2010

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Recommended Citation

Stillman, Leland, "Pollution and Public Health in a Shrinking World: Concentrated Animal Feeding Operations as a Paradigm for Emergent Needs in Environmental and Public Health Policy" (2010). *Self-Designed Majors Honors Papers*. 2.
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Pollution and Public Health in a Shrinking World:

Concentrated Animal Feeding Operations as a Paradigm for Emergent Needs in Environmental and Public Health Policy

by Leland Stillman

Abstract

Environmental factors play a major part in human health. Environmental pollutants are often as poisonous to humans as the environment. Presently, much time and energy is dedicated to keeping pollution apart from human society, with varying success. But as global population densities rise, current levels of pollution will become inviable due to public health concerns. An emergent example of this is in the concentration of livestock operations. Recent changes in the structure of U.S. hog farming have resulted in an industry-wide shift from small or medium production farms to high capacity, “concentrated animal feeding operations” (CAFO). These operations have become the subject of intense debate due to air and water pollution, including odor, that can be nuisances or outright public health threats to their communities. In addition, the quantities of animal wastes produced and seasonally sequestered by these operations can be accidentally released via natural processes like floods, often with catastrophic results. Finally, the animals live in conditions of high stress and poor hygiene that are conducive to disease and so most operations therefore feed their animals antibiotics on a regular basis. Recent studies have found increased incidence of antibiotic resistance resulting from this chronic application of antibiotics. Current regulations have failed to resolve these problems, and in 2003 the American Public Health Association issued a call for a moratorium on CAFO construction. The purpose of this paper is to explore economic and legal solutions to this harmful shift in industry structure.

Table of Contents

List of Figures

I. Introduction

In 1522, Ferdinand Magellan completed his first circumnavigation of the world, proving to the Western world that the earth was in fact round. Though perhaps few noted it at the time, this implied a disturbing corollary; the resources of the earth were limited.

Since then, people have asked, what is the final capacity of the earth to support human life? This is by no means a straight-forward question; the answer to such a question must take into account nothing less than all the biotic and abiotic factors of the biosphere. Estimates range into the billions, while some advocate population reduction to millions. Ergo, the endless quality of the debates over carrying capacity and the sustainability of human civilization.

In its grossest terms, however, the question comes down to one of global thermodynamics; how much energy can be harnessed from the sun to support human life? Part of this question is how much food can be produced.

The importance of agriculture has been inescapable since its innovation and the rise of settled human populations. In the United States agriculture has been valorized and fostered since the country's founding. Thomas Jefferson once wrote:

> I should wish [that]... all our citizens would be husbandmen. Whenever, indeed, our numbers should so increase as that our produce would overstock the markets of those nations who should come to seek it, the farmers must either employ the surplus of their time in manufactures, or the surplus of our hands must be employed in manufactures or in navigation. But that day would, I think, be distant.
>
> - Thomas Jefferson to G. K. van Hogendorp, 1785. ME 5:183, Papers 8:633

Jefferson might have marveled to know that just 225 years after the writing of this letter, his dream of overwhelming agrarian surplus has been realized. The Midwest is dotted with grain silos the size of what were in Jefferson's day mansions of the greatest magnitude, the modern

American has the luxury of eating meat every day, and it is all accomplished with the industry of less than 1% of the population (Demographics, EPA, 2009). The revolution in agricultural production has occurred in a very short time, only within the past several decades, catapulting American agriculture from the Jeffersonian paradigm of the yeoman farmer into something new.

Mention of the American farm may bring to mind images of quaint farmhouses set in rolling hills or big-sky plains, owned and operated by independent, rugged - quintessentially American - farmers. This was the reality of American agriculture until relatively recently. The current reality is one of sprawling monocrop farms reaching from one end of a state to another, of industrial fertilizers and pesticides dropped from planes or spread by massive combines, and factory farms where animals never see the sun and live in their own wastes. The cultural memory of agriculture persists as a veil for what it has become, an industry as inhumane as the mines and factories of Dickens and Sinclair.

