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Addressing Externalities From Swine Production to Reduce Public Health and Environmental Impacts

Animal agriculture in the United States for the most part has industrialized, with negative consequences for air and water quality and antibiotic use. We consider health and environmental impacts of current US swine production and give an overview of current federal, state, and local strategies being used to address them. (*Am J Public Health.* 2004;94:1703–1708)

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ONE OUTCOME OF THE industrialization and concentration of animal agriculture is that the vast majority of animals now raised for food in the United States live within concentrated animal feeding operations (CAFOs). This change has imposed costs on society, the full dimensions of which are only beginning to be appreciated. In this article, we consider some of the health and environmental impacts as economic "externalities" and give an overview of current federal, state, and local strategies being used to address them.

ECONOMIC EXTERNALITIES AND ANIMAL AGRICULTURE

Today's livestock and poultry facilities produce more animals, in more specialized buildings, on less acreage per animal than ever before. In 1966, 57 million hogs lived on 1 million American farms; by 2001, roughly the same number of hogs were on just over 80 000 farms, and fewer than 5000 farms accounted for more than half of all hogs produced in the United States.[1,2] The largest hog operations average 16.7 hogs per acre, the smallest just 1.4 hogs per acre.[2]

CAFO operations have also become more specialized. In Iowa, the largest producer state, 70% of farms had hogs as part of their farming operations in the 1960s, compared with approximately 12% in 2000.[3] Until the late 1980s, a typical hog farm raised fewer than 1000 animals from farrow (birth) to finish (ready for slaughter), and feed was from crops largely grown on-farm. Now it is common to have 4000 sows within a single breeding facility, each sow producing litter after litter. After early weaning, "feeder" piglets by the thousands are moved to "finisher" barns, where in 6 months as many as 12 000 pigs grow from about 50 to 250 pounds before being slaughtered. Industrialization also means that food animals have been largely brought indoors, and grain and other feedstuffs must be imported by the ton to serve them.

Manure waste must be disposed of, also by the ton. Manure from confined animal operations is 3 times the nation's volume of human waste.[4] Because it is uneconomical to transport for any distance, manure typically is stored in pits under buildings, or in lagoons adjacent to buildings, and later is applied to nearby fields. However, the largest CAFO facilities typically lack sufficient acreage to absorb manure nutrients. According to a survey by the US Department of Agriculture (USDA), "Large operations tend to view manure as a waste rather than a resource and dispose of it on land closest to the facility. For example, the 6% of farms larger than 1000 animal units [approximately 2500 market hogs] were estimated to generate 65% of the excess nitrogen and 68% of excess phosphorus in 1997."[2] Excess nutrients are those that exceed the nutritional needs of cropland.

The Environmental Protection Agency (EPA) reserves the term CAFO for animal feeding operations of at least 1000 animal

units, for example, 2500 large pigs or 100 000 chickens. We use CAFO to describe any concentrated animal feeding operation. Manure excess is an important public health issue. Excess nitrogen in drinking water may contribute to human disease. Manure contains pathogens that can cause severe gastrointestinal disease and complications, even death. Concentrations of manure can lead to elevated levels of toxic gases, like hydrogen sulfide and ammonia, resulting from manure degradation. Finally, manure can contain arsenic and other heavy metal compounds, as well as antibiotics, that are routinely added to animal feeds. Manure and manure-related contaminants readily move off-site in water and air.

In economic terms, air and water pollutants from CAFOs are classic externalities. Reservoirs of antibiotic resistance, to which CAFOs using antibiotic feeds clearly contribute, also are an externality. Each externality entails costs that are not directly borne (i.e., not internalized) by food animal producers and signals a market distortion or inefficiency.

Welfare economics theory assumes that markets would improve if these costs or externalities were more explicitly incorporated into a CAFO owner's decisions. Theoretically, producers could be forced to reduce pollution or to pay others to directly compensate for the external costs imposed on them.[5] Alternatively, those harmed by pollution could pay producers to take steps to avoid or reduce the pollution. In real life, the former typically occurs via government regulation under threat of fines or court action, whereas the latter might occur through subsidies offered by government agencies (such as the USDA) assumed to be acting on behalf of members of society who bear the brunt of the costs. Three kinds of externalities are described below, along with possible policy responses.

