, disulfides, amines, organic acids, phenols, alcohols, ketones, indole, skatole, carbonyls, esters, and nitrogen heterocycles (see Table 1).

Often overlooked are the particulate substances that are emitted from livestock feeding operations. There is a large quantity of organic dust generated from feed sources and the pigs (hair, dander, and dried feces). This dust contains many bioactive substances, including endotoxin and glucans (two very important inflammatory substances).[34] Also, there is a bioaerosol component of this dust. Many gram-negative and gram-positive bacteria, fungi, and molds have been identified.[104] Some of these organisms also grow in confinement buildings, contributing to concentrations of organisms that are also found in the air outside the building.[63] The vast majority of organisms identified in the air are saprophytic, and very few pathogens are identified. They are combined with dust that becomes a part of the total aerosolized particulates. The size of the particulates emitted is relatively small. About 50% are less than 10 μm, which means that they are inhalable. This fact implies a respiratory health risk for humans and animals.

Odors and Odorants

Most of the public concern over CAFOs has been about odor; however, to understand gaseous emissions, we need to define odors and odorants. An odor is an unpleasant sensation in the presence of an odorous substance (odorant). The odorant may or may not have additional harmful toxic effects. Ritter[91] identified the following classes of compounds from animal manure as odorants: organic acids, alcohols, aldehydes, carbonyls, esters, amines, sulfides, mercaptans, and nitrogen heterocycles. NH_3 and H_2S among the fixed gases are also odorants, but they are also well-known toxic substances.

Riskowski et al[89] described an odor phenomenon in livestock (mixed gas) environments where NH_3 and H_2S odors are detectable at much lower levels than previously published odor threshold concentrations. It is likely that in this mixed environment, other less-concentrated chemicals and particles interact to enhance the odor detection of these substances.

Researchers have looked at the fixed gases (e.g., NH_3 and H_2S) as potential surrogates for emissions and odors; however, the results of several researchers showed that measuring surrogate gases for odor is not entirely satisfactory[83, 101, 116] because there is no exact correlation between them and odors. Odors must depend on other gases, even though they exist at much lower levels.

The particulate emissions are well-documented toxic substances. They act synergistically with gases as important occupational health hazards. Gases and particulates are more highly concentrated inside the facilities compared to outside. Goodrich et al[48] showed (relative to background) a very high level of viable organisms downwind of manure sprinklers and inside beef and turkey facilities. Pickrell[85] showed swine barn environments to have significantly higher particle and microbe levels compared to other livestock environments. For example, microbe populations are 1000 to 1,000,000 times higher inside swine buildings compared to outside.[63] Very little is known about hazardous concentrations of odorants in outdoor air around CAFOs. We do know that there are serious worker health problems caused by H_2S and NH_3 in the interior; however, it is difficult to infer exterior conditions based on interior studies, because few quantitative area assessments have been made. Available data[88] suggest that NH_3 and H_2S are on the order of 1000 times higher inside buildings compared to outside. For example, measurements are made in parts per million inside the buildings and parts per billion outside.

Concerns about odors from livestock facilities can be considered a nuisance, which is often how courts treat them; however, there is growing evidence that odors may cause physical illness. Overcash et al[82] indicated that odors may cause nausea, vomiting, headache, shallow breathing, coughing, sleep disorders, upset stomach, appetite depression, irritated eyes, nose, and throat, and mood disturbances including agitation, annoyance, and depression. Ackerman[1] reported that odors can result in strong emotional and physical responses, particularly after repeated exposures. Odors can result in a mixing of emotional and physiologic responses. Shiffman et al[96] studied 44 persons living near large animal facilities and compared responses of the profile of mood states (POMS) to 44 matched persons not living near large facilities. She found that people living near the facilities were more angry, confused, tense, depressed, and fatigued. To determine acceptable distance and odor acceptance, Walsh, Lunney, and Casey[114] surveyed persons living in a 5-km area surrounding a large cattle feed lot. They measured odors according to an odor panel and found acceptable odor levels within the 5-km radius. Kass[62] suggested that the primary health effect is allergic reactions from inhaled organic dust, especially mold spores and protein material. Mahon and Jackson[69] suggested that a health problem exists from a delayed allergic condition called hypersensitivity pneumonitis, or farmer's lung, caused by animal feed exposure; however, more recent research suggests that the problem is one of long-term inflammation, secondary to inhaled dust and gases. Pickrell[85] pointed out that disease in animals and people is associated with increased particles. Donham et al[32] showed a strong dose-response relationship between particles and lowered pulmonary function. Recommended exposure limits were made based on this research.[32]

Fate of Emissions and Atmospheric Effects

There is emerging concern regarding gaseous emissions from livestock facilities relative to ammonia-nitrogen deposition to area surface waters and soil.[84] There is also concern about contributions to global greenhouse gases.[106] Western Europe, particularly the Netherlands, has taken the lead in research in this area, raising concerns and questions about the growth of large operations in the United States and other parts of the world.[106]

NH_3 vaporizes into the atmosphere from manure stored in lagoons and manure applied to land. Once in the atmosphere, it can be transported downwind to be deposited into surface waters and on soils as NH_3 or other nitrogen compounds.[57] About 50% of this total emitted NH_3 comes from land application, and about 40% from confinement (liquid) storage. Luebs et al[67] used acid traps to quantify atmospheric NH_3 in the vicinity of a concentrated dairy area in California. They found 8.5 kg of deposited NH_3 per hectare per week in a downwind location, and 1.4 kg NH_3 per hectare per week in a general 8-km area downwind of the facility.

Deposition of excess ammonia-nitrogen causes increased risk for eutrophication of ponds, lakes, and streams in the region. It can also bring excess fertilizer to natural areas, causing overgrowth by undesirable species and nitrate leaching through soil.[112]

NH_3 in the atmosphere may also react with acids already in the air, such as hydrochloric, sulfuric, and nitrous acids. This results in ammonium aerosols which are then transported with the wind and can return to earth with precipitation. ApSimon and Kruse-Plass[2] reported that these compounds may be more strongly acidifying to soils and water than strong acids.

