Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions

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A scientific conference and workshop was held March 2004 in Iowa City, Iowa, that brought together environmental scientists from North America and Europe to address major environmental health issues associated with concentrated animal feeding operations (CAFOs) in large, industrialized livestock production facilities. After one and a half days of plenary sessions, five expert workgroups convened to consider the most relevant research areas, including respiratory health effects, modeling and monitoring of air toxics, water quality issues, influenza pandemics and antibiotic resistance, and community health and socioeconomic issues. The workgroup reports that follow outline the state of the science and public health concerns relating to livestock production as they apply to each workgroup topic. The reports also identify areas in which further research is needed and suggest opportunities to translate science to policy initiatives that would effect improvements in public and environmental health. Viable solutions to some of the current environmental health problems associated with CAFOs are outlined. In addition, these reports bring to light several major concerns, including air and water contamination, the rise of antibiotic-resistant bacteria in livestock, and the specter of influenza outbreaks arising from siting industrialized poultry and swine production in proximity to each other and to humans. ***Key words:*** **air quality, animal confinements, antibiotic resistance, antimicrobial growth promotants, avian influenza, bioaerosols, livestock, poultry, swine, water quality.** ***Environ Health Perspect*** **115:296–297 (2007). doi:10.1289/ehp.8831 available via** ***http://dx.doi.org/*** [Online 14 November 2006]

Dramatic changes in livestock production have occurred over the past two decades. The trend in swine, poultry, and cattle operations has been toward fewer but increasingly larger operations. Traditional crop–livestock farms were balanced in that livestock manure supplied nutrients to grow the crops to feed those livestock. Farmers raised the quantity of livestock their croplands could support. Industrialized livestock production requires drawing feed from a wide area, often far away, whereas manure is distributed to a small, local landmass resulting in soil accumulation and runoff of phosphorus, nitrogen, and other pollutants (Iowa State University and University of Iowa Study Group 2002). The consolidation of the livestock industry has been observed throughout North America and Europe and has led to calls for increased regulation to reduce and control the wastes. The state of Iowa, which produces one-fourth of U.S. pork, exemplifies this trend. The number of farms in Iowa raising hogs decreased from 64,000 in 1980 to 10,500 in 2000—an 84% decrease—while the average number of hogs per farm increased from 250 to 1,430 over this same period (Otto and Lawrence 2000). Farms with more than 500 hogs now account for 65% of the statewide inventory and 75% of the U.S. inventory.

The results of the increasing intensity of livestock operations have been regionally higher levels of air contaminants and increased problems with contamination of surface waters with animal waste. Management practices such as feeding animals with antimicrobial growth promotants and housing poultry and swine in proximity are additional concerns. Fears of the communities and neighbors concerning potential adverse human health effects have increased, leading to the formation of citizen action groups in many locales. These groups have lobbied government officials at the local and regional levels to promulgate and enforce regulations to reduce environmental impacts and health hazards from nearby concentrated animal feeding operations (CAFO). A town meeting sponsored by the National Institute of Environmental Health Sciences (Research Triangle Park, NC) and the University of Iowa, Environmental Health Sciences Research Center (EHSRC), was held in Des Moines, Iowa, in 2001 to bring stakeholders together to seek common ground. This town meeting gave producers, concerned citizens, and regulators the opportunity to discuss the issues. Many areas of discord were identified, and a need for better translation of science to policy was recognized.

Findings from the 2001 town meeting prompted the EHSRC to organize the scientific conference and workshop "Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions" held March 2004 in Iowa City, Iowa, which brought together experts in environmental science from the United States, Canada, Sweden, Denmark, and the Netherlands to address major environmental health issues associated with CAFOs. The conference audience comprised scientists, agriculturalists, producer group representatives, environmental and community activists, government officials, and rural residents. Five workgroups of scientists convened to consider further the major topics and identify the state of the science. Their reports make up this mini-monograph. These reports outline the scientific issues and public health concerns relating to livestock production as it applies to each workgroup topic and identify areas in which further research is needed. They also suggest opportunities to translate science to policy initiatives that would advance public and environmental health.

Summary of Workshop Recommendations

The Workgroup on Health Effects of Airborne Exposures from CAFOs found a lack of data on the health effects of odors and complex mixtures emanating from CAFOs (Heederik et al. 2006). They also identified a need for research on susceptibility of people for ill health from CAFO exposures on the basis of age, gender, or genetic makeup. This workgroup expressed the view that international harmonization is needed for analytical methods for exposure assessment of biological agents such as bacterial endotoxin, fungal glucan, and other pathogen-associated molecular patterns. Additionally, they noted that recent advances have identified less invasive approaches for collection of body fluids from which more sensitive biomarkers of response can be measured. They recommended that panel studies be performed among susceptible populations exposed to CAFO emissions, as this approach is most effective for determining responsible agents and disease mechanisms. In terms of science translation to policy, they recommended that best practices for occupational hygiene be promoted for the livestock industry and that exposure standards for organic dust, biological agents, and toxic gases should be promulgated and enforced across the industry.

This article is part of the mini-monograph "Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions."

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The author thanks S. Kaliszewski, R. Ungar, J. Cook, and L. McCormick for handling the numerous arrangements for the conference and N. Newkirk for organizing and editing the workgroup reports in this mini-monograph.

This workshop was supported by grant P30 ES05605-14S from the Environmental Health Sciences Research Center at The University of Iowa and the National Institute of Environmental Health Sciences.

The authors declare they have no competing financial interests.

Received 9 November 2005; accepted 13 November 2006.

The Workgroup on Modeling and Monitoring of Emissions from CAFOs noted that the downstream concentrations of airborne effluents from CAFOs are not well understood (Bunton et al. 2006). They recommended establishment of monitoring networks for hydrogen sulfide and ammonia using many low-cost passive monitors and a lesser number of expensive realtime monitors. Some monitors should be located in relatively pristine areas away from livestock operations in order to characterize background levels in rural areas. There is a further need for particulate monitoring accompanied by analysis of adsorbed malodorous vapors and gases, since these appear to travel up to a kilometer from the source. This workgroup found that additional studies should seek to identify links between specific agents ascribed to CAFO emissions and health outcomes in the rural community. In terms of modeling fate and transport from livestock operations, the workgroup found that additional data are needed on emission rates from manure storage tanks or lagoons, land-applied manure, and livestock buildings that are tied to animal inventories and management practices. The workgroup determined that modeling has advanced as a science and should be better utilized for decisions on permitting, siting, and waste management of CAFOs. Further refinements should include models that account for chemical transformation of effluents and models that provide long-term concentration distributions at a regional level.

The Workgroup on Impacts of CAFOs on Water Quality listed several priority research areas, including monitoring of whole watersheds in order to understand the effects of extreme events on ecosystem health, toxicologic assessment of water contaminants from CAFOs, and studies of primary effluents and metabolites in soils, sediments and water (Burkholder et al. 2006). This workgroup recommended surveillance programs for rural private well water in areas at high risk for contamination. They suggested that effective waste and wastewater treatment practices known for managing human wastes, augmented with emerging technologies, should be translated into practice to prevent consumption of emerging contaminants such as veterinary pharmaceuticals (including antibiotics and anabolic hormones). The workgroup identified a need for implementation of best management practices through education and regulation to reduce release of CAFO contaminants into surface waters and aquifers.

The Workgroup on The Potential Role of CAFOs in Infectious Disease Epidemics and Antibiotic Resistance raised concerns about the practice of co-locating swine and poultry facilities and the specter of a global pandemic arising from new strains of avian influenza incubated in swine and transmitted to humans (Gilchrist et al. 2006). They recommended that minimum separation distances should be established and that animals should not be fed tissues, fecal matter, or contaminated water from other animals. This workgroup stated that solid tanks for storage of manure and municipal style waste treatment are necessary to limit microbial contamination of soil and water, prevent access to waterfowl, and limit the spread of disease. The workgroup strongly endorsed phasing out the use of antimicrobial agents as growth promotants in the United States, as is happening in the European Union and was called for by the World Health Organization and dozens of scientific and medical organizations. One complication is a difference between the United States and the European Union animal industries' interpretation of the terms "growth promoter" and "therapeutic use." In the United States some routine, nontherapeutic uses of antibiotics are not considered to be growth promotion, whereas in the European Union, they are defined as such. At the time Denmark phased out antibiotic use for animal growth promotion, all remaining antibiotic uses with animals were administered by prescription only. This phase-out resulted in an overall drop in antibiotic use of about 54%. On the other hand, the U.S.-based Animal Health Institute, which respresents pharmaceutical manufacturers, has in the past stated that only about 13% of antibiotic use in U.S. animal production is for growth promotion, and that 87% is for therapeutic use, and almost all U.S. antibiotics used in animal production are available over-the-counter. This differentiation is important, as a phase-out of antibiotics used for growth promotion as defined in the United States would likely result in a much smaller reduction (13%) than the phase-out of growth promotion in Denmark (54%), given that Denmark's numbers include some antibiotics administered routinely for disease prevention or therapy. The workgroup identified a need to establish national surveillance programs to track the transmission of antimicrobial-resistant organisms from livestock to humans and to identify ecologic reservoirs and impacts. Fingerprinting of antibiotic-resistant bacteria is a necessary component and will allow characterization of changes in resistance profiles over time.

The Workgroup on Community Health and Socioeconomic Issues Surrounding CAFOs considered the impacts of industrialization of livestock production on rural communities in terms of economics, social capital and quality of life (Donham et al. 2006). They recommended comprehensive community health studies comparing physical, mental and social health outcomes, and economic conditions in comparable communities with and without large livestock operations. This workgroup noted that much of the research funding for agriculture is directed toward nonsustainable production and recommended that funds be reoriented to sustainable systems. The workgroup concurred that there is sufficient information on the hazards of CAFOs to communities that a more measured approach to siting and permitting of facilities and waste management is needed and that permits should consider watershed level animal density and dispersion of airshed emissions. Decisions concerning the issuance of permits should also include greater involvement of communities through public hearings and open meetings. The workgroup suggested that permits for manure storage reservoirs should require bonding to ensure that spills will be cleaned up and manure lagoons will be decommissioned rather than abandoned, should the producer become insolvent.

There was general agreement among all workgroups that the industrialization of livestock production over the past three decades has not been accompanied by commensurate modernization of regulations to protect the health of the public, or natural public-trust resources, particularly in the United States. Even though the European Union has made greater strides, there is room for improvements in the control of air and water pollutants from CAFOs in Europe as well as the United States. Expansion of large CAFOs into central and eastern Europe and South America is occurring without attention to lessons learned from health and environmental problems in the United States. and western Europe. Major concerns exist over the role of intensive livestock production in influenza outbreaks and the emergence of antibiotic resistant organisms. Recent attention to these risks among the scientific community, the public, and governments is encouraging.