The epitome, the pinnacle of this centralized, industrial production are animal feedlots, more properly referred to as “concentrated animal feeding operations.” Over the past thirty years, CAFOs have become the norm for animal agriculture in the United States. These operations are large scale industrial facilities where animals are confined from birth to slaughter, where the farmers grow no crops and, frequently, where there is no pasture. These operations can house tens of thousands of animals, an exponential increase over the numbers of animals in traditional farms. Every year the United States produces more than 72 billion pounds of meat, 180 billion pounds of milk, and 77 billion chicken eggs (NASS, 2010). The vast majority of these are produced by CAFOs.

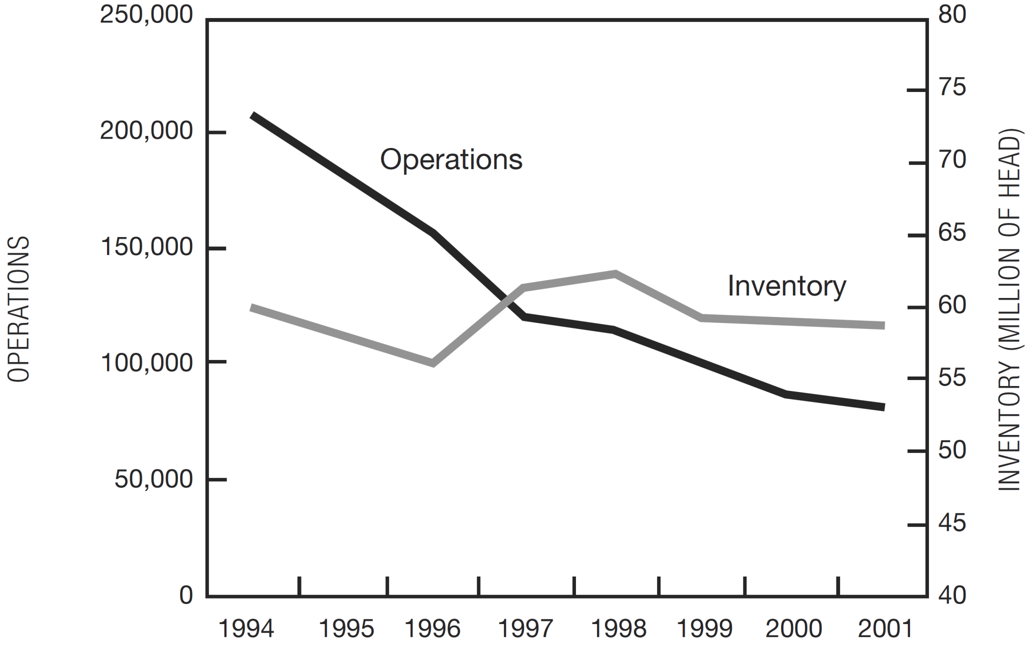

Figure 1: Number of Hog Operations and Inventory of Hogs. Source: Gurian-Sherman, 2008.

Pollution is a problem as old as agriculture. The abandonment of nomadic for settled lifestyles introduced the possibility for significant build up of dangerous waste products, first in the form of excreta and urine, from both humans and animals. Agrarian societies quickly realized the importance of using organic wastes as fertilizer, and most adjusted to dispose of wastes with relatively little public health impact (with the notable exception of cities for most of history). During the Industrial Revolution, agricultural pollution became overshadowed by pollutants from other industries. The advent of the flush toilet and wide spread implementation of basic sanitation by municipalities further removed agricultural wastes from the public concern.

The industrial revolution has since come full circle. Industrial processes eventually were developed to produce nitrogen, one of the limiting nutrients in plant growth. This allowed for the production of synthetic fertilizers, improving crop yields dramatically. In the 1940's, science and technology began to advance agricultural productivity in the so called “Green Revolution,” introducing pesticides, improved breeding of crops, and in more recent decades, genetically modified crops. But these advances in agriculture carry public health risks of their own, and so the industrial revolution which in many ways left public health better protected from agricultural pollution and facilitated unprecedented agricultural productivity has proven a double edged sword.