CH_4 is another important atmospheric emission. CH_4 is a strong greenhouse gas, contributing to global warming. On a molecular basis, CH_4 is 21 times stronger than CO_2 as a greenhouse gas and 58 times stronger on a mass basis[108, 109] because of its greater effect in absorption of longer wavelengths of light energy. Total world CH_4 emission is 354 million metric tons. The United States emits 27 million metric tons, and livestock (wastes and ruminant eructation) account for 7.4% of this total.[108, 109] Intensive confinement systems with anaerobic storage of manure increase the amount of CH_4 emissions along with large surface-area lagoons.[108, 109]

SUMMARY AND CONCLUSIONS

The concern about environmental issues centering around CAFOs is appropriate. The veterinary profession can be an important force in meeting these challenges by broadening its scope of knowledge and practice into the broader environmental field. Although animal agriculture's contribution to environmental concerns is the focus of this article, it is only one of several sectors that contributes to environmental degradation. Crop production, as well as livestock production industries, contribute to pollution. Manufacturing industries, municipalities, private individuals, our consumptive lifestyles, and agriculture all contribute to the degradation of our environment. One must keep in mind the huge importance of our agricultural industry and not single it out to the detriment of its progress. We have an abundance of high-quality foods at the lowest cost to the individual of any industrialized nation. We export over 40 billion dollars in agricultural products yearly. Agriculture sustains our rural economies and provides opportunities for over 2 million private enterprises scattered across the country; however, there is a goal that we have a sustainable agriculture. A big part of that depends on development and enhancement of an agriculture that does not pollute, that sustains its farm operators and workers, and that does not make the area residents ill or degrade their quality of life; however, the current situation is not promising.

Much remains to be learned about the actual acute and long-term health consequences of animal agricultural pollution. Many health concerns are speculative, even though based on sound facts. We know that many surface waters have excess N and P that leads to eutrophication and possibly enhanced growth of undesirable organisms such as *Pfiesteria piscicida.* We know that other animal pathogens, such as cryptosporidia, have caused large community outbreaks. There are other potential pathogens, such as *Salmonella* sp, for which we do not know the hazard. We know that our soils may become excessively laden with P, Cu, and Zn, which retard plant growth and create toxic conditions for grazing animals.

There are concerns about air pollution. Odors have negative sensory and physical health consequences. H_2S and dust may cause toxic effects on neighbors. NH_3 vaporizing from manure sources may be carried with precipitation to cause eutrophication in lakes or altered ecosystems in natural areas. CH_4 escaping from degrading manure contributes to greenhouse gases.

Workers in confined livestock structures have high risk for a variety of chronic respiratory conditions. They also are at risk for acute poisoning from H_2S in operations where liquid manure is stored in confined spaces.

There have been numerous health complaints in recent years from community neighbors of large-scale livestock operations. One study showed adverse altered mood states, and another showed evidence of respiratory illness similar to what workers experience. Although it has not been possible to objectively measure conditions and know toxic levels of substances causing these illnesses, there are so-called *extratoxic mechanisms,* such as inherent aversion to putrefactive odors and exacerbation of preexisting conditions that lower the tolerance threshold.

Environmental concerns regarding livestock production are not new. In the early and mid-1970s, there were many conferences and publications regarding odors and water contamination from livestock operations. Although most of what is known in this area has been known for 20 years, relatively little effective efforts have been made to correct the concerns. In fact, trends over this past decade have increased the concerns. This past decade has seen a tremendous acceleration in the concentration and consolidation of agriculture, capping a slow trend over the past 50 years toward larger, fewer, and more-specialized farms. This trend has gone against the old saying that "dilution is the solution to pollution." The general capitalistic market forces, our enhanced global economy, and many economic forces and policies have paved the way toward concentration and continue to do so.[35] These trends and forces were reviewed at a conference regarding the lack of human and environmental concerns in the concept of a sustainable agriculture.[35] Consolidation and concentration of agriculture is at the root of the recent environmentalists' and community concerns about agricultural pollution. Large-scale industrial livestock operations are likely to overrun the ecologic carrying capacity in many local areas. They enhance the total potential damage to the environment if there is a failure in a waste system. They increase social and economic disease in communities, making environmental and health concerns a focus of citizens' attacks. The upside of this situation is that with vertical integration, many of the production facilities are components of multinational food corporations that probably have the resources to conduct agriculture in an environmentally friendly manner. Will this happen? It remains to be seen. Is there enough political will to create policies that truly enhance a sustainable agriculture and that protect the environment, keep family-owned operations in business, enhance the health and social welfare of those that farm and the communities in which they live, and protect the health of workers and rural residents? If it is to be done, it must be done quickly, because our family-farming base is rapidly dissolving as corporate farming increases. Policies and regulations must go beyond simple local environmental regulations. We must examine regional, national, and international regulations, so that the industry does not just move to another state or another country where there is a perceived lesser environmental cost.

There are huge challenges, and action is required to change the trends that have taken place. It is not impossible; we have examples in Western Europe where giant steps have been taken to reach an environmentally friendly agriculture. Agricultural reform is one area in which we need to cooperate and not compete. Making effective changes will take the will of a large portion of our population and strong political leaders who are willing to battle special-interest groups. The question is, can it be done in time?

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Health Effects from Breathing Air Near CAFOs for Feeder Cattle or Hogs

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ABSTRACT. There is concern that livestock operations for fattening cattle and raising hogs known as concentrated animal feeding operations (CAFOs) release substances into the air that have negative effects on the health of persons living nearby. These substances include dust containing endotoxin and other microbial products as well as ammonia, hydrogen sulfide and a variety of volatile organic compounds. Odors from these farms are considered offensive by some neighbors. A variety of medical complaints are reported to be more common in those people who live near CAFOs for raising hogs than in people without this exposure. Respiratory health effects, including symptoms of pulmonary disease and lung function test result abnormalities, have been described in workers employed in CAFOs where hogs are raised. Health effects after inhalation exposure of neighbors to substances released into the ambient air from these farms is less well characterized. It must be noted that CAFO workers may differ from neighbors in terms of their exposures and general health status. The presence of dust and other substances from cattle feedlots also causes some neighbors to voice concerns about the impact on their health but this exposure has been studied less extensively than exposure to substances released from CAFOs where hogs are raised. Further research needs to be done to look for measurable health effects attributable to living near all CAFOs in order to better understand the impact of these farms.