Water Quality and CAFOs

Current farming practices are responsible for 70% of the pollution in the nation's rivers and streams.[6] Although sediment, nutrients, and pesticides make up much of this water contamination, manure is a large contributor because there is so much of it. An EPA inventory of water pollution problems finds that "improperly managed manure has caused serious acute and chronic water quality problems throughout the United States."[4(p7176)]

Microbes break down the nitrogen in manure into nitrate, and studies have found both waste lagoons and cropland application of manure correlate with groundwater nitrate levels.[7] Infants and others drinking nitrate-contaminated water can develop methemoglobinemia, or "blue-baby syndrome," a potentially fatal condition. An estimated 4.5 million Americans drink water from wells containing nitrates above the 10 mg/L standard set by the EPA to prevent this disease.[8]

Three microbes commonly found in livestock—*Escherichia coli, Campylobacter,* and *Cryptosporidium*—have caused serious disease outbreaks via contaminated drinking water. In 1993, manure runoff from dairy feedlots along rivers contributing to Milwaukee's water supply was implicated in a *Cryptosporidium* outbreak in that city, the nation's largest waterborne disease event to date. Over 400 000 persons fell ill with diarrhea, cramps, fever, and vomiting, and at least 54 died.[9,10]

CAFO-related water pollution can stem from manure lagoon spills or leaks, from direct runoff from buildings, and from fields where manure has been applied. Rare lagoon breaches capture brief public attention: in 1995, after hurricane rains, 2 lagoons burst in North Carolina, releasing 34 million gallons of animal waste into nearby water bodies.[11] But manure spills and leaks are commonplace; indeed, the latter are expected. State laws in Iowa, for example, authorize a legal leakage rate for a 7-acre manure lagoon of up to 16 million gallons annually. Moreover, one Iowa study found that more than half of the manure storage structures tested leaked at rates above the legal limit.[12] There are approximately 5600 such structures in the state. The Environmental Integrity Project report documented 329 manure spills in Iowa between 1992 and 2002. For 307 spills for which the cause was known, failure or overflow of manure storage structures accounted for 24% of the spills (Table 1). Other important causes were uncontrolled runoff from open feedlots, improper manure application on cropland, and equipment failures. Surprisingly, 18 spills, or 6%, were from deliberate actions such as pumping manure onto the ground or deliberate breeches in storage lagoons.[13]

Besides effects on local water bodies, the nitrogen and phosphorus from spills and other nonpoint loadings can exert downstream impacts. Hypoxia is one consequence of Midwest nutrient application. In this context, hypoxia is used to mean the lowering of dissolved oxygen in a water body to levels that cannot support most animal life. Hypoxia occurs each summer in the Northern Gulf of Mexico, when decomposing organic material consumes more oxygen than the system generates through photosynthesis. As oxygen levels drop, marine organisms grow more slowly. As levels drop further, mobile organisms leave the area, and finally those that remain die. Fishers who harvest shrimp in the Gulf have

TABLE 1—Determined Causes of 307 Major Iowa Manure Spills: 1992–2002

Identified Causes	No. Spills	Percentage of Total
Failure or overflow of manure storage structures	74	24
Uncontrolled runoff from open feedlots	56	18
Improper application to cropland	43	14
Equipment failure	73	24
Deliberate spills (pumping manure to the ground; deliberate breaches in storage lagoons, etc.)	18	6
Other (e.g., transportation accidents)	43	14
Total	307	100

Source. Merkel M.[13] Data are from 3 Iowa Department of Natural Resources (IDNR) databases: IDNR Fish Kill Database; IDNR Enforcement Database, and IDNR Emergency Response Database.

seen their catch per unit of effort decline, although there is not yet a statistically significant correlation between catch and hypoxia.

One of the primary causes of hypoxia in the Gulf is excess nitrogen delivered by the Mississippi–Atchafalaya river system: 56% of excess nitrogen originates from nonpoint sources above the confluence of the Ohio River, and another 34% from the Ohio River itself.[14] The USDA states, "In the Mississippi River's drainage basin, animal manure was estimated to contribute 15% of the nitrogen load entering the Gulf of Mexico."[15(p8)]

Air Quality and CAFOs

Donham reports that it was only in the late 1970s, a decade after swine production first came "indoors," that health hazards of CAFO production workers were seriously examined. He points out that although these workers are at risk for "traumatic injuries, noise-induced hearing loss, needle sticks, hydrogen sulfide and carbon monoxide poisonings, and infectious diseases,"[16(p568)] respiratory illness is the most recognized occupational risk. Air inside confinement buildings can exert a variety of effects (Table 2).