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Health Effects of Airborne Exposures from Concentrated Animal Feeding Operations

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Toxic gases, vapors, and particles are emitted from concentrated animal feeding operations (CAFOs) into the general environment. These include ammonia, hydrogen sulfide, carbon dioxide, malodorous vapors, and particles contaminated with a wide range of microorganisms. Little is known about the health risks of exposure to these agents for people living in the surrounding areas. Malodor is one of the predominant concerns, and there is evidence that psychophysiologic changes may occur as a result of exposure to malodorous compounds. There is a paucity of data regarding community adverse health effects related to low-level gas and particulate emissions. Most information comes from studies among workers in CAFO installations. Research over the last decades has shown that microbial exposures, especially endotoxin exposure, are related to deleterious respiratory health effects, of which cross-shift lung function decline and accelerated decline over time are the most pronounced effects. Studies in naïve subjects and workers have shown respiratory inflammatory responses related to the microbial load. This working group, which was part of the Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions, concluded that there is a great need to evaluate health effects from exposures to the toxic gases, vapors, and particles emitted into the general environment by CAFOs. Research should focus not only on nuisance and odors but also on potential health effects from microbial exposures, concentrating on susceptible subgroups, especially asthmatic children and the elderly, since these exposures have been shown to be related to respiratory health effects among workers in CAFOs. ***Key words:*** **air quality, asthma, biological agents, endotoxin, inflammation, odor, poultry, swine.** ***Environ Health Perspect*** **115:298–302 (2007). doi:10.1289/ehp.8835 available via** ***http://dx.doi.org/*** **[Online 14 November 2006]**

Background and Recent Developments

Gases and vapors. A number of toxic gases and vapors are emitted by concentrated animal feeding operations (CAFOs) into the work and general environments. In particular, occupational studies have yielded information about exposure levels of ammonia (NH_3), hydrogen sulfide (H_2S), and carbon dioxide (CO_2). The characteristic odor of a CAFO is the result of a complex mixture of these gases and many volatile and semivolatile organic compounds. Odor emissions are especially associated with quality of life issues for exposed populations. Specific gases such as H_2S are being used as proxies to estimate or regulate exposure to the whole complex mixture. Although this approach has the advantage of simplicity and exposure estimates can be compared with guideline exposure values, it also has several limitations. Situations may arise where the surrogate compound does not co-vary with other toxicants in the mixture. The issue of which specific community health effects may result from CAFO emissions is open and controversial. There is limited evidence that symptom patterns may be the result of CAFO exposures in individuals living in their vicinity. Changes in immunoglobulin A responses have been observed in individuals and associated with exposure to odor, suggesting that psychophysiologic responses can occur (Avery et al. 2004). The underlying mechanistic explanation is that these physiologic changes are most likely stress related; however, other mechanisms including sensitization may also contribute.

Very little information exists about lung function changes among populations living in the vicinity of CAFOs. Emission studies, in combination with modeling approaches, are helpful but not sufficient to relate exposures to health effects because the exposure depends on personal activity patterns and time spent near different sources. A recent report from Germany found that people residing in proximity to many CAFOs (> 12 within a 500-m radius) experienced significantly increased prevalence of self-reported wheezing and decreased forced expiratory volume in 1 sec (FEV_1) indicative of inflammatory effects of CAFO emissions in the lungs (Radon et al. 2005). However, a problem with the interpretation is that clear differences existed in sensitization rates between rural participants and the urban comparison population. In addition, it can be expected that differences existed within the rural population associated with childhood exposure patterns to animals on these farms compared with those experienced with CAFOs. This raises methodologic issues regarding appropriate comparison populations and confounders or effect-modifying variables that need to be included in multiple regression models to make accurate comparisons. Nevertheless, the results from this study are of interest and similar studies need to be undertaken in other populations with more subjects living in proximity to CAFOs.

Most information on potential health effects comes from working populations. Gases seem to play a limited role in the explanation of work-related respiratory symptoms in CAFO workers, but this may not be true for humans living in the surrounding areas. The distribution of adverse effects by age is different, and susceptibility may be an important issue, with children and elderly individuals belonging to the most vulnerable populations. Also, socioeconomic relationships between workers and companies, as opposed to neighbors and companies, are different, and this will have an impact on the willingness to tolerate hazardous exposures, and bear an increased burden of ill health.

Exposure inside CAFOs. In early studies on respiratory health of CAFO workers, several constituents of dust have been considered. Exposure to allergens from pigs and storage mites has received some attention, but most studies have shown that sensitization rates to swine urine proteins among farmers are relatively low and cannot explain the high symptom rates in CAFO workers (Brouwer et al. 1990; Cormier et al. 1991; Crook et al. 1991;

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This workshop was supported by grant P30 ES05605-14S from the Environmental Health Sciences Research Center at The University of Iowa and the National Institute of Environmental Health Sciences.

The authors declare they have no competing financial interests.

Received 10 November 2005; accepted 13 November 2006.

Harries and Cromwell 1982; Katila et al. 1981). Similarly, responses against storage mites seem to be explained mainly by cross-reactivity to house dust mites.

Early studies have shown that the CAFO industry environment is rich in microbial life. Kiekhaefer et al. (1995) made detailed microbial characterizations of the environment in various types of CAFOs across seasons and showed that moderately elevated culturable mold levels exist with an overall mean concentration of 5.3×10^3 colony-forming units/m^3 and mean total organisms (orgs) concentrations of 1.1×10^8 orgs/m^3. The predominant fungal types were *Cladosporium* and *Alternaria* in the summer and fall and yeasts *Penicillium* and *Fusarium* in the winter and spring. Mainly gram-positive bacteria are found in CAFOs, but gram negatives play an important role as well. As a result, endotoxin levels are clearly elevated. Although microbial markers other than endotoxin have been associated with respiratory health and specific respiratory inflammation (Zhiping et al. 1996), endotoxin has been most extensively studied in experimental studies with naïve subjects and epidemiologic studies using a range of study designs.

Endotoxin exposure. Particulate exposure in the environs surrounding CAFOs occurs but has not received much attention to date. Considerable information exists about workplace exposure to dust from CAFOs (Schenker et al. 1998), and since the 1980s, endotoxins have been identified as important causal and toxic agents (Attwood et al. 1987; Donham et al. 1984).

Endotoxin is composed of lipopolysaccharides (LPS) and is a nonallergenic cell-wall component of gram-negative bacteria with strong proinflammatory properties. Endotoxins are ubiquitous and commonly present inside CAFOs, the general environment, and house dust (Douwes et al. 1998, 2000; Michel et al. 1991; Peterson et al. 1964; Schenker et al. 1998; Thorne et al. 2005). Very high endotoxin exposure occurs in farming, particularly livestock farming (Kullman et al. 1998; Schenker et al. 1998). Elevated endotoxin levels are present in homes where children have regular contact with farm animals and in homes where pets are present (Douwes et al. 2000; Thorne et al. 2003; von Mutius et al. 2000). Larger numbers of family members, poverty, and roach infestation are also associated with higher endotoxin in homes (Thorne et al. 2003, 2005). Inhalatory endotoxin exposure has been associated with a range of respiratory health effects in both the work and the domestic environment (Douwes and Heederik 1997; Douwes et al. 2002). Because results of research on respiratory health effects of endotoxin exposure were focused on different aspects for the occupational and domestic environments, overall results are reviewed briefly here for both environments.

Work environment exposures and adult onset allergy and asthma. Early studies on endotoxin exposure and farming activities began in about 1982. Swine production facilities have especially been studied since that period. Endotoxin exposure is high for workers in these industries, and several large-scale studies suggest that the mean exposure varies between a few hundred up to 15,000 endotoxin units (EU)/m^3 of air in situations where ventilation is limited because of extreme climatic conditions (Douwes and Heederik 1997). These exposures have been associated with increased symptoms, both respiratory and systemic (Rylander et al. 1989), across-shift lung function changes (Donham et al. 2000), reduced lung function in cross-sectional studies and accelerated decline in lung function in longitudinal studies (Vogelzang et al. 1998). Neutrophil-mediated inflammation has been observed in naïve subjects and swine confinement workers after exposure that is limited to periods of a few hours (Jagielo et al. 1996; Sandström et al. 1992; Von Essen and Romberger 2003). The exact pathophysiology is not clear, but it is well established that it is mediated by an acute inflammatory response involving a variety of cytokines, including interleukin (IL)-1, IL-6, IL-8, and tumor necrosis factor (TNF)-α, and the subsequent massive recruitment and activation of neutrophils in the lower and upper airways. The inflammatory reactions are orchestrated by alveolar macrophages that carry specific endotoxin binding receptors [LPS binding protein, CD14, MD2, toll-like receptor (TLR) 4], which play a crucial role in the activation of these cells and the subsequent inflammatory processes (Gioannini et al. 2003). Considerable interindividual variability in response to endotoxin has been observed in endotoxin provocation experiments with naïve subjects (Kline et al. 1999).

Recent studies suggest that environmental endotoxin exposure might protect against the development of atopy and possibly allergic asthma (Gereda et al. 2000a, 2000b; Liu and Leung 2000; Martinez and Holt 1999; von Mutius et al. 2000). A low prevalence for atopy, hay fever, and to a lesser extent, asthma has been observed in the children and adolescents of farming families and first-year university students with a farming background (Braun-Fahrländer et al. 1999; Ernst and Cormier 2000; Kilpelaïnen et al. 2000; Portengen et al. 2002; Riedler et al. 2000; von Ehrenstein et al. 2000). Contact with livestock in the first year of life appeared to be one underlying determinant of this reduced risk. These observations are usually referred to as the "hygiene hypothesis." Hence, exposure to endotoxin may reflect two sides of a coin: *a*) producing a protective effect with regard to atopy, and *b*) inducing inflammation that leads to nonallergic asthma. Two recent studies of adult farmers are in agreement with this hypothesis (Douwes et al. 2002). In the European Community Respiratory Health Survey, which investigates occupational asthma in 15,637 randomly selected people 20–44 years of age, the highest risk of asthma was shown for farmers [odds ratio (OR) = 2.6; 95% confidence interval (CI), 1.3–5.4] and agricultural workers (OR = 1.8; 95% CI, 1.0–3.2) (Kogevinas et al. 1999). An increased risk of asthma morbidity and mortality for farmers has been reported in several other studies as well (Fishwick et al. 1997; Neijari et al. 1996; Toren et al. 1991). Farmers involved in animal production seem to have the highest risk for asthma compared with subjects not involved in animal production (Melbostad et al. 1998). In the same study population, asthma in the absence of atopic sensitization to common allergens was associated with an increased exposure to endotoxin (Eduard et al. 2004). Other studies have reported conflicting results for the association of endotoxin exposure and asthma in farmers (Kimpbell-Dunn et al. 1999; Omland et al. 1999; Vogelzang et al. 1999). A study among Dutch pig farmers showed that the prevalence of atopic sensitization decreased sharply with increasing occupational endotoxin exposure, with the lowest prevalence at levels above 750 EU/m^3 (Portengen et al. 2005). A study from Iowa showed an increased prevalence of childhood asthma on farms with increasing numbers of swine (Merchant et al. 2005). This raises the question as to whether exposures that begin in adulthood may lead to lowered risk for atopic sensitization as well, as opposed to the prevailing belief that a healthy worker selection is responsible for this phenomenon.