KEYWORDS. Concentrated animal feeding operations, endotoxin, organic dust, hog dust, cattle feedlots, respiratory health

INTRODUCTION

Increasing numbers of cattle and hogs are raised or fattened in intensive livestock operations in North America, Europe and elsewhere. Some people who live near these farms have voiced concerns about human health effects from exposures related to their presence, particularly hog confinement facilities and cattle feedlots.[1,2] There has been a great deal of public debate about the medical, economic and social impacts of this type of livestock farming. Also, the possible impact on human health of these operations has been the focus of a number of research studies.

Intensive livestock operations are often known as concentrated animal feeding operations (CAFOs). CAFOs, and their smaller rela-

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tives, animal feeding operations (AFOs) are defined by the U.S. Environmental Protection Agency (EPA) according to the total number and liveweight of the herd on feed.[3] The majority of the information published about human health effects from breathing the air in and near CAFOs comes from studies conducted on persons who work inside hog confinement barns. Some respiratory conditions and related health problems are more common in these workers than in the general population. As this complex topic is discussed, care must be taken to avoid drawing conclusions about the nature or extent of neighborhood human health effects using only what is known about occupational health problems seen in CAFO employees. For example, hog odor can be quite apparent in the neighborhood as well as inside the barns. However, one cannot assume that the neighborhood exposure is sufficient to cause the same health effects that some workers experience. Assumptions should not be made about neighborhood human health effects from measuring the impact on air quality without (1) directly assessing those effects and (2) measuring the air-quality parameters thought to be associated with them.

The presence of excessive airborne dust in the air is the concern raised most often by persons living near cattle feedlots. Identifying and understanding the human health effects of living near feedlots are complicated by the fact that neither the occupational health effects in feedlot workers nor the neighborhood health effect of these facilities has been formally studied. This paper reviews neighbor health and worker effects of airborne emissions from hog and cattle CAFOs.

THE HOG CONFINEMENT BARN ENVIRONMENT

Hog confinement facilities are buildings in which the hogs spend their entire lives. They are given a feed that consists of ground grain and soybeans. The animal waste is typically flushed out with water, the manure slurry collected and usually stored under anaerobic conditions in one of several possible structures: a pit below the concrete floor of the building, a lagoon, or in a deep basin. This manure slurry is applied to the land as a fertilizer at a later date. Hog confinement barns are complex environments from an air quality perspective. Dust collected within the barns consists largely of feed components but also contains swine fecal matter and dander, bacteria and molds.[4] More than 330 volatile organic compounds and fixed gases have been described from swine facilities using gas chromatography and mass spectroscopy.[5] Most of the gases are present in very low amounts and likely contribute only to the characteristic odor associated with swine confinement operations. Respiratory symptoms in workers have been found to be associated with total and respirable dust concentrations, endotoxin in the dust and ammonia measured in the air of the barns.[6,7,8,9]

Dust in swine confinement barns is rich in bacteria and other microbes.[10,11] Endotoxin is a highly inflammatory substance found within the external cell membrane of Gram negative bacteria, which are abundant in manure. Endotoxin is the substance that has been most consistently associated with impairment of lung function in workers.[12] The presence of ammonia results from metabolism of urea in hog urine by the enzyme urease. Available evidence suggests that dust, ammonia and endotoxin act together to cause the airway disorders described above, as reviewed elsewhere.[12] Concern has been raised in several states in the U.S. by concerned citizens about the human health effects in workers and neighbors of hydrogen sulfide, a malodorous gas that comes from anaerobic manure storage facilities as well as from a number of other sources, such as the petroleum industry.[1] Hydrogen sulfide is a very toxic gas when present in hog barns at high concentrations ($\geq$ 500 ppm by volume), which is an unusual event. Short-term exposures at this level have caused death in swine confinement workers. A severe, life-threatening exposure to hydrogen sulfide has also been associated with reactive airway dysfunction syndrome, a form of asthma, in a worker with heavy exposure to hydrogen sulfide.[13] However, published studies do not support the idea that hydrogen sulfide causes respiratory disease in persons working in hog confinement facilities under ordinary conditions, when the levels are in the range of 2-3 ppm or less.[5,14,15] Hydrogen sulfide levels in swine confinement barns do not appear to be predictors of respiratory outcomes in workers.[7]

The dust emitted from the barns has not been completely characterized and has not become the focus of regulation. In contrast, gases released from hog confinement barns and lagoons into the ambient air have received more attention. Hydrogen sulfide (H_2S) can be detected at the property line of these farms in some instances and has been the subject of current or proposed ambient air quality standards in more than half of the states in the U.S., including Minnesota, Nebraska and Iowa.[16,17] Ambient air quality standards for ammonia are likewise being considered in various livestock-producing areas of North America, most notably in the province of Alberta, Canada.[18] There is an ammonia standard in place in North Carolina that can be applied to production agriculture and several other states have ammonia standards as well.[19]

The regulation of odors from hog confinement facilities and other CAFOs is a controversial topic. Recently, a group of experts was unable to reach consensus concerning the control of odors from CAFOs.[20] Some experts favor specific air quality standards limiting airborne concentrations of odor, NH_3 or H_2S at the CAFO property line. Regulatory action at the state level might be similar to that which is used to enforce the National Ambient Air Quality Standard.[21] Others favor measuring odor at residences or in public-use areas and using dispersion modeling tools to factor in the impact of frequency, duration and concentration of exposure to odor at the residence, thereby avoiding extensive monitoring.