TABLE 2—Respiratory Diseases Associated With Swine Production

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

Source. Reproduced from Donham KJ.[16(570)]

Diminished air quality also poses a public health concern for those living or recreating near lagoons, buildings, and fields where manure is stored or applied. Degrading animal manure and urine produces a complex mixture of dust particles, bacteria, endotoxins, hundreds of volatile organic compounds including hydrogen sulfide and ammonia, and odors.[16] The downwind concentrations of manure-related aerosols are of course lower than those within confinement buildings, and the exact composition of ambient air contaminants differs; nonetheless, young children, asthmatic people, elderly people, and others with respiratory conditions may be especially vulnerable to airborne CAFO discharges.[16]

An association between health problems and air emissions from CAFOs in Iowa was documented in 2002 by a joint report from a team of researchers from both Iowa State University and the University of Iowa, assembled at the request of Governor Tom Vilsack. The team used a "weight-of-evidence" approach to evaluate evidence of (1) known occupational hazards, (2) 3 studies of neighbors exposed to air emissions from CAFOs, (3) exposure limits for hydrogen sulfide and ammonia established by the Agency for Toxic Substances and Disease Registry and the EPA, and (4) state regulations for hydrogen sulfide, ammonia, and odor. On the basis of their evaluation, the 2 major Iowa universities jointly stated that there was evidence that for neighbors "CAFO air emissions may constitute a public health hazard."[17(p7)]

CAFO air emissions can travel beyond the immediate neighborhood. Ammonia alone can "impact atmospheric visibility, soil acidity, forest productivity, terrestrial ecosystem biodiversity, stream acidity, and coastal productivity."[18(p43)]

Antibiotic Use and Increasing Resistance

The growing resistance of bacterial infections to antibiotic treatment is a global crisis. Antibiotic overuse is a key factor because greater exposure to antibiotics tends to select for more bacteria that are resistant as well as for more resistance among those bacteria. Industry and other estimates agree that at least 20 million pounds of antibiotics annually are given to animals to promote growth or compensate for the heightened infection risk of raising animals under confined, stressful conditions.[19–21] The Union of Concerned Scientists estimates that 13 million pounds of those antibiotics used annually in livestock and poultry are "medically important," that is, identical or closely related to antibiotics used in human medicine.[21] This is more than 4 times the estimated annual amount of these same medicines given to humans.

The emerging scientific consensus is that this routine antibiotic use in animal feeds contributes to increasing antibiotic resistance transmitted to humans, typically (although not exclusively) by way of contaminated food.[22,23] Several studies confirm that retail poultry and ground meat products are routinely contaminated with pathogenic bacteria, a significant percentage of which are resistant to 1 or multiple antibiotics. A microbiological understanding of resistance and limited testing suggest that poultry products from birds raised organically, or otherwise without routine antibiotics, may carry lower levels of antibiotic-resistant bacteria.[24]

Responding to concerns about human resistance to antibiotics, some meat retailers have altered their meat-purchasing policies. In June 2003, McDonald's Corp announced it would buy meat preferentially from suppliers who use fewer medically important antibiotics for growth promotion.[25] In December 2003, Bon Appétit, a food service provider to corporations, universities, and other clients in 21 states, announced a similar policy of preferential purchasing from producers who use fewer medically important antibiotics for any nontherapeutic purpose.