Domestic endotoxin exposure and allergy and asthma in children. Most research on domestic endotoxin exposures has focused on the question of whether this exposure can explain the observations made in several studies describing a protective effect related to the development of atopy and allergic asthma in children who have grown up on small, traditional farms (Braun-Fahrländer et al. 1999; Klintberg et al. 2001; Portengen et al. 2002; Riedler et al. 2000; von Ehrenstein et al. 2000). It was indicated that contact with livestock reduced the risk of atopic asthma in children (von Ehrenstein et al. 2000) and young adolescents (Portengen et al. 2002). Although no specific protective factors were determined in these studies, it has been suggested that respiratory exposure to endotoxin may play an important role (Klintberg et al. 2001; von Ehrenstein et al. 2000), as it is well known, especially from occupational studies, that animal husbandry is associated with high exposures to bacterial endotoxin. However, exposures to other bioaerosol components such as fungi, gram-positive and gram-negative bacteria, bacterial DNA motifs, storage mites, and allergens from crops and animals are expected to be higher on farms and could also play a role.

The immune system is known to be skewed toward a proatopic direction during fetal and perinatal life. It has been proposed that proinflammatory microbial products, such as bacterial endotoxin, prokaryotic DNA, and glucans, markedly modulate the response of the immune system away from its tendency to develop atopic immune responses (Liu and Leung 2000; Martinez and Holt 1999). This may be a dose-dependent phenomenon, with low doses of these compounds providing some protective effects (as accounted for in the hygiene hypothesis of allergic asthma and atopy) and higher doses leading to a skewed and harmful response. Bacterial endotoxin and prokaryotic DNA can strongly induce IL-12 production by antigen-presenting cells, leading to the elaboration of interferon (IFN)-γ, IL-18, and other mediators. These mediators, many of which are transduced through one of the conserved TLR, are well recognized as promoting T helper (Th)1 (counter to Th2) responses. It has also been shown that the protective effect of farming exposure is regulated by a TLR2 response, as only children with the wild type of this gene were protected from allergy, given they were born on a farm (Eder et al. 2004). More recently, however, the promotion of "regulatory" responses (e.g., regulatory $CD4^+$ T-cells and antigen-presenting cells such as dendritic cells and macrophages) has received prominent attention. These cells, when activated by microbial products referred to as pathogen-association molecular patterns (PAMPs) use IL-10 and TGF-β to mediate their attenuation effects; regulatory responses can downregulate both Th1 and Th2 immune responses. This category of inflammation may account for the observations that both Th1-mediated diseases (e.g., diabetes mellitus) and Th2-mediated diseases (asthma and atopic disorders) have been rising in industrialized countries over the past several decades where children are exposed to lower levels of microbial products and infections than in the past or in preindustrialized or agricultural societies. Further infections associated with eosinophilia (e.g., helminth infestations), that promote both Th2 and regulatory responses, can protect against asthma and atopy (Kline et al. 1998; Shirakawa, 1997; Yazdanbakhsh et al. 2002).

To date few studies have produced direct *in vivo* evidence that endotoxin exposure may protect against the development of atopy by enhancing Th1 responses. A U.S. study of infants with documented wheezing episodes showed that endotoxin levels were correlated with IFN-γ–producing T cells (Th1) but not with IL-4–, IL-5–, or IL-13–producing cell proportions (Th2) (Gereda et al. 2000b). A Swiss–German study of farm children showed a decreased capacity to release IFN-γ, TNF-α, IL-10, and IL-12 in peripheral blood leucocytes upon stimulation with LPS, with increasing endotoxin load in the beds (Braun-Fahrländer et al. 2002), which could be a consequence of "exhaustion" of the atopic immune system as proposed in association to atopy by Kruger et al. (2004). Animal experimental studies with ovalbumin and endotoxin have not yielded consistent results.

Studies that found a consistent protective effect of farming exposure against atopy (Braun-Fahrländer et al. 2002; von Mutius et al. 2000) have shown only a weak protective effect against asthma itself, or they have shown a dual response in children with atopic asthma and allergy to be lower with increasing LPS exposure, and contrary to this, an increased prevalence of nonatopic wheeze with increasing LPS exposure (Braun-Fahrländer et al. 1999). There is considerable evidence that endotoxin exposure may both exacerbate preexisting asthma and induce new asthma. Several studies have also shown that endotoxin in house dust is associated with exacerbations of preexisting asthma in children and adults (Michel et al. 1991, 1996, 1997). A cohort study in 499 infants with a familial predisposition to asthma or allergy showed that early indoor endotoxin exposure was associated with an increased risk of repeated wheeze during the first year of life rather than a decreased risk (relative risk = 1.6; 95% CI, 1.03–2.38) (Shirakawa et al. 1997). A recent study of endotoxin in 831 homes across the United States demonstrated that indoor endotoxin was a significant risk factor for asthma symptoms, medication use, and wheezing. The adjusted OR for households with both bedding and bedroom floor endotoxin exceeding 19.6 EU/mg compared with those below was 2.83 (95% CI, 1.01–7.87). This effect was seen regardless of allergy status (Thorne et al. 2005).

Thus, for asthma alone, there is consistent evidence that endotoxin is both a secondary and primary cause of asthma, and that this occurs through nonatopic (i.e., nonimmunoglobulin E–mediated) mechanisms.

Because of the health effects related to environmental exposures, exposure standards have been suggested (Rylander 1997). The Health Council of the Netherlands proposed a health-based occupational exposure limit of 50 EU/m^3 over 8 hr for the working environment, which has been modified to 200 EU/m^3 because of feasibility issues. The introduction of this standard has been postponed because agricultural industries cannot meet this level, but exposure reduction action plans are being implemented so that this level can be met in a few years.

Workshop Recommendations

Priority research needs.

- Candidate agents: Most research has been focused on specific gases, organic dust, or on bioaerosols containing endotoxins. Occupational studies indicate that exposures occur to other agents, such as antibiotics and disinfectants, and that these agents may be related to increased risks for respiratory disease.
- Odor: There is a need to investigate in greater detail psychophysiologic responses related to malodor exposures in people living in proximity to swine CAFOs, exploring different potential mechanisms. The influence of factors such as mood and coping styles on perceived responses to odors and physiologic responses has been minimally investigated in relation to CAFO exposures.
- CAFO mixed exposures: CAFO exposures involve, by definition, exposure to complex mixtures. These include pulmonary irritants, inflammatory agents, odoriferous compounds, allergens, and antibiotics. Problems of the interaction in mixtures need to be addressed.
- Environmental particulate matter exposures: Studies of particulate-matter exposure in rural areas are needed because of the huge gap in knowledge. Exposure mechanisms for particulates are expected to be different than those for gases because particulates from CAFOs are biologically active and are known to be relatively large. Therefore, sedimentation out of the air is expected to be considerable at short distances. Resuspension in the air, walk-in, and take-home exposures are important candidate mechanisms of transfer leading to exposure indoors. Finally, exposures arising from the handling and distribution of manure to the fields as primary aerosol and secondary re-suspension need to be addressed.
- Analytical techniques: International harmonization of methods for bioaerosol exposure assessment is needed. In the case of harmonization of endotoxin assay, the United States should give serious consideration to adoption of the existing European Committee for Standardization protocol.
- Susceptibility and genetics: Only scarce information is available for evaluating the susceptibility of groups to the effects of organic dust exposure. The candidate genes responsible for changes in the reactions to specific agents have been only sporadically investigated.
- Susceptibility and gender: Recent studies from Canada suggest that women are more prone than men to develop asthma from

working in CAFOs. This points to the need for renewed investigations regarding gender effects in workers exposed to high concentrations of organic dust.

- Outcome assessment: There is a need to collect information regarding respiratory health in people living in proximity to CAFOs. Respiratory symptom status and lung function should be measured, as has been done in confinement workers in the last decades. Information on sensitization rates to common allergens and presence of allergic responses is crucial, as clear differences exist with nonrural populations and within rural populations, depending on early childhood exposure to animals. Recent developments in outcome assessment include more sensitive markers of inflammation, for example, IL-1β, IL-8, TNFα, C-reactive protein, and new sources to be studied by noninvasive approaches such as tear fluid, nasal lavage, exhaled breath condensate, and whole blood. These markers can elucidate the nature of the inflammatory response and facilitate a more detailed interpretation of the available information.
- Design: Panel studies have been shown to be powerful tools in air pollution research and should be pursued in studies of communities exposed to organic dust and CAFO emissions. They enroll sensitive individuals as a starting point and consider exacerbations of disease over time as the end point of interest. Exposure assessment in these studies requires combinations of exposure modeling, use of time-activity patterns and personal exposure assessment to calibrate the modelling. Alternatively, large-scale studies using hospital admission data in combination with spatial analysis to map the patients' homes and schools to CAFOs may be a cost effective and useful additional approach.

Translation of science to policy.

- Surveillance studies of workers in agricultural industries and panel studies in communities are warranted.
- The livestock industry should promote good housekeeping practices locally and worldwide and develop hygienic strategies to reduce exposure in the workplace and emissions to the general environment. Occupational health and hygiene expertise is scarce in these industries and should be improved. The cost effectiveness of various technological solutions should be established.
- Exposure standards should be promulgated for some key agents, including endotoxin, and where they exist, exposure levels should be maintained below the current standards. International guidelines for occupational and community health are needed for specific toxicants.

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Monitoring and Modeling of Emissions from Concentrated Animal Feeding Operations: Overview of Methods

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Accurate monitors are required to determine ambient concentration levels of contaminants emanating from concentrated animal feeding operations (CAFOs), and accurate models are required to indicate the spatial variability of concentrations over regions affected by CAFOs. A thorough understanding of the spatial and temporal variability of concentration levels could then be associated with locations of healthy individuals or subjects with respiratory ailments to statistically link the presence of CAFOs to the prevalence of ill health effects in local populations. This workgroup report, which was part of the Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions, describes instrumentation currently available for assessing contaminant concentration levels in the vicinity of CAFOs and reviews plume dispersion models that may be used to estimate concentration levels spatially. Recommendations for further research with respect to ambient air monitoring include accurately determining long-term average concentrations for a region under the influence of CAFO emissions using a combination of instruments based on accuracy, cost, and sampling duration. In addition, development of instruments capable of accurately quantifying adsorbed gases and volatile organic compounds is needed. Further research with respect to plume dispersion models includes identifying and validating the most applicable model for use in predicting downwind concentrations from CAFOs. Additional data are needed to obtain reliable emission rates from CAFOs. ***Key words:* ammonia, animal feeding operation, dispersion model, hydrogen sulfide, monitor, odor, particulate matter, poultry, swine. *Environ Health Perspect* 115:303–307 (2007). doi:10.1289/ehp.8838 available via *http://dx.doi.org/* [Online 14 November 2006]**

Background and Recent Developments

Airborne contaminant emissions emanating from concentrated animal feeding operations (CAFOs) include toxic gases and particulates. A combination of gases or particulates of sufficient concentration and chemical composition may also be perceived as an irritant odor downwind of a CAFO. There is a need to accurately assess the concentrations of these contaminants in order to determine the effect they may have on the health of residents living in proximity to CAFOs.