THE CATTLE FEEDLOT ENVIRONMENT

Cattle feedlots, as we are using the term, consist of outdoor unvegetated corrals or pens in which cattle are confined, fed and watered. Pens usually have unpaved, earthen surfaces on which manure excreted by the animals accumulates over time. In arid, semi-arid or temperate regions where long-term evaporation exceeds the sum of effective precipitation (rainfall or snowmelt that remains on the pen surface instead of running off) and the moisture excreted by the animals in manure and urine, the accumulating manure will dry out over time. If compacted by machinery or hoof action, this manure consolidates into a firm surface layer. Manure that is not well consolidated, however, becomes a reservoir of "parent material" for fugitive dust, which is generated and suspended in air primarily by the shearing action of the bovine hoof on the unconsolidated manure.[22] Because fugitive dust emissions from the feedlot surface are closely tied to animal behavior, and because cattle feedlots are typically open to the environment, concentrations of airborne dust downwind of feedlots vary both diurnally and seasonally.[23] Peak concentrations of feedlot dust generally coincide with the evening spike in cattle activity combined with neutral or stable atmospheric conditions at ground level.[23] Neutral or stable conditions are characterized by low wind speeds and little to no thermal mixing. These peak concentrations are known to decrease visibility on nearby roadways and to create nuisance conditions at downwind receptors.[24]

Ongoing research across the United States and Australia is confirming that the emission of odorous trace gases (e.g., volatile fatty acids, phenols, organic sulfides, amines, NH_3 and H_2S) from cattle feedlots is likewise episodic and is closely associated with rainfall events and warm temperatures. That association is a direct result of the incomplete, microbially mediated, temperature-dependent, anaerobic digestions that occurs when excessive moisture displaces oxygen from the pore space of the surface manure layer in a cattle feedlot. Although emission rates of those gases are as yet gross and variable estimates, their ground-level concentrations downwind of open feedlots seldom approach established health-based standards or guidelines.[25,26,27,28]

NEIGHBORS' CONCERNS ABOUT ODOR AND DUST FROM CAFOS

Workers rarely complain about the odors from cattle feedlots or hog confinement barns. However, odors associated with both cattle feedlots and hog confinement facilities can be perceived as offensive by people who live nearby or drive by these facilities on public roadways.[29] Some of these individuals allege that the odors have adverse health effects as well as a negative impact on their quality of life.[30] The characteristic odors from CAFOs are caused by a number of contributing compounds, including volatile organic compounds (VOCs), NH_3 and H_2S.[31] These odors are complex, resulting from fresh manure and its aerobic and anaerobic fermentation. Those processes result in the release into the air of VOCs, including fatty acids, alcohols and aromatic ring compounds containing carbon, sulfur and/or nitrogen.[32,33,34,35]

Dust emissions from cattle feedlots have also been an increasing concern for rural communities.[36] Dust concentrations can cause limited visibility on public roadways. Although feedlot dust has not been associated with an increased incidence of vehicle collisions overall, the risk continues to be a concern. This is especially true for feedlots located on the prevailing, windward side of high-traffic roadways. A recent chain-reaction motor vehicle accident in Nebraska with multiple fatalities was attributed to feedlot dust blowing across a road.[37] Feedlot dust concentrations are usually highest in the early evening and lowest in the early morning.[23] Odor intensity measured as dilutions to threshold (DT), appears to increase with increasing dust concentrations.[38] Published 24-hour averaged dust concentrations of PM_{10} and total suspended particulate (TSP) immediately downwind of cattle feedlot corrals have approached 1,200 and 430 micrograms per cubic meter for TSP and PM_{10} respectively, as reconstructed from sequential, short-term (3 to 6 hour) monitoring data.[38] Absolute PM_{10} concentrations and therefore compliance with National Ambient air Quality Standards for PM_{10} depended heavily on which monitoring instrument was used.[21]

Odors clearly have important effects on humans. For example, results from recent studies using imaging of the brain indicate that odors have the ability to influence emotion.[39] The study of human reactions to odors is complicated by the large variation between individuals in the ability to perceive odors.[40] Also, persons who describe themselves as having heightened sensitivity to odors may not have enhanced ability to detect and identify odors but rather report more negative symptoms when exposed to odors they find unpleasant.[41] They may state that their ability to breathe is affected by certain odors, but it has been difficult to document objective negative effects on lung function from offensive odors.[42,43] Odors are described either in terms of concentration, offensiveness or hedonic tone.[44,45] Thus, there are a number of variables to be considered when determining the impact of the presence of livestock odors.

Quantifying livestock odors in a reproducible, technically feasible way has proven to be difficult. Investigators have worked to quantify odors from livestock facilities as a first step toward controlling them, using both trained panelists (e.g., dynamic, forced-choice olfactometry) and electronic odor sensors.[46,47] At this point, olfactometry is still the gold standard in odor assessment although newer methods show promise.[48]

STUDIES ON HEALTH EFFECTS IN CAFO NEIGHBORS FROM INHALATION EXPOSURES

The effect of feedlot dust on rural communities has not been extensively studied although it has been a source of complaints voiced at community meetings and to local health departments. Communities have also responded negatively to a variety of odor sources, both agricultural and industrial as well as those related to municipal activities such as sewage treatment.[49] Some CAFO neighbors allege that odors from feedlots and hog barns represent a risk to human health. While it is clear that many persons consider these odors to be unpleasant, the health implications of this exposure are not yet fully understood.

A small number of studies have been published that specifically address other human health effects of living near large hog confinement facilities. The first of these papers describes the findings of Schiffman and colleagues, who studied 44 neighbors of large-scale hog operations in North Carolina using the Profile of Mood States psychological testing tool. Results from testing the hog-farm neighbors were compared to findings from a group of rural residents who did not live near hog confinement facilities.[50] Persons living near the swine operations reported significantly more tension, depression, and anger than did the control subjects. They also reported less vigor, more fatigue and more confusion. The authors concluded that these differences could be explained by neighborhood exposure to hog odors, although they did not measure actual exposures or estimate the likelihood of exposure as a function of distance and direction from the hog confinement facilities.

Thu, Donham and colleagues conducted a study of 18 Iowa residents living within a 2-mile radius of a 4,000-sow hog confinement facility. These rural residents were compared to a group of demographically similar rural residents who did not live near large livestock facilities.[51] Measurements consisted of self-reported symptom histories. Their findings included several clusters of symptoms more commonly in the confinement facility neighbors than in rural residents who did not live near hog confinement facilities. The authors divided the symptoms into clusters as follows: Cluster 1 symptoms included sputum, cough, shortness of breath, chest tightness and wheezing; Cluster 2 complaints were nausea, dizziness, weakness and fainting; Cluster 3 consisted of headaches and plugged ears; Cluster 4 included runny nose, scratchy throat and burning eyes; and "other" symptoms were muscle aches, hearing problems, skin rash and fever. Cluster 1, 2 and 3 symptoms were statistically more common in hog facility neighbors than in control subjects. Cluster 4 symptoms were reported by more hog farm neighbors than control residents ($p = .12$) but the difference between the two groups was not as great as for Cluster 1-3. Symptoms in the "other" category were not more common in hog farm neighbors. A medical assessment was not done to look for objective physiologic measures of ill health in either population. Questionnaires were administered to look for evidence of depression and anxiety. Both the hog confinement neighbor and comparison populations scored in the normal range on the depression and anxiety surveys.