CAFO use of antibiotics likely contributes to antibiotic-resistant bacteria being found in rural environments, as well as in food. It is estimated that as much as 75% of antibiotics given to food animals is excreted in urine and feces.[26] The US Geological Survey has detected residues of antibiotics at low concentrations in nearly half of 139 streams surveyed nationwide. Livestock production facilities were upstream of 45% of the sites surveyed, although wastewater treatment plants were also implicated.[27] A recent study found antibiotics in approximately one third of surface and groundwater samples

proximal to large-scale swine operations, and in about two thirds of samples proximal to large-scale poultry facilities.[28] Antibiotic residues are also detected in manure lagoons, and studies show that manure lagoons and sprayfields can leach antibiotic-resistant bacteria, in addition to antibiotics and other contaminants, into surface and groundwaters.[29,30] An Illinois study found that bacterial genes conferring resistance to the antibiotic tetracycline migrated directly from swine manure lagoons into underlying groundwater and then traveled at least 250 meters by way of subsurface water flow.[26]

Antibiotic residues persist in manure-applied soil, and in the dust of swine finisher buildings to concentrations as high as 12.5 mg/kg of dust.[31] Not surprisingly, antibiotic-resistant bacteria have also been found at higher concentrations in soil and air emissions from livestock facilities that used feed antibiotics at lower-than-therapeutic levels (20 g/metric ton of feed), compared with facilities not using feed antibiotics.[32,33]

POLICY RESPONSE

As the scientific evidence of public health risks from industrialized animal agriculture continues to increase, policy responses are emerging from a variety of sources, from corporate meat-purchasing policies to the 2003 policy statement by the American Public Health Association (APHA).[34] Citizen responses have also taken various forms, from protests to court actions.

Environmental health laws generally emerge from federal, state, and local levels of government. To keep laws consistent, it is common for higher levels of government to constrain (or preempt) lower levels, and in the case of environmental legislation, state governments occasionally prevent local governments from passing stronger environmental health standards. Preemption of local action has been widely discussed in the literature.[35]

CAFO owners and their supporters must realize it is cheaper and easier to influence only 1 legislative body when they exert a preference for regulation at the state rather than local level; certainly the expense of monitoring and lobbying decisions by hundreds of different local governments would far exceed the costs of operating at the state level.

The federal government has the power to regulate water quality associated with animal agriculture under the Clean Water Act, although the EPA admits that compliance with existing Clean Water Act regulations has been inadequate and the regulations themselves have needed revision.[4] In early 2003, the EPA updated its rules to require the largest CAFOs to acquire permits regulating future water discharges. Air regulation of CAFOs is also on the table. Currently, the EPA and some of the largest animal producers are negotiating an agreement on air emissions that would effectively exempt CAFOs from immediately meeting requirements under the Clean Air Act in exchange for voluntary Clean Air Act compliance and testing of emissions.[36]

Water and air quality of CAFOs are a recent interest of the federal government. Consequently, state and local governments have been the focus of activity until the last few years. In Iowa, which produces the most hogs in the nation, there have been attempts to control CAFOs through a combination of state statutes, county ordinances, and court action by individuals.

The first major Iowa law that placed restrictions on CAFO operators, which passed in 1995, attempted to balance protection of Iowa's environment and neighbors with continuation and expansion of the hog industry. Manure management plans were required of the large producers. Separation distance requirements of CAFOs from neighbors and public use areas were intended to reduce conflicts over air emissions and odor. A 2002 law extended the separation distances, reduced the size of operations needing construction permits, and included limits on air quality for the first time. Both laws sought to constrain local government from legislation in this area, although the new law gave local governments a very limited say in where CAFOs might be sited.

The joint report from the Iowa universities described previously resulted in 2002 state legislation that called for emission limits on hydrogen sulfide, ammonia, and odors. On the basis of this law, the Iowa Department of Natural Resources is making its second attempt to write rules on hydrogen sulfide from animal production units.

The Iowa Department of Natural Resources has attempted to reduce the manure discharges into state waters by fining perpetrators and assessing restitution for the value of some fish species killed. The state legislature has limited the maximal penalty per violation per day for discharges to $5000.[37] Therefore, the cost to a polluter is rather modest. For example, the fine for the largest manure spill (1.5 million gallons in 1995) was only $8000 because so few fish had formerly lived in the stream hit by the discharge.[13] For the crime of contaminating a drinking water aquifer, the state assessed a $3000 fine for pollution of groundwater, and the EPA levied an additional $10 000 fine under the authority granted it by the federal Safe Drinking Water Act.[13]

Local governments have historically not been eager to place limits on agricultural operations, but the increasing size and corporate ownership of animal-feeding operations are influencing their decisions.[38] Counties have been limited in their actions with respect to CAFOs, however. The Iowa Supreme Court held that all agriculture, including an animal-feeding operation, is exempt from any county zoning. Humboldt County in 1996 attempted to put controls on CAFOs as a proper application of "home rule" authority but lost in the Iowa Supreme Court. In the face of state preemption, a Worth County, Iowa, ordinance sought to regulate CAFO operators based not on home rule but on the county's ability to protect public health. The public health ordinance was struck down by a district court in March 2003 and is now under appeal. Some counties have attempted to influence CAFO siting through so-called moratorium resolutions, but these may not be legally binding.