A variety of analytical methods are available for measuring toxic gases, particulates, and odor and vary significantly in terms of cost, precision, accuracy, portability, maintenance requirements, and the ability to conduct continuous measurements. When using these methods, both the spatial and temporal variability of the pollutant concentrations must be considered. For example, the temporal variability for a certain location can be measured with a direct-reading instrument, but this will not indicate the level of a contaminant over a broad area. Instruments of this type tend to be accurate but expensive. Similarly, time-integrating samplers, which typically are inexpensive but lack accuracy, can be deployed over a large area to assess the spatial variability of a pollutant. In a recent study conducted in the United States, air pollution problems caused by emissions from animal feeding operations into ambient air were characterized as "local" scale if neighbors living near the animal feeding operation were affected, or "regional" or "national" scale if the pollution emitted affects the quality of life in a multistate or national area (National Research Council Ad Hoc Committee on Air Emissions from Animal Feeding Operations, Committee on Animal Nutrition 2003). Ammonia was classified as a major pollutant on the regional scale, whereas hydrogen sulfide, particulate matter, and odor were classified as major pollutants at the local scale.

Another method for determining the spatial variability of an airborne contaminant is to utilize a plume dispersion model. A model of this type can develop concentration isopleths over an area from weather data averaged over a variety of time periods such as a day, month or year. The corollary approach is to use a spatial interpolation method such as kriging (Carletti et al. 2000; Zirschky 1985) to formulate concentration isopleths from measurements derived from time-integrated samplers. However, this review focuses on the instruments available for measuring gases, particulates, and odor, and on plume dispersion models applicable to the determination of contaminants in the vicinity of CAFOs.

Ammonia monitoring. Relatively accurate but expensive instruments (> US$10,000) are available for measuring ammonia and hydrogen sulfide at the limit of detection (parts per billion level) needed to determine the low concentrations of these gases expected at the local scale. There are several types of detection devices available for each gas, including chemiluminescence analyzers for oxides of nitrogen (NO_x) and pulsed fluorescence analyzers for sulfur dioxide (SO_2) that are commonly used for ambient air quality monitoring and contain thermal oxidizers for the quantification of ammonia (NH_3) and hydrogen sulfide (H_2S), respectively (Thermo Electron Inc., Waltham, MA, USA). The U.S. Environmental Protection Agency (U.S. EPA) guidance for continuous reference methods dictates that these monitors must be operated between 20 and 30°C, necessitating a temperature-controlled enclosure at the monitoring site. McCulloch and Shendrikar (2000) concluded that an ammonia analyzer of this type reliably measured hourly ambient ammonia concentrations with a high degree of accuracy.

Ammonia monitors based on a photoacoustic infrared absorption technique are also in current use (Innova Air Tech Instruments, Ballerup, Denmark; Pranalytica Corporation, Santa Monica, CA, USA). The ammonia molecule has infrared absorption bands, and pulses of infrared radiation can be converted to pressure waves in a measurement cell containing ammonia (Pushkarsky et al. 2002). Correcting for infrared absorption by water vapor and carbon dioxide allows for quantification of ammonia concentrations. A design that has been widely used in the Netherlands

This article is part of the mini-monograph "Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions."

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This workshop was supported by grant P30 ES05605-14S from the Environmental Health Sciences Research Center at The University of Iowa and the National Institute of Environmental Health Sciences.

The authors declare they have no competing financial interests.

Received 10 November 2005; accepted 13 November 2006.

for ambient ammonia monitoring involves the use of a semipermeable membrane (Mechatronics Instruments, Hoorn, the Netherlands). The membrane selectively passes gaseous ammonia, which is then absorbed into a liquid reagent inside the sampler. A conductivity detector records the changing conductivity of the reagent solution, which is proportional to the ammonia concentration (Erisman et al. 2001). This measurement method compared favorably with others in a European study (Mennen et al. 1996). Another design incorporating a semipermeable membrane and a special liquid reagent has been proposed by Li et al. (1999). After the reagent reacts with ammonia, it forms a compound (1-sulfonatoisoindole), which when illuminated with ultraviolet light, fluoresces at a known wavelength. A photodiode records the amount of fluorescent light, which is proportional to the ammonia concentration. A fluorimetric enzyme method with a limit of detection of 110 µg/L was used to measure ambient ammonia levels in the vicinity of a swine facility (Subramanian et al. 1996).

Open-path monitoring methods for ammonia are commercially available and have been used extensively by the state of Missouri and the U.S. EPA for investigative surveys and emission factor development near CAFOs (Childers et al. 2001; Harris et al. 2001; Hashmonay et al. 1999a, 1999b). Open-path monitoring methods measure the absorption of light as the light beam traverses the path between the light source and a reflector. The absorption spectra obtained from these instruments is used to uniquely identify ammonia among other light-absorbing gases, and the amount of absorption measured may be used to determine the average ammonia concentration along the path. An open-path monitor produces path-average concentrations, and this average may be higher or lower than the concentrations measured at particular points along the path.

At the regional scale, a nationwide monitoring network designed to measure the deposition of ammonia and other ions in rainfall has been constructed as part of the National Atmospheric Deposition Program. Atmospheric deposition of ammonia or ammonium gives rise to the eutrophication of ecosystems (Bouwman and Van Vuuren 1999; Burkholder et al. 2006; Sheppard 2002). Ammonium nitrate and ammonium sulfate are also significant contributors to regional fine particulate pollution problems present in California and in parts of the eastern and southeastern United States (U.S. EPA 2003a) and contribute to visibility reduction at national parks in the United States (National Research Council Committee on Haze in National Parks and Wilderness Areas 1993). The U.S. EPA also funds the operation of a nationwide network of fine particulate speciation samplers known as the Speciation Trends Network. Chemical analyses of filters from these samplers are used to establish levels of ammonium sulfate and ammonium nitrate and other constituents of fine particulate. The National Park Service operates a similar nationwide network of speciated fine particulate samplers as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program.

Hydrogen sulfide monitoring. A variety of analytical methods ranging in cost from US$5,000 to US$20,000 are available for measuring hydrogen sulfide. Parbst et al. (2000) has compared the variability obtained from different portable and nonportable hydrogen sulfide monitoring equipment. Some agricultural states, including Nebraska, Minnesota, and Missouri, have established their own air quality standards for hydrogen sulfide or total reduced sulfur. Monitoring networks established by these states use pulsed fluorescence analyzers to determine subhourly concentrations for comparison with state standards (State of Colorado 1999; State of Minnesota 2003; State of Missouri 2004; State of Nebraska 2002).

One type of portable hydrogen sulfide monitor determines hydrogen sulfide concentrations from changes in conductivity across a gold film (Arizona Instruments, Tempe, AZ, USA). The conductivity of the film varies as a function of the amount of hydrogen sulfide that has been deposited on its surface. A second portable monitoring design relies on the color change of a chemically treated tape as it is exposed to hydrogen sulfide. One type of tape used to measure hydrogen sulfide is coated with lead acetate. Upon exposure to hydrogen sulfide, a color change occurs as a result of the formation of lead sulfide. A recent study (Campagna et al. 2004) of ambient and indoor hydrogen sulfide levels in a community in Nebraska used a proprietary tape-based monitor (Zellweger Analytics, League City, TX, USA). A monitor of this design has been approved for hydrogen sulfide monitoring in Minnesota. Toda et al. (2001) have performed interference and sensitivity tests involving gold-film and tape-based hydrogen sulfide monitoring methods.

Odor measurements. The quantitation of odor is more challenging because it represents a varying complex mixture of free and particle-bound compounds. An ideal approach to odor measurement would begin by characterizing the chemical constituents associated with a particular offensive odor. Odors could then be quantified objectively based on the identification and quantification of the speciated constituents. However, the correlation between human response and specific compounds identified by instrumental methods such as gas chromatography remains quite poor (Powers et al. 2000). One possible explanation is that the human nose may be sensitive to concentrations that lie below instrumental detection limits. Also, the simultaneous instrumental determination of more than 200 compounds that have been identified in livestock odors is difficult because different groups of compounds require different types of columns for efficient separation as well as different operating parameters and detectors. Currently, existing limitations of instrumental methods make the human observer a necessary part of the odor measurement methods. Livestock odor measurement techniques currently rely on trained human raters for odor quantification. In Colorado and Missouri, measurements are taken using a scentometer, a simple portable device used to dilute odorous air with odor-free air (Barnebey Sutcliffe Corp., Columbus, OH, USA, and St. Croix Sensory, Inc., Lake Elmo, MN, USA) (State of Colorado 1999; State of Missouri 2003). A more accepted method for odor assessment is olfactometry, which has been established as American Standards of Testing and Measurements (ASTM) methods E1432-91 and E679-91 (ASTM 1997a, 1997b, respectively). Odorous air samples are taken in the field using Tedlar bags, and returned to the laboratory for evaluation by a trained panel of odor observers using a device known as an olfactometer (St. Croix Sensory Inc.), which allows the panel members to sniff increasing dilutions of the odorous air randomly delivered to one port or another with odor-free air until no odor can be detected. Comparability of odor measurements taken with a scentometer with data taken with an olfactometer is problematic (Bottcher 2001). While olfactometers filter out particulate matter, filters are not used in commercially available scentometers. Scentometers, on the other hand, have limited resolution. It has been reported that an important fraction of odorous material may adhere to the surface of particulate matter (Powers et al. 2000).

Particulate matter monitoring. Particles may act as carriers for microorganisms and endotoxin, adsorbed gases and vapors such as ammonia, and a variety of compounds that contribute to odor. Instrumentation for the measurement of ambient particulate concentrations are well developed and have been in use for decades as part of national ambient air quality sampling networks. Typical gravimetric instruments used for this purpose draw air through a large filter at a high flow rate (1–40 cfm or 30–1,200 L/min). Air inlets are often applied to segregate the smaller, potentially more harmful, particles. Information on the use of these instruments can be found through the Technology Transfer Network of the U.S. EPA (U.S. EPA 2003a). Direct-reading particulate monitors are also available (Watson et al. 1998). Although numerous studies have been conducted to indicate particulate concentrations within CAFOs, very few have involved the detection of dust levels downwind of these facilities, perhaps because of the many sources for dust in rural areas, such as unpaved roads, that would confound results.

Dispersion models. Dispersion models were first approved for regulatory application in 1977 when they were incorporated into the Clean Air Act (Jacobson et al. 1999). Since that time, the state of science of dispersion modeling has improved greatly. Dispersion models are a set of mathematical equations that attempt to simulate (model) the transport, diffusion, chemical transformation, physical interactions, and removal of pollutants in the atmosphere. Typically, model solutions are expressed as concentrations for some time period at "receptor" locations. Currently, the U.S. EPA has approved a number of models for regulatory application, and lists them in Appendix A of the *Guideline on Air Quality Models* [published as Appendix W of 40 CFR Part 51 (U.S. EPA 1998)]. These are divided into three categories: preferred or recommended refined dispersion models, screening models that can precede the use of a refined modeling analysis, and refined air quality models for use on a case-by-case basis for individual regulatory applications. In addition to models developed by the U.S. EPA, proprietary or research models have been developed to examine pollutant dispersion for specific needs.

Various inputs into these models include the source type such as point, line, area, pit, or volume, and source data such as location, gas temperature and velocity, and pollutant release rate (mass/time). In addition, hourly meteorologic data are added to these models and should contain wind speed and direction, ambient air temperature, stability class, mixing height, and precipitation, and pressure. Some models also contain options for inclusion of chemical transformation of gases. Regional models may contain inputs for geophysical data, such as terrain elevations and land use, surface and upper air meteorology, precipitation data, cloud observations, and visibility and deposition flux calculations.