Wing and Wolf surveyed several rural communities, one of which was near a 6000 head hog operation and two of which were near large dairy operations.[30] Another community studied was near no large livestock farms. The 155 participants were not told that the reason for the survey was concern over the health effects of living near large-scale livestock facilities. Symptoms that were significantly increased in persons living near the hog operations included the following: headaches, runny noses, sore throats, excessive coughing, fatigue, diarrhea and burning eyes. Quality of life, as measured by the number of days residents were not willing to open their windows or go outside in pleasant weather, was significantly reduced in those who lived near a hog operation compared to both of the other groups. As with the other studies, the authors did not conduct a physical assessment of the subjects or perform exposure monitoring to corroborate their findings.

In summary, there is evidence from a small number of published research studies that people living in the neighborhood of large-scale hog facilities are more likely to have a variety of medical complaints. These complaints range from respiratory problems to burning eyes, sore throats, nausea and diarrhea, fatigue, headaches and plugged ears. Some but not all of these symptoms are like those of the hog confinement workers, who receive a much more intense exposure to the dust and odors associated with this industry. At this time, there are no published studies in which scientists have attempted to find exposure-corroborated, physiologic evidence of negative health effects in populations of neighbors of hog facilities. Neither healthy subjects, nor potentially more vulnerable subjects such as asthmatics or persons with chronic obstructive pulmonary disease, have been assessed in this way. It is conceivable that odors from CAFOs could worsen their symptoms and lung function, but this has not been demonstrated. Psychological symptoms, including tension, depression and anger were more common in hog facility neighbors studied by the group of researchers that looked at psychological aspects of the neighborhood health issue. Quality of life does appear to be affected by the presence of the unpleasant odors associated with this industry.

RESPIRATORY HEALTH IN HOG CONFINEMENT BARN WORKERS

Studying worker health effects can be useful for developing a better understanding of the respiratory conditions for which the CAFO neighbors might be at risk. One can expect the workers' exposures to be similar in terms of the substances inhaled but much more intense than that of the neighbors. Therefore, studying the workers can contribute to the understanding of potential health effects in CAFO neighbors. However, the healthy worker survivor effect is likely a factor in this environment.[52] This effect could indirectly cause the health effects on neighbors to be underestimated. Specifically, vulnerable groups such as children or anyone with underlying cardiopulmonary disease could be more severely affected than workers that are healthy and who have demonstrated their ability to tolerate this environment. Also, there is evidence that exposure to this environment results in an adaptation to the inflammatory response by the chronically exposed worker.[12,53] It is unclear how the adaptation phenomenon applies to the understanding of the neighborhood effect.

Health effects of working in the hog confinement barn have been studied extensively by investigators in North America and in Europe using symptom surveys and lung function testing.[8,9,54-70] It has been known for some time that working in hog confinement facilities causes chronic or intermittent lower respiratory tract symptoms in approximately one-third of workers. These respiratory symptoms consist of cough with or without production of phlegm, chest tightness, wheezing and shortness of breath with heavy exertion. Depending on the constellation of symptoms displayed and the results of pulmonary function testing, the worker may suffer from chronic bronchitis, the asthma-like syndrome, or exacerbation of preexisting asthma.[71] Rarely, a true allergy to hogs develops in the workers. This hog allergy can be associated with allergic asthma.[11,72] It is said that exacerbation of underlying asthma can also occur secondary to hog barn exposures, although the extent of this problem is not well documented. The respiratory impairment directly attributable to this work is usually not severe if the workers suffer from the asthma-like syndrome or chronic bronchitis. However, lung function test values below the normal range are commonly seen in workers with respiratory complaints. Even a small decrease in lung function can result in shortness of breath with exertion in workers who perform heavy physical labor.

Hog confinement workers who smoke cigarettes are at risk for developing changes in measures of lung function at lower exposure thresholds than nonsmokers.[7] Some of those workers, including persons without a history of cigarette smoking, meet the criteria for chronic obstructive pulmonary disease, which is commonly known as COPD.[73] Approximately 6% of the U.S. population suffers from chronic obstructive pulmonary disease, the term used to describe emphysema and chronic bronchitis.[74] The majority of this disease burden is attributed to cigarette smoking, but occupational factors, including agricultural exposures, are also important.[75]

Nasal symptoms are also common in swine confinement workers. Up to 74% of workers have been described as reporting nasal stuffiness, sinusitis symptoms and other nasal complaints.[54] Olfactory function defined as the ability to recognize odors using a scratch-and-sniff odor identification tool, was described as being compromised in women, but not in men, who work in hog confinement barns in a recently published study.[76] Other evidence of impairment in nasal function has not been identified in persons who work in this setting. However, neutrophilic nasal inflammation has been documented in normal volunteers exposed to the swine confinement barn. Interestingly, there is evidence for adaptation of the nose over time to these exposures.[53] Burning of the eyes and a sore throat are also reported by some workers. The constellation of nasal, eye and throat symptoms are known as the mucous membrane irritation syndrome.