Direct action by citizens at the local level can impact public policy through a combination of petitions, packing of courthouse meetings, and protests.[39] More than 600 citizens showed up to protest a proposed egg plant near the Iowa community of Clear Lake; soon after, plant proponents decided not to locate there.

In December 2003, citizens were able to administratively overturn a construction permit for a hog facility.[40] Such behavior is not limited to Iowa.[41]

Local citizens seeking to control CAFOs can also bring a private cause of action under a nuisance claim, although some states have attempted to blunt individual legal action through "right-to-farm" legislation. Such laws are based on the principle that "existing farm operations should not become nuisances due to the later development of non-agricultural uses in the surrounding area."[42(p104)] However, CAFOs have often arrived later than established residents in rural communities and often cause harm to established farmers.

More recently, 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.[43,44] Several CAFO nuisance suits are in the Iowa courts at this time including an October 2002 decision (now settled), which obtained a jury verdict for the plaintiff of $1 million for actual damages and $32 million for punitive damages. Nuisance suits may prove to be a powerful incentive for CAFO owners to reduce emissions in Iowa and other states.[45]

CONCLUSIONS AND RECOMMENDATIONS

Concentrated, industrialized food animal production predominates in the United States today. Although we have focused on Iowa—the number 1 state in hog inventory and hog production—the situation is similar throughout the Midwest. In North Carolina, the second biggest hog-producing state, problems with CAFOs caused the legislature to institute a moratorium on new facilities in 1997; the moratorium has been extended and is still in place today.

CAFOs have public health impacts. CAFO workers suffer documented ill effects from manure-related gases, odors, and degradants; dust; bacteria; and endotoxins. CAFOs, including swine CAFOs, produce water and air emissions that may affect the health of neighbors, surrounding communities, and the environment. CAFOs also make routine use of antibiotics and other feed additives to offset the greater risk of infection from the concentration and accelerated production of animals. This contributes to the global crisis of antibiotic resistance.

Our conventional economic and regulatory models have thus far done a poor job of addressing the environmental health impacts of CAFOs. From an economist's perspective, the prevailing methods of producing livestock and poultry carry many externalities. Historically, producers have not internalized these costs, either voluntarily or by necessity. In theory, organizational, governmental, or legal action could serve as potential mechanisms for reducing those externalities. As discussed, nuisance lawsuits have in a few isolated situations given neighbors some legal leverage over CAFO emissions affecting their health or quality of life. In Iowa and elsewhere, there have also been some recent attempts to better address CAFO emissions through legislative or regulatory means, but their efficacy in terms of protecting public health remains under question. Federal action is too recent to evaluate.

As new purchasing policies by McDonald's and Bon Appétit demonstrate, retail corporations can exert some leverage over the livestock practices of their suppliers. But these policies are somewhat limited to 1 aspect of meat production—the routine use of medically important antibiotics—and in any case are no substitute for enforceable, verifiable regulation of pollution practices.

Given the ongoing disconnect between the certain impacts of CAFO emissions on worker and public health, and the so-far-inadequate policy response to the problem, perhaps APHA has the right idea in trying to address these problems:

> Therefore, the American Public Health Association hereby resolves that APHA urge federal, state and local governments and public health agencies to impose a moratorium on new Concentrated Animal Feed Operations until additional scientific data on the attendant risks to public health have been collected and uncertainties resolved.[34]

By placing the burden on proponents of new CAFOs to demonstrate the safety of future operations, the APHA approach presumably would spur more innovative animal production methods, or at least ones with lower risk impacts on air emissions, water quality, and the effectiveness of antibiotics. ■

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Contributors

D. Osterberg contributed to the sections on water quality, air quality, and public policy. D. Wallinga contributed to the sections on water quality, antibiotic resistance, and public policy. Both authors helped to conceptualize ideas and interpret findings and reviewed drafts of the article.

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