Models can be applied for analysis of dispersion on both a local and regional scale. Local scale dispersion modeling usually predicts concentrations in an area < 50 km, and determines ambient impacts from one or more facilities. For assessing short-range transport of pollutants, the U.S. EPA recommends the Industrial Source Complex Short-Term Model, version 3 (ISC-ST3) (U.S. EPA 1995). The ISC-ST3 model is a steady-state, Gaussian plume model suitable for a wide range of industrial applications and special cases. Models of this type operate under the assumption that the contaminant disperses from a source with a concentration profile defined by a normal or Gaussian curve. It should be noted that the U.S. EPA recommended a new Gaussian plume model, the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD), for regulatory applications in November of 2005. Both ISC-ST3 and AERMOD may be used for regulatory purposes during a one year transitional period ending in November 2006, at which time AERMOD will become the U.S. EPA recommended model (U.S. EPA 2005).

Regional modeling is used to calculate pollutant concentrations over a much greater area (> 50 km). For assessing the long range transport of pollutants, the U.S. EPA recommends the use of CALPUFF, a non-steady-state Lagrangian puff dispersion model that depends on high-definition meteorologic data. Models of this type can account for an intermittent release rather than assuming a steady, continuous stream by simulating pollutant releases as a continuous series of puffs. More detailed applications of regional pollutant modeling are conducted with photochemical models that incorporate detailed atmospheric chemistry processes on large scales. Examples of these models include the Comprehensive Air Quality Model with extensions (CAMx) model maintained by the Environ Corporation (Newark, NJ, USA), the Community Modeling Air Quality (CMAQ) model developed by the U.S. EPA, and the Fine Resolution Atmospheric Multi-Pollutant Exchange (FRAME) regional model, developed specifically to describe atmospheric transport and deposition of ammonia (Singles et al. 1998). While these models include sophisticated chemical and physical processes, application for local-scale studies likely will be problematic because of the grid cell-level dilution.

Modeling pollutants emitted from CAFOs. Attempts have been made to use air dispersion models to estimate concentrations of both odor and contaminants downwind of CAFOs. These studies are complicated by three important factors: there may be several sources of a contaminant; the emission rate from each source is difficult to precisely determine; and the regulatory models do not typically include provisions for the degradation and deposition of gases in transport downwind from the source.

The ISC-ST3 model has been recommended for estimating air quality impacts of feedlot operations (Earth Tech 2001). However, ISC-ST3 has known deficiencies during stable or near-calm conditions when CAFO odors are most offensive, and it cannot directly account for effects of vegetation on concentrations or small-scale effects of terrain on the wind fields. In addition, Gaussian plume models may not adequately predict concentrations of compounds that are heavier than air, such as hydrogen sulfide, a pollutant of concern near animal feeding operations. Modifications to the Gaussian plume model that better represent agricultural sources have been investigated (Gassman and Bouzaher 1995; Keddie 1980; Rege and Tock 1996). A detailed discussion of transport from ground-level agricultural sources can be found in Smith (1993) with an emphasis on the dispersion of particulates from low-level sources given by Fritz et al. (2002). The AERMOD model may have particular applicability to modeling emissions from animal agriculture by including the air boundary layer above surface releases, such as from manure storage basins (Jacobson et al. 1999). There have also been efforts to use computational fluid dynamics to model the dispersion of contaminants from agricultural buildings (Quinn et al. 2001). These need further development.

CALPUFF has recently been used to model ammonia and hydrogen sulfide in the vicinity of a CAFO (Minnesota Pollution Control Agency 2003). Some of the attributes of CALPUFF are especially pertinent to conditions associated with CAFOs: variable wind directions, calm-wind algorithm, buoyant area and line sources, nonuniform land patterns, and multifacility applications. The state of Minnesota has opted to use the ISC-ST3 model for single facilities and the CALPUFF model for multi-facility applications (Earth Tech 2001) and the U.S. EPA has adopted CALPUFF as the preferred model for assessing long-range transport of pollutants (U.S. EPA 2003b).

Other studies have focused on the dispersion of odor primarily to determine setback distances between CAFOs and local residences (Heber 1997; Jacobson et al. 2001; Zhu et al. 2000). Gaussian plume models that have been widely used for odor dispersion modeling include the Australian Plume (AUSPLUME) model (Environmental Protection Authority–Victoria 2000), ISC-ST3 (U.S. EPA 1995), and STINK (Smith and Watts 1994). Studies have shown varying degrees of agreement between model results and odor measurements (Carney and Dodd 1989; Gassman 1992; Guo et al. 2001; Li et al. 1994). Gassman (1992) reviewed literature on odor modeling using the Gaussian plume method and concluded that the method was best applied on a relative basis for comparing differences between different facilities. Koppolu et al. (2002) compared results obtained from AERMOD and STINK after modeling the dispersion of low molecular weight volatile odorous fatty acids. They found better agreement between model results and measured values when using

AERMOD. The Gaussian Integrated Puff (INPUFF-2) model has also been used to predict odor dispersion (Zhu et al. 2000).

Workshop Recommendations

Priority research needs.

- Monitoring networks: There is a need to accurately determine long-term average concentrations for a region under the influence of CAFO emissions using a combination of instruments based on accuracy, cost, and sampling duration. This may include an array of passive monitors in combination with occasional spot-checks using portable devices, co-located instruments and laboratory testing for quality control. Passive monitors for hydrogen sulfide are available with detection limits of 0.1 ppb (Radiello Inc., Italy; MAXXAM Analytics, Inc., Calgary, Alberta, CN). Information of this type could be used to correlate contaminant exposures to chronic health effects through the use of community surveys, questionnaires, medical examinations, or other validated methods with contaminant exposures. Similar correlations could be made using existing direct-reading instruments to gather short-term data coincidental with acute effects. Monitoring networks have been established to measure gases and odors in the vicinity of CAFOs, but few have incorporated particulate measurements, especially the components of particles that contribute to odor such as adsorbed gases and volatile organic compounds. Instruments are needed to accurately detect these compounds. Furthermore, spatiotemporal geostatistical techniques for accurately placing monitors and interpolating concentration measurements derived from monitoring networks are needed. Similarly, the integration of data from a variety of sources such as model predictions, satellite data, and monitored values should be explored.
- Background levels: Research is needed to determine background levels in rural areas as well as to obtain a better understanding of concentrations inside residences and schools relative to outdoor concentrations. This work should also include an assessment of how far gases and particulates travel from CAFOs to determine their area of influence.
- Causative agents: Epidemiologic studies are needed to determine the actual causative agents related to health outcomes to ensure that the most-important contaminants are being measured. A metric to relate odor with health symptoms is needed.
- Model selection: Research should be conducted to identify and validate the most applicable model for CAFO emissions. Specifically, models that account for the chemical transformation of pollutants, such as ammonia and hydrogen sulfide, are needed. Model accuracy should be evaluated and prediction error determined through comparison of predicted values with actual monitoring data. In addition, future research that involves dispersion modeling is needed to assess public health concerns by determining long-term concentrations within a region, providing exposure data for health outcomes research, assessing meteorologic conditions during the past that could induce events, and forecasting future events. There is further need for models that will enable evaluation of concentration/exposure scenarios after an event that triggered hospital visits (e.g., asthma attack) and nuisance complaints.
- Toxicant emissions: Tied to the development of accurate dispersion models is the need for improved understanding of the rate of contaminant emissions from CAFOs. Research is needed to obtain reliable emission rates that consider temporal variations and the influence of management practices in addition to current knowledge concerning emissions related to the CAFO type, the number of animals, and the manure storage and handling.

Translation of science to policy. Modeling is an important tool for use in regulatory applications regarding industrial sources, but its use should be expanded to CAFOs. For existing livestock facilities, modeling could be used to determine the results of best management practices through estimation of potential reductions or expected concentrations on downwind receptors. For proposed livestock facilities, modeling could be used by local zoning officials or state or federal regulatory agencies to assess potential impacts on surrounding rural populations or environmentally sensitive areas prior to construction. Additionally, the use of modeling could enable policy makers to establish setback distances prior to construction of a livestock facility that are based on predicted concentration profiles, and would therefore be protective of public health. Finally, modeling could be used to survey situations affecting a single community, eliminating some across the board regulations for more of a case-by-case approach.

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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)

This article is part of the mini-monograph "Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions."

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This workshop was supported by grant no. P30 ES05605-14S from the Environmental Health Sciences Research Center at The University of Iowa and the National Institute of Environmental Health Sciences.

The authors declare they have no competing financial interests.

Received 10 November 2005; accepted 13 November 2006.

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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The Potential Role of Concentrated Animal Feeding Operations in Infectious Disease Epidemics and Antibiotic Resistance

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The industrialization of livestock production and the widespread use of nontherapeutic antimicrobial growth promotants has intensified the risk for the emergence of new, more virulent, or more resistant microorganisms. These have reduced the effectiveness of several classes of antibiotics for treating infections in humans and livestock. Recent outbreaks of virulent strains of influenza have arisen from swine and poultry raised in close proximity. This working group, which was part of the Conference on Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions, considered the state of the science around these issues and concurred with the World Health Organization call for a phasing-out of the use of antimicrobial growth promotants for livestock and fish production. We also agree that all therapeutic antimicrobial agents should be available only by prescription for human and veterinary use. Concern about the risk of an influenza pandemic leads us to recommend that regulations be promulgated to restrict the co-location of swine and poultry concentrated animal feeding operations (CAFOs) on the same site and to set appropriate separation distances. ***Key words:*** **antibiotic resistance, influenza, manure lagoon, poultry, swine, zoonotic disease.** ***Environ Health Perspect*** **115:313–316 (2007). doi:10.1289/ehp.8837 available via** ***http://dx.doi.org/*** **[Online 14 November 2006]**

Background and Recent Developments

As a general principle, the concentration of humans or animals in proximity enhances potential transmission of microorganisms among members of the group. It also creates greater potential for infecting surrounding life forms, even those of different species. The conditions created also may be a breeding ground for new, more infectious, or more resistant microorganisms.

As the human population increases, and mega cities grow, there is greater risk that infectious diseases will evolve, emerge, or spread readily among the populace. The increasing food needs of the growing human population likely will lead to greater populations of livestock. The concentration of animals may augment the risk of zoonoses, diseases transmissible from animals to humans. All segments of livestock production might potentially contribute to zoonotic disease, including transportation of livestock, manure handling practices, veterinary medicine, meat processing and animal rendering. Ideally, everyone involved in each of these components of the industry should be cognizant of the infectious disease risks to animals and humans alike.

Among the many examples of existing risks, some of the more recent are highly pertinent. Nipah virus infections, which occurred in concentrated swine herds in Malaysia and Singapore, killed swine and swine workers (Chua et al. 1999; Paton et al. 1999). Avian influenza has recently infected and caused deaths among poultry and poultry workers in Asia, South America, North America, and Europe [Centers for Disease Control and Prevention 2005; World Health Organization (WHO) 2004]. Many zoonoses may not be related solely to concentrated animal husbandry, but this workshop was devoted to those at least partially attributable to concentration and practices associated with them. While there are many known potential risks for human infection that may result from high concentrations of animals, this article will focus on two—influenza and antibiotic resistance. In addition, we briefly discuss the means of transmission or propagation of infectious agents, including water, animal feed, and human food.