A number of other health problems are associated with work in hog confinement barns. Some workers develop a flu-like illness called organic dust toxic syndrome (ODTS) from heavy exposure to organic dust in their work.[69,77] Symptoms of ODTS include fever, chills, headache, muscle aches, malaise, fatigue and dry cough. This illness usually lasts for several days and is rarely life threatening. There is evidence that having had ODTS makes people more sensitive to having respiratory symptoms such as cough and chest tightness with subsequent exposures to organic dust such as grain dust or hog dust and that it contributes to the presence of chronic bronchitis.[68,78]

Hydrogen sulfide is a gas that has the odor of rotten eggs and is present in low amounts in the hog barns under ordinary conditions. When amounts of H_2S rise to very high levels secondary to agitation of a manure pit under the floor of the barn, inhalation of this gas can be fatal to workers.[79] Reactive airways dysfunction syndrome, a form of occupational asthma, has been described in a hog confinement worker after exposure to a high level of H_2S.[13] Inhalation of low amounts of hydrogen sulfide by workers has not been shown to be associated with respiratory effects.[7] Interestingly, a recent study has suggested that communities presumably exposed to long-term, low-level H_2S from industrial sources might be at increased risk of respiratory and central nervous system complaints.[80]

In conclusion, hog confinement workers clearly are at risk of developing chronic or intermittent respiratory disorders. While these disorders are not usually life-threatening, they can interfere with their ability to perform their work and may be reason for workers to leave the industry. The substances that cause these problems include hog dust, endotoxin and NH_3. Hydrogen sulfide, while quite malodorous, has not been conclusively associated with the presence of chronic respiratory disease in workers or the public although it causes death from acute, high-level exposures.

RESPIRATORY HEALTH IN CATTLE FEEDLOT WORKERS

A limited amount of information has been published about occupational health problems in cattle feedlot workers.[12,81] The information available at this time about worker health pertains mainly to non-respiratory problems and does not contribute to the understanding of health concerns of feedlot neighbors. Studying the workers' respiratory health status may provide an opportunity for better understanding the potential health effects of the dust from these feedlots.

FUTURE DIRECTIONS

Our understanding of how many persons living near hog confinement operations or cattle feedlots consider their health to be negatively impacted or who have changes in their health status that can be quantified by physiological testing is still quite limited. There is an urgent need to document the health status of subjects in larger samples of hog confinement facility and cattle feedlot neighbors and to make careful comparisons with rural residents who do not live near such facilities. Such research projects should use objective measures of health as well as subjective information obtained by asking persons about symptoms of illness. Moreover, it is essential to compare the prevalence of symptoms and signs of human illness with accepted measures of actual exposures to specific air pollutants made in the neighborhood. Until this research has been done, we will not have a true understanding of the human health implications of constructing more hog confinement facilities, cattle feedlots or other CAFOs. Also, we will not know how to monitor existing CAFOs to assess their potential for causing human illness in the neighborhood.

These studies represent a very important step in addressing the neighborhood health effects aspect of the CAFO debate. However, much more work remains to be done before there are enough data about the human health neighborhood effect of large-scale hog and cattle facilities in order to draw firm conclusions that could have a permanent impact on the industry, its neighbors and its stakeholders.

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School Proximity to Concentrated Animal Feeding Operations and Prevalence of Asthma in Students*

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Study objectives: **Asthma prevalence and severity are rising in industrialized nations. Studies supporting the hygiene hypothesis suggest that being raised on a farm protects against atopy and, often, asthma. In rural United States, however, an increased rate of asthma has been found among schoolchildren. We hypothesized that the rural US environment may not be protective against airway inflammation, perhaps due to environmental effluents from a relatively high number of concentrated animal feeding operations (CAFOs). We compared the prevalence of asthma in two Iowa elementary schools, one adjacent to a CAFO, and the other distant from any large-scale farming operations.**

Design: **Cross-sectional questionnaire-based study.**

Setting: **Two rural Iowa elementary schools: the study school is located one-half mile from a CAFO, and the control school is distant from any large-scale agricultural operation.**

Participants: **Children, kindergarten through grade 5, who attended either the study school or the control school.**

Results: **Children in the study school had a significantly increased prevalence of physician-diagnosed asthma (adjusted odds ratio, 5.71; p = 0.004). Although this group was more likely to live on a farm and have parents who smoke, these potentially confounding variables did not account for increased prevalence in a multivariate model. No difference in measures of asthma severity was found between the two populations. Because different sets of physicians are responsible for the medical care of the groups of children, it is possible that physician bias is responsible for the different prevalence of asthma diagnoses. This was not explored in the study.**

Conclusions: **This study supports a role for exposure to rural environmental toxicants in the etiology of asthma, and suggests a need for further study of this relationship.**

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Key words: environmental air pollutants; pediatrics; rural health

Abbreviations: CAFO = concentrated animal feeding operation; ED = emergency department; OR = odds ratio

Asthma results from complex interactions between genetic predisposition and environmental influences.[1] Its prevalence has increased in industrialized nations over the past several decades despite improved medical care and living conditions.[2] Although environmental pollution has been linked to asthma exacerbations, asthma prevalence does not correlate well with measures of air quality. Other proposed etiologic factors include environmental tobacco smoke, airtight buildings, declines in breast feeding,

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increased obesity, and reduced fitness[3–7]; none of these hypotheses completely explains the current trends in asthma prevalence. An important alternative theory, the hygiene hypothesis, postulates that increasing asthma and atopy may result from decreased childhood exposure to infections and microbial products. These exposures promote immune responses that can down-regulate the T-helper type 2 immune pattern associated with asthma and atopy.[8] Since exposure to microbial products appears to offer some protection against asthma and atopy, it is reasonable that childhood exposure to a microbe-laden agricultural environment may offer similar benefit. Indeed, numerous studies have shown that children raised in a farm environment,[9–13] as well as farmers who enter agriculture as adults,[14] are relatively protected from asthma and atopy. In the United States, however, this protective effect of an agricultural environment has not been observed; indeed, in some cases, the opposite seems to be the case. A study[15] of a rural community in Iowa found a significantly higher rate of childhood asthma than the national average.

There are a number of characteristics of farms in the United States, and in Iowa in particular, that distinguish them from those in Europe and elsewhere. Iowa is one of the largest hog producers in the world, and most hogs are reared in large-scale "factory farms" or concentrated animal feeding operations (CAFOs) that house large numbers of animals (> 3,500) in high density. Operations of this type release multiple irritant and inflammatory substances that can adversely affect the health of workers as well as the air quality in surrounding communities.[16–18] This raises the possibility of a causal relationship between CAFOs and increased rates of asthma among children in rural environments. To evaluate the hypothesis that childhood exposure to effluents from CAFOs may promote airways disease and symptoms, we surveyed students from two elementary schools in rural Iowa, one located in proximity to a CAFO, and the other distant from any large-scale animal farming operation, regarding their prevalence of asthma and airway symptoms.