CAFOs are the pinnacle of this industrialized agriculture for a number of reasons. Raising animals in such concentrated conditions requires large imports of foods, foods which are ideally non-perishable and inexpensive. Only the wide spread use of fertilizers and pesticides can grow cereals in such quantities at low cost. The result is the incredible productivity of the American livestock industry, but for the billions of pounds of food produced, there are also more than 317 million metric tons of animal wastes produced annually. But whereas before CAFOs, animal wastes could be used as fertilizers, the concentrated nature of production renders this unsafe. Wastes must now be sequestered, treated, and somehow disposed of without the catastrophic impacts they might have on public health and the environment. Wastes are stored in pits (if solid), lagoons (liquid and solid), or piles (again, if solid), and are disposed of by application as fertilizer. But storage containers are subject to natural events like flooding and rainfall, which carry pollutants into groundwater or river systems. Wastes are often over applied to agricultural fields, and are subject to the same water borne problems as when stored. Even in their storage forms, wastes emit substantial quantities of gases, and the farms themselves emit particulate matter. Animal agriculture has thus become one of the greatest polluters of both air and water in the United States.

Considerable debate exists as to what level of precaution must be taken in dealing with animals wastes, specifically from CAFOs. The result is that significant public health problems have arisen, so severe that in 2003 the American Public Health Association called for a moratorium on CAFO construction. There have been significant calls for government to step in regulate the industry to prevent injury to the public or the environment. These have met with mixed successes. Despite improved government regulation, many experts are still calling for more stringent regulations, and many for an end to the CAFO production system. There are also those who oppose increased regulations. Industry proponents argue that increased regulations are unfair to interferences in the free market. Farmers complain that increasing regulations will increase their costs and force them out of business. "Right to farm" statutes exist in several states to protect the interests of farmers and industry. This dichotomous conflict is typical of environmental and public health policy debates.

Policy makers have thus sought to balance industry demands with public health and environmental concerns. This balance implies two extremes; first, the demands of industry, who if allowed to pollute *ad libitum* could achieve higher production and profit margins, resulting in increased economic growth, and second, the desire of citizens for pristine environmental quality. These interests have competed with one another since the first complains about CAFOs. However, at that time the public health effects of CAFO pollution were unclear. The literature has since grown extensively, and a whole generation of work stands as evidence that CAFOs are taking a significant toll on public health. The challenge before policy makers is how to reformulate policy to protect public health while incurring the least damage to industry.

Surprising findings have been made in all these areas of research. CAFO pollution is more pernicious than was previously thought. It has the potential to affect massive populations both directly and indirectly, and even has public health ramifications for the global community. But perhaps more surprising is that CAFOs are not an economic necessity arising from normal market forces; they are the result of market failure. Government subsidies and unassessed externalities (not to mention import tariffs) allow CAFOs to sell their products at lower than their actual cost of production, with the public shouldering the burden of environmental remediation and subsidization. These findings point to a free market environmentalist approach to CAFO regulation and to environmental regulation in general, a model in which property rights must be very carefully and strictly established to allow people to negotiate environmental factors or to uphold their rights to environmental quality, regardless of the protests of industry. Finally, this thesis concludes that in the case of both public health and economics, the ideal is realized when scientific efficiency is optimized, and that the best way of achieving that optimization may lie in free market environmentalism.

In the first section, I review the literature on CAFO pollution and public health. This literature review focuses on types of CAFO pollution and the pollutants in each category, their characteristics, concentrations, and health effects, and then lists incidences in which actual public health cases have been reported.

Second, a review of the policy concerns for CAFOs and the economic issues at stake must be made to determine what interests oppose possible increased regulation. This review highlights some of the economic research being done into industry dynamics and structure, and how policy should respond to the problems posed by CAFOs.