Antibiotic resistance. **State of science.** Antibiotic resistance is increasing among most human pathogens. The many bacteria resistant to multiple antibiotics in particular has heightened concern. In some cases there are few or no antibiotics available to treat resistant pathogens [Institute of Medicine (IOM) 1998; Mølbak et al. 1999]. Development of new antibiotic classes has lagged behind pharmaceutical innovation in other areas, and some innovative new approaches to combating infection are still immature and unproven (Infectious Diseases Society of America 2005; IOM 1998). Escalating resistance has raised concern that we are entering the "post antibiotic era," meaning we may be entering a period where there would be no effective antibiotics available for treating many life-threatening infections in humans. If this proves true, deaths due to infection will once again become a very real threat to substantial numbers of children and young adults as well as the sick and the elderly.

Increased antibiotic resistance can be traced to the use and overuse of antibiotics. Much of that use occurs in human medicine. Health care policy and practice changes designed to minimize this phenomenon are in place in many countries, yet much more can be done. Although antibiotic overuse in animals is problematic, the magnitude of the problem is unknown. There is no national mechanism for collecting data on antibiotic use in many countries and the pharmaceutical industry treats production and sales figures as confidential business information. However, the Union of Concerned Scientists (2001) has estimated that 11.2 million kg of the antibiotics used annually in the United States are administered to livestock as growth promoters. This compares with their estimate of 1.4 million kg for human medical use. Their estimates indicate that 87% of all antibiotic use is for animals, while 13% is for human therapeutic and nontherapeutic use. One researcher suggests lower figures for antibiotic use in growth promotion, stating that no more than 40% of antibiotics in the United States is for animals (Levy 1998). As the IOM recently concluded,

> Clearly, a decrease in antimicrobial use in human medicine alone will have little effect on the current situation. Substantial efforts must be made to decrease inappropriate overuse in animals and agriculture as well. [National Academy of Sciences (NAS) 2003]

Therapeutic antibiotic administration at high levels for the duration of an illness is obviously an important aspect of veterinary care. However, most animal antibiotic use is

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This article is part of the mini-monograph "Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions."

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This workshop was supported by grant no. P30 ES05605-14S from the Environmental Health Sciences Research Center at The University of Iowa and the National Institute of Environmental Health Sciences.

The authors declare they have no competing financial interests.

Received 10 November 2005; accepted 13 November 2006.

designed to promote growth and improve feed conversion ratio. However, the growth rate gains with antibiotic growth promotants are less significant with currently used breeds of swine and poultry (Wegener 2003). This prolonged use of antibiotics, especially at low levels, presents a risk of not killing the bacteria while promoting their resistance by selecting for resistant populations. The resistance genes can pass readily from one kind of bacteria to another (Levy 1998). Thus, workers in the animal units may become colonized with resistant organisms and can pass them on to co-workers and family members or friends. Consumers of meat may also become colonized through mishandling of raw meat or through insufficient cooking. Ultimately, these genes may pass into pathogens, and diseases that were formerly treatable will be capable of causing severe illness or death (NAS 2003).

Evidence of resistance associated with antimicrobial growth promotants has been emerging over the past three decades. Tetracycline-resistant organisms were found in 1976 in chickens raised on feed supplemented with tetracycline, a human-use antibiotic. In a prospective study of 11 poultry farm members and 24 neighbors, Levy and co-workers (1976a) found that before the use of tetracycline on the farm neither the farmers nor the animals were positive for tetracycline-resistant intestinal flora. Within 5 months of the introduction of tetracycline in the poultry feed, 31.3% of fecal samples from farm members harbored intestinal flora that were resistant to tetracycline even though none had been treated clinically with tetracycline. Tetracycline-resistant bacteria were found in only 6.8% of the samples from neighbors. Vancomycin-resistant enterococci arose in livestock in Europe in the 1970s because of use of Avoparcin as an antibiotic growth promotant. Neither Avoparcin nor vancomycin was approved for use in livestock in the United States, and vancomycin-resistant enterococci did not emerge in U.S. livestock (Levy et al. 1976b). White and co-workers purchased 200 samples of ground meat in the Washington, DC, area and found that 20% contained culturable *Salmonella*. Of these, 84% of the organisms were resistant to at least one antibiotic tested, and 53% were resistant to three or more (White et al. 2001). Tetracycline resistance genes were identified in a swine CAFO and also in the manure lagoon serving that CAFO and in groundwater 250 m downstream of the lagoon (Chee-Sanford et al. 2001). Using a medicated feed containing tylosin (a macrolide antibiotic), Zahn et al. (2001) compared swine CAFOs with CAFOs using a nonmedicated feed and observed a 3-fold higher concentration of tylosin-resistant bacteria in the exhaust air from the CAFOs. Antibiotics have also been measured in the dust from swine CAFOs (Hamscher et al. 2003).

Several recent studies clearly demonstrate the transmission of multidrug-resistant pathogens from swine to humans. A French group studied 44 nasal *Staphylococcus aureus* isolates from healthy pig farmers and 21 healthy controls. Five isolates were found in pig farmers that were methicillin resistant. Other isolates were resistant to penicillin, lincomycin, erythromycin, pristinamycin, kanamycin, pefloxacin (Armand-Lefevre et al. 2005). By comparing these findings with analyses of isolates from swine infections, the authors concluded that transmission of these resistant organisms from swine to pig farmers may be frequent. Voss and co-workers (2005) in the Netherlands studied methicillin-resistant *S. aureus* (MRSA) among 26 Dutch farmers living nearby a sentinel case of MRSA. Their study demonstrated transmission of three strains of MRSA from swine to pig farmers, from pig farmers to their family members, and from a hospitalized patient (the sentinel case) to a nurse. Investigators in the United States collected air samples via liquid impingers in a swine CAFO and analyzed the samples for viable isolates of antibiotic resistant bacteria (Chapin et al. 2005). Enterococci, staphylococci, and streptococci were analyzed for resistance to erythromycin, clindamycin, virginiamycin, tetracycline, and vancomycin. None of the isolates were resistant to vancomycin, which has never been approved for use in livestock in the United States. In contrast, 98% of the isolates displayed resistance to two or more of the other four antibiotics that are commonly used as growth promotants in swine. It is important to note that 37 of 124 isolates were resistant to all four of these antibiotics (Chapin et al. 2005).

Sweden banned the use of antibiotics as feed additives for growth promotion in 1985 (Swedish Veterinary Antimicrobial Resistance Monitoring 2003). At that time Sweden used 20 metric tons of antibiotics for growth promotion, 14 metric tons for group treatment and 17 metric tons for treating individual sick animals. In 2003, with no use allowed for growth promotion, the amount of antibiotics used for group treatment was 2 metric tons (down from 14 metric tons), accompanied by a decrease, rather than an increase, of individual treatment use from 17 to 14 metric tons. This demonstrates that the banning of growth promotants did not lead to increased antibiotic use in other categories. In Denmark, veterinary researchers observed a 74% incidence of vancomycin-resistant *Enteroccocus faecium* in broiler chickens in 1995. Following a 1997 ban, the level of resistance fell to 2% by 2000 [Aarestrup et al. 2001; Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP) 2004]. In the European Union, antibiotics also used for human medicine were removed from animal use in 1998, and all use of antibiotics as growth promotants are being phased out by 2006 (Casewell et al. 2003). Currently, Sweden and Denmark use less than 3 g of antimicrobial agents per pig slaughtered, whereas the United States uses 47 g (WHO 2003). The experience from the antibiotic bans for broiler chickens demonstrates that the decrease in production—in terms of decreased feed efficiency—is small and is offset by the savings in the cost of antimicrobial growth promotants (Wegener 2003). According to the WHO the increased cost to producers of producing pigs without antibiotic growth promotants is approximately 1% (WHO 2003) and should be compared with the "likely human health benefits to society of antimicrobial growth promoter termination" (WHO 2003).

Animal crowding, CAFO hygiene, temperature and ventilation control, and stress all have an impact on growth rate and the ability of animals to resist disease. Research on the use of other treatments such as probiotics and vaccines holds promise. Probiotics involve the deliberate use of harmless or even beneficial colonizing organisms in food production. It will be important to provide solutions for the spread of antibiotic resistance via air, water, and direct contact to CAFO workers.

The WHO has called for human and veterinary antimicrobial agents to be sold only under prescription. They have also recommended that all countries establish monitoring programs for tracking use and resistance to antimicrobials. The WHO has also called for a rapid phase-out of the use of antimicrobial growth promotants and the creation of prudent use guidelines for veterinary care (WHO 2003).

These practices are not limited to CAFOs. However, it is widely recognized that antibiotic resistance can be staunched only if every effort is made to limit inappropriate use, both with humans and animals.

Risk assessment. Microbial risk assessment is an evolving discipline. Methods have not been developed for estimating risks associated with more than one antibiotic and one bacterium at a time. This approach does not fully address the reality of the CAFO environment, where animals harbor multiple microbial species that are exposed to multiple antibiotics over the course of their lives. Moreover, the existence of genetic multidrug resistance determinants (e.g., plasmids carrying genes coding for resistance to multiple drugs) means that exposure to one antibiotic may lead to increased reservoirs of multiple other antibiotics as well. The fact that resistance determinants may be transferred from benign to pathogenic bacteria means that exposure of one bacterium to antibiotics today hypothetically could result in manifestation of human disease only months to years later. Reservoirs of resistance may develop relatively rapidly and may not be completely reversible. This suggests that reducing antibiotic usage may not lead to equivalent reductions in resistance among all bacteria of concern. Thus, research should be concurrent with new public policies to reduce antibiotic overuse and ensure the protection of public health.

Vaccines. Development of vaccines could reduce our reliance on antibiotics. The timing of vaccine administration with respect to maternal antibody levels in infants should be studied. Human vaccine administration is undergoing a revolution in anticipation of mass vaccination strategies that may be required to respond to a bioterrorism event. These strategies may also be applicable to animals in veterinary disease prevention. Several diseases afflicting livestock require further research, including necrotic enteritis in poultry (and the use of ionophores for coccidiostats); pasteurella respiratory disease, and; swine ileitis and swine dysentery, as well as diseases of swine at weaning.

Policy initiatives. A number of policy initiatives should be explored to establish consistent and responsible operating practices as well as to promote a shift in current thinking about the value of antibiotic-free meat products. These policies should address all levels of CAFO operation, from the CAFO operators themselves to local, state, and federal governments, veterinarians, agricultural and pharmaceutical industries, and the scientific research community. To ensure sensible use of antibiotics, these issues should also be included in the curricula of pharmacists, doctors, and other medical providers. Furthermore, patients must be suitably informed on the proper use of antibiotics including safe disposal.