Materials and Methods

Study Design

This cross sectional study was designed to assess whether location of an elementary school in the vicinity of a CAFO is associated with higher rates of asthma. The study was reviewed and approved by the Institutional Review Board of the University of Iowa, as well as by officials of both school districts participating in the study. Parents of all participants, who included students in kindergarten through fifth grade in participating schools, were contacted by mail and asked to fill out a questionnaire. Nonresponders were telephoned up to three times to request participation. Data collection was performed between February and June 2003.

Study Location

Two schools in rural areas of Iowa were selected. The study school is located in Northeast Iowa approximately one-half mile from a CAFO that houses approximately 3,800 hogs. The control school is located in East Central Iowa, > 10 miles away from any CAFO.

Questionnaire

The questionnaire had 20 items (available as on-line Appendix). Two questions involved the location of the primary residence (rural vs town) and whether the participant is currently living on a farm. Eight items were adapted from the International Study on Asthma and Allergies in Children[19] and relate to frequency of asthma symptoms, nighttime and exercise symptoms, and medication use. The remainder covered asthma-related issues such as activity limitation, urgent-care utilization, and frequency of rescue inhaler use. A similar questionnaire has been used and validated in a study[15] on rural school children in Iowa.

Diagnosis of Asthma

Three items on the questionnaire were used to determine whether the child had asthma: item 3 ("Has a doctor ever told you that your child has asthma?"); item 5 ("Has your child had wheezing or whistling in the chest in the last 12 months?"); or item 7 ("Has your child used medication for his or her wheezing in the last 12 months?").

Statistics and Data Analysis

This was a cross-sectional study assessing the prevalence of asthma diagnosis, symptoms, and risk factors. The χ^2 test was used to evaluate differences between variables with a dichotomous outcome. For continuous variables, we utilized a *t* test. A multivariate logistic regression model was fitted to analyze possible interactions between variables and the association between the outcome (asthma) and other variables. The dependent variable in the multivariate regression model was physician-diagnosed asthma. Variables, other than the primary outcome of interest, were included in the model if they were considered to have a plausible causal relationship with asthma (*eg*, tobacco smoke exposure, farm rural residence, and pet ownership). Significance levels were set at $p < 0.05$. Statistical analysis was accomplished using statistical software (version 8; SAS Institute; Cary, NC).

Results

Study Population

The study school serves 116 students in kindergarten through grade 5; the control school serves 456 students in kindergarten through grade 5. Mean age is higher in the study school: 9.5 years vs 8.7 years. Children in the study school were more likely to live in a rural area and on a farm, have smoking parents, and have a pet cat. Gender distribution was similar between the two schools. Individual family income levels were not assessed in this study, but mean yearly income is very similar in both locations according to US Census Bureau 2004 data[20]; racial and ethnic makeup differs slightly: the population in the area of the study school is 97% white, while the population in the area of the control school is 90% white. Study population characteristics are outlined in Table 1. Response rates were similar in the two schools: 61 participants (52.6%) responded from the study school, and 248 participants (54.4%) responded from the control school. Nine participants (7.8%) from the study school and 32 participants (7.0%) from the control school requested not to be included in the study.

Prevalence of Asthma

A significant difference in the prevalence of physician-diagnosed asthma was found between the two schools: 12 children (19.7%) from the study school and 18 children (7.3%) from the control school gave a history of physician-diagnosed asthma (odds ratio [OR], 5.60; p = 0.0085). Although the diagnosis of asthma was more common among students in the study school, medication use and emergency department (ED) visits did not significantly differ between the two groups (Table 2). Eighteen percent of children from the study school but only 9.7% of children from the control school reported wheezing in the past year, which nearly reached statistical significance (p = 0.07). Using the broadest definition of asthma (physician diagnosis, asthma-like symptoms, or asthma medication use), the prevalence of asthma in the study school remained significantly greater than that in the control school (study school, 24.6%; control school, 11.7%; p = 0.0412). When analyzed in a multivariate model that included smoking status, pet ownership, age, and residence in a rural area or on a farm, the positive association between the study school and physician-diagnosed asthma remained (adjusted OR, 5.719; p = 0.0035) [Table 3]. Using multivariate analysis, the secondary outcomes of asthma severity and alternative asthma definitions did not show increased levels of statistical significance.

Table 1—*Characteristics of Study and Control Populations**

Variables	Study School	Control School	p Value
Response rate	61 (52.6)	248 (54.4)	NS
Refused to participate	9 (7.8)	32 (7.0)	NS
Mean age, yr	9.5	8.7	0.05
Male gender	32 (52.5)	134 (54.0)	NS
Live in rural area, %	90.4	73.4	< 0.05
Living on a farm, %	63.5	6.8	< 0.0001
Parents smoking, %	28.9	14.9	< 0.05
Cat in the home, %	63.5	39.4	< 0.005
Dog in the home, %	71.2	57.2	NS

*Data are presented as No. (%) unless otherwise indicated. NS = not significant.

Table 2—*Prevalence of Asthma Diagnosis, Symptoms, and Exacerbations**

Variables	Study School (n = 61)	Control School (n = 248)	p Value, Univariate Analysis
Physician diagnosis of asthma	12 (19.7)	18 (7.3)	< 0.01
Whistling or wheezing (ever)	17 (27.9)	53 (21.4)	NS
Whistling or wheezing (past year)	11 (18.0)	24 (9.7)	0.07
Active inhaler medication use	8 (13.1)	22 (8.9)	NS
Asthma (by any of three criteria)†	15 (24.6)	29 (11.7)	< 0.05
ED visits in past year	2 (3.27)	7 (2.8)	NS

*Data are presented as No. (%). See Table 1 for expansion of abbreviation.

†Physician diagnosis, wheezing in past year, or active inhaler medication use.

Asthma and Household Variables

A univariate analysis showed a significant association between currently smoking parents and a diagnosis of asthma (p = 0.0486; Table 4). This association disappeared in the multivariate model (Table 3). Smoking was significantly less common in the rural population (rural, 14%; vs nonrural, 30%; p = 0.0044). No association was found between asthma and pet (cat or dog) ownership. Living in a rural area or on a farm did not alter the risk of asthma in this study (Table 4). A subgroup analysis of all the asthmatics (n = 30) showed no difference in parental smoking rates between asthmatics from the two schools, but parental smoking rates were significantly higher in asthmatics compared with nonasthmatic children (33.3% vs 16.1%) [Table 4].