II. Literature Review

(a) Air Pollution

Hazardous air pollution from CAFOs takes a number of forms. Pollutants range in size from small molecules to coarse particulate matter, and include: methane, hydrogen sulfide, ammonia, carbon dioxide, endotoxins, microbes, volatile organic compounds (VOCs), bioaerosols, and dust. Pollutants are produced either directly by animals or during waste storage. These pollutants are produced by any livestock operation, but the high density of animals at CAFOs results in larger concentrations. Size of CAFOs, number of operations in proximity, terrain, and other atmospheric variables, such as temperature, humidity, wind, etc., all impact the prevalence of CAFO air pollutants.

The severity of air pollution has been well characterized in the literature, though data on specific health effects is lacking. What is clear from the data and other epidemiological investigations, is that the additive effects of these pollutants cause health effects below the normal toxicity thresholds of individual pollutants. Pollutant concentrations that are multiple orders of magnitude smaller than established toxic thresholds can elicit health effects, some of which might not even have been expected. The indication is that the full health effects of CAFO pollution are not understood, an important consideration in the formulation of policy.

1. Chemical Species

Ammonia, hydrogen sulfide, methane, and carbon dioxide are the chief chemical species produced by CAFOs. VOCs are a category of gaseous pollutants which are also emitted from CAFOs in large concentrations. The gases emitted by CAFOs are of significant concern both for their environmental damage and their effects on human health. These gases are low molecular weight compounds which are produced either directly by the animal, or from storage of wastes in open lagoons. Gaseous pollutants are typically degraded in the atmosphere by reaction with hydroxyl radical (Baird and Cann, 2005, pg. 71).

i. Ammonia

Characterization

Ammonia is produced as an end product of the degradation of urea and organic matter by anaerobic bacteria in waste lagoons (U.S. EPA, 2001, cited in Blunden and Aneja, 2008). It is a volatile gas occurring at ambient levels below the parts per trillion range and up to 5.6 ppb (Toxicological Profile for Ammonia, 2004). It has a lifetime in the atmosphere of 1 to 5 days, approximately, and may deposit through wet or dry mechanisms (Warneck, 2000, cited in Blunden et al., 2007). While ammonia neutralizes acids in the atmosphere, it also forms ammonium sulfates and nitrates, which are the principle particulate components of smog (Renard et al., 2004). Studies have found odor detection levels for ammonia ranging from 25 ppm to 53 ppm (Toxicological Profile for Ammonia, 2004).

Concentrations

Wilson and Serre (2006) found elevated levels of ammonia at schools near swine CAFOs. Mean concentrations were found to increase with decreasing proximity to CAFOs. Another study by Wilson and Serre (2007) found mean ammonia concentrations of 13.8 ppb near homes and schools less than 2 km from swine CAFOs, with sample values as high as 80 ppb. The study further confirmed the authors' previous correlation between CAFO proximity and atmospheric ammonia concentration.

Health Effects

The U.S. EPA inhalation reference concentration (RfC) exposure level is 100 μg/m3 (Ammonia, 1991). The reference concentration is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (Summary of the Toxicity Assessment of Hydrogen Sulfide, 2004). The state of California sets its inhalation reference exposure level at 200 μg/m3 (300 ppb) (Chronic Toxicity Summary, 2000). The California Office of Environmental Health Hazard Assessment notes that nasal lesions have been recorded in rats at exposures of 250 μg/m3 (Broderson et al., 1976, cited in Chronic Toxicity Summary, 2000). The Agency for Toxic Substance and Disease Registry sets its minimum risk level for chronic exposure (365 days or more) at 0.1 ppm (Toxicological Profile for Ammonia, 2004).

ii. Sulfur Compounds

Sulfur compounds are produced liberally by CAFOs in the manure degradation process, whether in lagoons, manure piles, or land application as fertilizer. The predominant sulfur compounds produced are hydrogen sulfide (H_2S), carbon disulfide, dimethyl sulfide (DMS), and mercaptans (IAQS, 2002, pg. 88). These compounds can undergo reactions in the environment to form other sulfur compounds, such as methane sulfonic acid (MSA) or sulfuric acid (H_2SO4) (IAQS, 2002, pg. 89). Sulfuric acid in the atmosphere produces acid rain.