Producers and industry leaders can and should be afforded the opportunity to assume a leadership role in reducing antibiotic overuse. This should be encouraged by identifying existing producers—either domestic or international—who are using no or reduced antibiotics and might assume demonstration projects. Along with this, a mentoring system could be created for the purpose of sharing practices that have proven successful in established CAFOs. For example, partners in Sweden and Denmark—countries that have experienced successful transitions to antibiotic-free meat production—might be visited by demonstration team producers, along with veterinarians from the respective countries. Where possible, Danish immigrants or American producers of Danish descent might be paired with Danish producers and veterinarians. These collaborative efforts would require travel funds and the availability of antibiotic-free feed at market prices for the duration of the project. Costs should be tracked and producers reimbursed at the outset so that the interval of adjustment to the new antibiotic-free regimen is not burdensome.

Measures to improve the domestic market for meat raised without routine antibiotics should be sought to promote its vitality as a marketable commodity in the United States. At the same time, new overseas markets should be identified, and these special U.S. products heavily promoted as imports of value and interest to the global economy. In addition, product labeling could be made more comprehensive and explicit so that consumers can identify the product and make selections according to their value system. In fact, such improvements in labeling could be an integral part of an overall quality assurance program that drives the label.

Infectious diseases. **Influenza.** Zoonoses can be transmitted via water, air, consumption or handling of meat products, or by direct transmission from animals to humans. Recent work by Myers and colleagues demonstrated significantly elevated seroprevalence of antibodies against H1N1 and H1N2 swine influenza virus in occupationally exposed adults compared with controls without swine exposure (Myers et al. 2006). Odds ratios for swine H1N1 infection were 35.3 for farmers, 17.8 for veterinarians, and 6.5 for meat processors. For H1N2 infection odds ratios were 13.8, 9.5, and 2.7, respectively (all significant).

The transmission of influenza is a continuing concern. Whether it comes to humans from avian species or swine, or from avian species via swine, or perhaps from humans to swine, strains of high transmissibility and pathogenicity are likely to evolve and create another pandemic (Nature 2005; Webster and Hulse 2005). Recent outbreaks in Asia have shown that transmission of infectious agents can arise from small farms raising poultry in proximity to domiciles and to other animals. However, because CAFOs tend to concentrate large numbers of animals close together, they facilitate rapid transmission and mixing of viruses. There is a concern that increasing the numbers of swine facilities adjacent to avian facilities could further promote the evolution of the next pandemic. The swine industry has adopted a set of guidelines to minimize these risks, including *a*) entry of wild birds and rodents into CAFOs should be limited; *b*) untreated surface water that may have influenza viruses from aquatic birds should not be used for washing facilities, and *c*) waterfowl use of farm lagoons should be minimized. Such prudent practices will minimize risk. To avoid their becoming a mixing vessel for swine or poultry viruses with human viruses, CAFO workers should be immunized against influenza routinely, preferably with the killed vaccine.

The best means to limit transmission of influenza may already be inferred from available data. However, new questions may arise as practices change. What distances should be established between CAFOs housing swine and those housing poultry? Is there a definable, small farm size with minimal numbers of animals that may be allowed?

Surveillance programs should be instituted that maintain biosecurity in CAFOs while maximizing the ability to identify and respond to animal and zoonotic disease outbreaks quickly and effectively.

Waterborne diseases. Concerns persist about surface and groundwater contamination that may have ecosystem and human health impacts. Optimal siting and improved construction practices of CAFOs would reduce the potential for contamination. Escrow accounts or insurance policies that would ensure restoration of a vacated manure lagoon to previous conditions should be imposed on those considering building a CAFO. Solid tanks or reservoirs rather than earthen waste lagoons and municipal-style waste treatment are needed to prevent manure contamination of surface and groundwater with infectious agents or antibiotic resistance genes.

Animal feed containing animal by-products. Animal feed containing animal tissues and by-products is a major concern, as sporeforming bacteria likely will be present even after processing. Included are feathers, offal, carcasses, bone and blood meal, and nervous system and brain tissue. Gram-negative enterobacteria of the genus *Salmonella* will multiply in the food when it is reintroduced at the feeding unit. *Salmonella* can be transmitted to humans through the slaughtering process. Meat packing and CAFO workers are at greater risk of acquiring infection because of their close access to animals and feed. CAFOs are so large and densely populated that when a pathogen is introduced into the system, it is difficult to eliminate. Biosecurity should be rigorous, and extreme quality assurance systems are warranted in these large operations.

Meat for human consumption. Pathogens tend to be amplified in animals raised in CAFOs and, thus, are more difficult to eliminate in meat packing processes. Research is needed to develop better ways of controlling pathogen growth in meat. Studies should investigate measures to control *Salmonella* cycling within a CAFO. Improved hygiene and ventilation may be sufficient measures. Better controls on the food processing environment are also indicated. Organisms can amplify very efficiently in a holding pen containing live animals. Multidrug-resistant pathogens are of grave concern and are more likely to arise in animal feeding operations that rely on nontherapeutic antibiotic use instead of enhanced hygiene, air filtration, biosecurity and disease surveillance.

Finally, research needs include developing better means to reduce colonization of animals and meat with *Campylobacter*, *Salmonella*, *Escherichia coli*, and other organisms.

Workshop Recommendations

Priority research needs.

- Discontinue nontherapeutic use in the United States: The practice of feeding antibiotics to animals as growth enhancers should be phased out in the United States as it has in the European Union and as called for by the WHO, the IOM, and many scientific and public health organizations. Research studies should monitor the discontinuation to ensure that the ban on antibiotic use for growth promotion is not supplanted by increased therapeutic use.
- Surveillance programs: Coordinated nationwide surveillance programs (Aarestrup 2004) should be instituted to fully assess the contribution of antibiotic use in livestock production to the creation of ecological reservoirs of resistance, or the transmission of that resistance to humans.
- Strain identification: Fingerprinting of isolates of antibiotic-resistant bacteria and the resistance elements should be conducted to establish relationships among members of the same species. Results should be used to identify unknown sources of resistance and to track changes in resistance profiles in response to diminished antibiotic use.
- Influenza risk: Countries and states should establish minimum separation distances for swine and poultry facilities to reduce the risk of influenza outbreaks.
- Manure storage and waste processing: Livestock production facilities should incorporate solid tanks for manure storage and municipal style waste treatment to limit microbial and nutrient contamination of surface and groundwater.

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Community Health and Socioeconomic Issues Surrounding Concentrated Animal Feeding Operations

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A consensus of the Workgroup on Community and Socioeconomic Issues was that improving and sustaining healthy rural communities depends on integrating socioeconomic development and environmental protection. The workgroup agreed that the World Health Organization's definition of health, "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity," applies to rural communities. These principles are embodied in the following main points agreed upon by this workgroup. Healthy rural communities ensure *a*) the physical and mental health of individuals, *b*) financial security for individuals and the greater community, *c*) social well-being, *d*) social and environmental justice, and *e*) political equity and access. This workgroup evaluated impacts of the proliferation of concentrated animal feeding operations (CAFOs) on sustaining the health of rural communities. Recommended policy changes include a more stringent process for issuing permits for CAFOs, considering bonding for manure storage basins, limiting animal density per watershed, enhancing local control, and mandating environmental impact statements. *Key words:* animal confinements, environmental impact, livestock, mental health, odor, poultry, right-to-farm legislation, swine. *Environ Health Perspect* 115:317–320 (2007). doi:10.1289/ehp.8836 available via *http://dx.doi.org/* [Online 14 November 2006]

Background and Recent Developments

The agricultural community in areas of large-scale livestock production. The rural and agricultural community has changed dramatically over the past half century. The trends include an overall reduction in the number of farms, an increase in size of the farms, and economic concentration in the industries that supply inputs and purchase commodities from farms. The structure of the pork industry has also changed dramatically during the past three decades. The number of hog producers in the United States was more than 1 million in the 1960s but fell to about 67,000 by 2005 [U.S. Department of Agriculture (USDA) 2005]. Although the total inventory of hogs has changed little over the years, the structural shift toward concentration has been dramatic with the 110 largest hog operations in the country, each of which has over 50,000 hogs, now constituting 55% of the total national inventory (USDA 2005). The swine industry includes the following types of producers: small independent "niche" operators who often market organic pork to local markets, traditional independent operators, and large family or unaffiliated corporations. Former independent operators are increasingly raising livestock on contract for larger corporations. According to the U.S. Government Accountability Office, in 1999 contract production constituted more than 60% of total hog output and 35% of the cattle market (U.S. Government Accountability Office 2005), while poultry is produced almost entirely via contracts. Corporate producers or incorporated family-based operations employ from a few individuals to several hundred. Most often upper management and many of the workers in such operations do not come from or live in the vicinity of concentrated animal feeding operations (CAFOs).

The community of people living in the region of large-scale livestock production consists of residents of small family farms (that may or may not produce pork), workers at the production facilities, rural nonfarm residents, and the residents of neighboring towns. The challenges CAFOs place on neighbors were extensively reviewed in 1996 (Thu 1996) and again in a 2002 report accompanied by a number of consensus recommendations for the future of the hog industry in Iowa (Iowa State University and University of Iowa 2002). A number of additional scientific reviews and symposia summaries have been issued (Centers for Disease Control and Prevention 1998; Cole et al. 2000; Donham 2000; National Academy of Sciences 2002; Schiffman et al. 2000; Thu 2002).

Economic health. Economic concentration of agricultural operations tends to remove a higher percentage of money from rural communities than when the industry is dominated by smaller farm operations, which tend to circulate money within the community. Goldschmidt (1978) documented this as early as 1946 in California, one of the first states where industrialized agriculture developed. Specifically, he compared two agricultural communities, one dominated by larger industrialized farms with absentee ownership and a high percentage of hired farm labor, and the other community was dominated by smaller owner-operated farms. The latter community was found to have a richer civic and social fabric with more retail purchases made locally and with income more equitably distributed. A similar study by MacCannell (1988) of comparable types of communities found that the concentration and industrialization of agriculture were associated with economic and community decline locally and regionally. Studies in Illinois (Gomez and Zhang 2000), Iowa (Durrenberger and Thu 1996), Michigan (Abeles-Allison and Conner 1990), and Wisconsin (Foltz et al. 2002) demonstrated decreased tax receipts and declining local purchases with larger operations. A Minnesota study (Chism and Levins 1994) found that the local spending decline was related to enlargement in scale of individual livestock operations rather than crop production. These findings consistently show that the social and economic well-being of local rural communities benefits from increasing the number of farmers, not simply increasing the volume of commodity produced (Osterberg and Wallinga 2004).

Physical health. There have been more than 70 papers published on the adverse health effects of the confinement environment on swine producers by authors in the United States, Canada, most European countries, and Australia (Cormier et al. 1997; Donham 2000; Donham et al. 1977, 1982, 1986, 1990, 2002; Kirkhorn and Schenker 2002; Kline et al. 2004; Preller et al. 1995; Reynolds et al. 1996; Rylander et al. 1989; Schiffman

This article is part of the mini-monograph "Environmental Health Impacts of Concentrated Animal Feeding Operations: Anticipating Hazards—Searching for Solutions."

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This workshop was supported by grant P30 ES05605-14S from the Environmental Health Sciences Research Center at The University of Iowa and the National Institute of Environmental Health Sciences.

The authors declare they have no competing financial interests.