Severity of Asthma Was Not Different in the Two Populations

When comparing the two populations of subjects with physician-diagnosed asthma, no difference was

Table 3—*Multivariate Model of Factors Potentially Associated With Asthma Prevalence*

Variables	OR	95% Confidence Interval	p Value
School*	5.72	1.776–18.422	0.0035
Living in rural area	0.67	0.223–2.035	0.4832
Living on a farm	3.99	0.905–17.597	0.0676
Parents smoking	1.77	0.602–5.205	0.2997
Cat in the home	0.84	0.546–1.291	0.4261
Dog in the home	0.88	0.556–1.405	0.6011

*OR for control school as reference point.

Table 4—*Relationship Between Physician-Diagnosed Asthma and Household Variables**

Variables	Asthma (n = 30)	No Asthma (n = 279)	p Value, Univariate Analysis
Parents smoking	10 (33.3)	45 (16.1)	0.049
Rural residence	22 (73.3)	215 (77.1)	NS
Living on a farm	5 (16.7)	51 (18.3)	NS
Cat in the home	12 (40)	124 (44.4)	NS
Dog in the home	16 (60.0)	169 (60.1)	NS

*Data are presented as No. (%). See Table 1 for expansion of abbreviation.

seen in severity of symptoms as measured by frequency of asthma attacks, asthma-related sleep disturbance, visits to the ED, limitations on activity, and the use of rescue inhalers (Table 5).

Discussion

A significant difference was found in the prevalence of physician-diagnosed asthma among students in the two schools studied. In the study school, located near a CAFO, the asthma prevalence was quite high, 19.7%, approaching the prevalence of asthma reported among inner-city socioeconomically disadvantaged children.[21] The prevalence in the control school was 7.3%, which is quite close to the overall rate reported for Iowa of 6.7%.[22] The presence of asthma was significantly related to parental smoking in a univariate analysis, which is not surprising because environmental tobacco smoke is known as a risk factor for asthma in children and adults.[23–25] Smoking was more common among parents in the study population, but the significance of parental smoking disappeared in a multivariate model taking into account pet ownership, age, and residence in a rural area or on a farm; in this analysis, smoking did not affect the positive association between physician-diagnosed asthma and the study population. Limitation of activity and disturbed sleep due to asthma symptoms were quite common in asthmatic children from both schools, possibly suggesting inadequate asthma control, but there was no significant difference in markers of severity between the groups. There was no connection between pet ownership and asthma, in contrast to other studies[26] that have found early-life pet exposure protective. Living in a rural area was neither a risk factor nor protective in our study in contrast to previous studies[9,13] showing a potential benefit. Living on a farm approached statistical significance as a risk factor for asthma (OR, 3.99; p = 0.068). As the majority of the children in the study population lived on a farm, this cannot be excluded as a significant factor.

Table 5—*Severity of Symptoms**

Variables	Study School (n = 12)	Control School (n = 18)	p Value
Limitations on activity	5 (41.7)	8 (44.4)	NS
Four or more asthma attacks in past year	2 (16.7)	4 (22.2)	NS
Sleep disturbed by asthma	4 (33.3)	5 (27.8)	NS
Visits to an ED in past 12 mo	1 (8.3)	2 (11.1)	NS
Rescue inhaler use three or more times a month	7 (58.3)	7 (38.9)	NS
One or more of above items	8 (66.7)	10 (55.6)	NS

*Data are presented as No. (%). See Table 1 for expansion of abbreviation.

Our study has several limitations. First is the relatively low response rate: only slightly over half of eligible participants participated in the study, leading to a potential for selection bias. However, the response rates were similar in both populations, thus likely minimizing the effect of such a bias on study results. Second, our definition of asthma includes reporting of physician-diagnosed asthma, raising a potential for recall bias. Participants were not informed of our hypothesis, however, and were not aware whether they were in the study or comparison group, making this less likely. Furthermore, since different physicians provide medical care for children who attend the two schools, one of the groups may have been more or less likely to receive a diagnosis of asthma for similar symptoms. Addressing the diagnostic criteria for asthma among the physicians in these communities was outside the scope of this study, but would be an important aspect of future studies; we have previously shown[27] that understanding of the National Heart, Lung, and Blood Institute guidelines and diagnostic criteria can vary widely, even among asthma specialists. Third, smoking rates were different among parents in the two populations compared. However, although smoking prevalence in general is higher among parents of the study students, using a multivariate model that included parental smoking did not decrease the significantly different asthma prevalence rates in the study and the control school. Finally, it is possible that the socioeconomic background of children differ between the two schools. The study population is predominantly rural with a large farming community, while the control population is more diverse. The US Census Bureau shows similar income levels on a community basis, but we have no data on the household incomes for participants in this study.

Environmental pollution from CAFOs consists of a mixture of organic dust and chemicals including

NH_3 and H_2S. Swine dust, endotoxin, and endotoxin-laden grain dust with and without ammonia have been shown to be a respiratory irritant in numerous exposure studies.[28–31] Furthermore epidemiologic studies[32] have shown that exposure to swine dust causes decline in pulmonary function over time. Although exposure to allergens, endotoxin, and other bioproducts may potentially have a beneficial effect on the developing immune system, protecting from the development of asthma and allergies, exposure to the complex mixture of airborne pollutants emanating from CAFOs, sometimes in high concentrations,[16] may have a detrimental effect.

The difference in asthma prevalence that we found in this cross-sectional study of two schools may be linked to multiple factors, including socioeconomics, different medical practices, and household smoking patterns. Although each of these factors could play a role, it is impossible to exclude a role for environmental factors, such as the proximity of the school to CAFOs and exposures generated by family farms, on the profound difference in asthma rates. Our findings are similar to those of Chrischilles et al,[15] who found a significantly increased asthma prevalence in a rural population of Iowa children. The hypothesis that CAFOs contribute to environmental pollution adversely affecting respiratory health in young children needs to be further explored. A prospective study in which concentrations of environmental pollutants are correlated with airway symptoms and physiologic measures in exposed children will be important to follow up these findings.

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