Received 10 November 2005; accepted 13 November 2006.

et al. 1995; Schwartz et al. 1992; Thu et al. 1997; Wing and Wolf 2000). It is clear that at least 25% of confinement workers suffer from respiratory diseases including bronchitis, mucus membrane irritation, asthmalike syndrome, and acute respiratory distress syndrome. Recent findings substantiate anecdotal observations that a small proportion of workers experience acute respiratory symptoms early in their work history that may be sufficiently severe to cause immediate withdrawal from the work place (Dosman et. al. 2004). An additional acute respiratory condition, organic dust toxic syndrome, related to high concentrations of bioaerosols in livestock buildings occurs episodically in more than 30% of swine workers.

Environmental assessments of air quality inside livestock buildings reveal unhealthful concentrations of hydrogen sulfide, ammonia, inhalable particulate matter, and endotoxin (Iowa State University and University of Iowa 2002; Schenker et al. 1998). While there is less information on adverse effects among residents living in the vicinity of swine operations, that body of literature has been growing in recent years (Avery et al. 2004; Bullers 2005; Centers for Disease Control and Prevention 1998; Kilburn 1997; Merchant et al. 2005; Mirabelli et al. 2006a; Reynolds et al. 1997; Schiffman et al. 1995, 2000; Thu 2002; Thu et al. 1997; Wing and Wolf 2000).

Thu et al. (1997) documented excessive respiratory symptoms in neighbors of large-scale CAFOs, relative to comparison populations in low-density livestock-producing areas. The pattern of these symptoms was similar to those experienced by CAFO workers. Wing and Wolf (2000) and Bullers (2005) found similar differences in North Carolina. A case report associated with hydrogen sulfide exposure from a livestock processing facility in South Sioux City, Nebraska, revealed excessive diagnoses of respiratory and digestive disturbances in people living nearby (Campagna et al. 2004). Schiffman and colleagues reported that neighbors of confinement facilities experienced increased levels of mood disorders including anxiety, depression, and sleep disturbances attributable to exposures to malodorous compounds (Schiffman et al. 1995, 2000). Avery et al. (2004) found lower concentration and secretion of salivary immunoglobulin A among swine CAFO neighbors during times of moderate to high odor compared with times of low or no odor, suggesting a stress-mediated physiologic response to malodor (Shusterman 1992).

Community environmental air quality assessments have shown concentrations of hydrogen sulfide and ammonia that exceed U.S. Environmental Protection Agency (U.S. EPA) and Agency for Toxic Substances and Disease Registry recommendations (Reynolds et al. 1997). A recent study revealed that children living on farms raising swine have an increased risk for asthma, with increasing prevalence of asthma outcomes associated with the increased size of the swine operation (Merchant et. al. 2005). Children in North Carolina attending middle schools within 3 miles of one or more swine CAFOs and children attending schools where school staff report CAFO odors in school buildings were found to have a higher prevalence of wheezing compared with other middle school children (Mirabelli et al. 2006a, 2006b). It should be noted that these studies (although controlled) lack contemporaneous exposure assessment and health outcomes ascertainment. Additional research to include environmental exposure data related to biomarkers of response is needed.

Mental health. Living in proximity to large-scale CAFOs has been linked to symptoms of impaired mental health, as assessed by epidemiologic measures. Greater self-reported depression and anxiety were found among North Carolina residents living near CAFOs (Bullers 2005; Schiffman et al. 1995). This finding was not corroborated in a small study by Thu et al. (1997) of depression among people living near to or far from CAFOs. However, it should be noted that the study of Thu et al. differed in that residents were not asked to report on their mental state during an actual odor episode as was the case in the study by Schiffman et al. (1995).

Greater CAFO-related posttraumatic stress disorder (PTSD) cognitions have been reported among Iowans living in an area of CAFO concentration compared with Iowans living in an area of a low concentration of livestock production (Hodne CJ, unpublished data). PTSD cognitions were consistent with interviewees' multiple concerns about the decline in the quality of life and socioeconomic vitality caused by CAFOs, in areas of CAFO concentration with declining traditional family farm production.

Social health. One of the most significant social impacts of CAFOs is the disruption of quality of life for neighboring residents. More than an unpleasant odor, the smell can have dramatic consequences for rural communities where lives are rooted in enjoying the outdoors (Thu 2002). The encroachment of a large-scale livestock facility near homes is significantly disruptive of rural living. The highly cherished values of freedom and independence associated with life oriented toward the outdoors gives way to feelings of violation and infringement. Social gatherings when family and friends come together are affected either in practice or through disruption of routines that normally provide a sense of belonging and identity—backyard barbecues and visits by friends and family. Homes are no longer an extension of or a means for enjoying the outdoors. Rather, homes become a barrier against the outdoors that must be escaped.

Studies evaluating the impacts of CAFOs on communities suggest that CAFOs generally attract controversy and often threaten community social capital (Kleiner AM, Rikoon JS, Seipel M, unpublished data; 2000; Ryan VD, Terry Al, Besser TL, unpublished data; Thu 1996). The rifts that develop among community members can be deep and long-standing (DeLind 1998). Wright et al. (2001), in an in-depth six-county study in southern Minnesota, identified three patterns that reflect the decline of social capital that resulted from the siting of CAFOs in all six rural communities they studied: *a*) widening gaps between CAFO and non-CAFO producers; *b*) harassment of vocal opponents of CAFOs; and *c*) perceptions by both CAFO supporters and CAFO opponents of hostility, neglect, or inattention by public institutions that resulted in perpetuation of an adversarial and inequitable community climate. Threats to CAFO neighbors have also been reported in North Carolina (Wing 2002). Clearly, community conflict often follows the siting of a CAFO in a community. What is not known is if community conflict resulting from the siting or presence of CAFOs has an impact on the ability of communities to act on other issues.

Environmental injustice. Disproportionate location of CAFOs in areas populated by people of color or people with low incomes is a form of environmental injustice that can have negative impacts on community health (Wing et al. 2000). Several studies have shown that a disproportionate number of swine CAFOs are located in low-income and nonwhite areas (Ladd and Edwards 2002; Wilson et al. 2002; Wing et al. 2000) and near low-income and nonwhite schools (Mirabelli et al. 2006a, 2006b). These facilities and the hazardous agents associated with them are generally unwanted in local communities and are often thrust upon those sectors with the lowest levels of political influence. CAFOs are locally unwanted because of their emissions of malodor, nutrients, and toxicants that negatively affect community health and quality of life. Low-income communities and populations that experience institutional discrimination based on race have higher susceptibilities to CAFO impacts due to poor housing, low income, poor health status, and lack of access to medical care.

Failure of the political process. In 2005 the U.S. Government Accountability Office issued a report on the effectiveness of U.S. EPA efforts in meeting its obligations to regulate concentrated animal feeding operations (U.S. Government Accountability Office 2005). The report identified two major flaws:

a) allowing an estimated 60% of animal feeding operations in the United States to go unregulated, and *b*) lack of federal oversight of state governments to ensure they are adequately implementing required federal regulations for CAFOs. Additionally, many states have not taken a proactive stance to comply with the U.S. EPA regulations. Therefore, the concentration of livestock production, most noted by CAFO-style production, has continued to expand in most states. This has resulted in many rural communities and individuals taking action on their own, through local ordinances or litigation, as they have not been able to find access through usual governmental channels.

Several studies have found that property values decrease when CAFOs move into a community (Abeles-Allison and Conner 1990; Hamed et. al. 1999; Herriges et al. 2003; Palmquist et al. 1997). Neighbors of CAFOs are interested in preventing loss of property value, loss of their homes and land, forced changes in their life style, adverse changes in their communities, and threats to their health (Thu and Durrenberger 1998). The democratic process offers citizens access to lawmakers, to the courts, and to direct action to redress their grievances. However, the legislative process in many states has often been unresponsive to citizen wishes concerning CAFOs (Cantrell et al. 1996). For example, 13 states have enacted laws that inhibit citizens from speaking freely about agriculture if it is disparaging. A representative example can be seen in a South Dakota law that defines disparagement as

> dissemination in any manner to the public of any information that the disseminator knows to be false and that states or implies that an agricultural food product is not safe for consumption by the public or that generally accepted agricultural and management practices make agricultural food products unsafe for consumption by the public. (South Dakota Codified Laws 2006)

All 50 states have some form of right-to-farm legislation. This legislation serves to protect farming operations from zoning laws or lawsuits that would overly restrict the ability of farmers to do business (Chapin et al. 1998; Hamilton 1998). Right-to-farm legislation varies from state to state but may include laws that prevent zoning from limiting farm practices that have substantial detrimental effects on neighbors, such as CAFO production. Right-to-farm laws may also include preemption of other actions of local government that normally could limit what businesses are allowed to do, known as home rule. For example, the Iowa Supreme Court has ruled that county governments cannot use home rule powers or protection of public health to promulgate laws that are more restrictive than state laws currently in force (Worth County Friends of Agriculture v. Worth County, Iowa, 2004). Although local governmental action has been limited by the bias toward agricultural producers, individual actions have not. Courts in several states have ruled that right-to-farm laws give only limited protection from nuisance action. The Iowa Supreme Court in June 2004 found that CAFO immunity provisions written in Iowa statutes were unconstitutional (Gacke v. Pork XTRA 2004). A district court in Illinois granted a temporary injunction stopping the construction of a nearby CAFO based on an anticipatory nuisance premise (Nickels et al. vs. Burnett 2002) that such a facility would constitute reasonable interference with neighbors' quality of life.

Most states have enacted some forms of environmental laws aimed at protecting the environment from agricultural discharges or emissions. One form of these laws requires establishment of manure management plans. Typically, these laws call for certain sizes of operations to apply for permits. These permits may include the filing of a manure management plan, which calls for a plan for CAFO operators to manage their manure in a manner to prevent water and soil pollution. However, there is little if any performance inspection or enforcement of these plans (Jackson et al. 2000). Nonenforcement is primarily due to the lack of personnel and technical resources at state environmental agencies. For example, some states may have 2,000 or more such operations but not enough staff to efficiently process permit applications, much less get out into the field to inspect performance of these operations.

Workshop Recommendations

Priority research needs. **Community health studies**. Although sufficient research supports actions to protect rural residents from the negative impacts of CAFOs on community health, additional research could be conducted to further delineate mechanisms of effects and impacts on susceptible subgroups. These areas include psychophysiologic impacts of malodor; impacts of malodor on mental health and quality of life; and respiratory impacts of bioaerosol mixtures, especially among asthmatics, children, and the elderly. Wider and more effective application of community-based participatory research will be important to advance research in these areas.

Sustainability of livestock production. Federal funding for agricultural research should be reoriented to promote innovation in sustainable livestock production.

Translation of science to policy. Requirements for issuing permits for CAFOs should include increased protections for health and the environment including the following:

- CAFOs should be sited and issued permits on the basis of total animal density allowed in a given watershed as determined by the carrying capacity.
- Environmental impact statements should be mandated for all new CAFOs. These should include environmental health, social justice, and socioeconomic issues.
- Decisions to issue permits for CAFOs should be considered in public meetings and decided at the local level.
- CAFOs should be regulated using standards applied to general industry based on the level of emissions and type of waste handling.
- Permits for manure storage basins should require bonding for performance and remediation.
- The current state of knowledge of community impacts of CAFOs warrants support for the American Public Health Association recommendation for a moratorium on all new CAFO construction.

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