These chemicals have varying lifetimes, and by extension varying geographic ranges. Likewise, they interact with the atmosphere in varying ways, resulting in different environmental fates (i.e. deposition and degradation). Hydrogen sulfide and DMS are quickly degraded by hydroxyl radical, MSA forms aerosol particles that serve as cloud condensation nuclei, thereby altering weather effects on a regional or global scale. Some of these pollutants have very long lifetimes in the environment. Carbonyl sulfide, for example, has a lifetime of 44 years (IAQS, 2002, pg. 89). Aside from human impacts, these chemicals are altering the environment on a regional and ultimately a global scale, and the full consequence cannot be predicted. Below I discuss sulfur compounds in more detail.

1. Hydrogen Sulfide

Characterization

Hydrogen sulfide is one of the chief malodorous pollutants from CAFOs. It has a very low odor threshold of 0.0005 to 0.3 ppm, and so the odor effects may still exist far from the site (Toxicological Profile for Hydrogen Sulfide, 2004). Hydrogen sulfide is a reduced form of sulfur that is typically eliminated from the environment by reaction with hydroxyl radical (IAQS, 2002, pg. 89). Hydrogen sulfide generally persists in the atmosphere for no more than one day, though in colder temperatures it can persist up to 42 days (Hydrogen Sulfide: Human Health Aspects, 2003). Odor is generally detectable at concentrations greater than 12 ppb (Collins and Lewis, 2000).

Concentrations

Ambient concentrations are extremely low, 0.03-0.10 $\mu g/m^3$, whereas rates of evaporation as high as 13.3 $\mu g/m^2$ min have been recorded from swine waste lagoons in summer (Hydrogen Sulfide: Human Health Aspects, 2003; and Blunden and Aneja, 2008). Wing et al.(2008) found concentrations as high as 126 μg/m^3 (reported as 90 ppb, converted using 1 mg/m3 = 0.71 ppm at standard temperature and pressure), and routinely in the parts per billion range, for residences within 1.5 miles of CAFOs. In some cases, residences were located within 1.5 miles of as many as 16 CAFOs (Wing et al., 2008).

Health Effects

Hydrogen sulfide is well characterized as a toxicant. Acute exposures may prove fatal, and quickly (Hydrogen Sulfide: Human Health Aspects, 2003). Exposures to CAFO neighbors are chronic, fluctuating seasonally and with other abiotic factors such as terrain, temperature, and atmospheric dynamics (Blunden and Aneja, 2007). The current U.S. EPA reference concentration is 0.02 mg/m^3 (15 ppb), and the California Air Quality Standard is 0.042 mg/ (30 ppb); concentrations that are well below the levels found by Wing et al. (Toxicological Review of Hydrogen Sulfide, 2003; Collins and Lewis, 2000; and Wing et al., 2008). In considering the toxicological profile, it is important to keep in mind that some populations are more vulnerable than others. Children, persons with preexisting upper respiratory problems, and the elderly are all at greater risk (Collins and Lewis, 2000). At concentrations reported by Wing et al.(2008), hydrogen sulfide affects the pulmonary and cardiovascular system, increasing blood pressure and respiration rate, reduces cytochrome C oxidase activity, causes cardiac arrhythmia and slight pulmonary oedema, olfactory paralysis, and nasal lesions (Hydrogen Sulfide: Human Health Aspects, 2003; and Summary of the Toxicity Assessment of Hydrogen Sulfide, 2004).

iii. Volatile Organic Compounds

Characterization

Volatile organic compounds have varying definitions, but are characterized in general by high volatility and reactivity. They are all low molecular weight carbon compounds which may undergo photochemical reactions in the atmosphere, or reactions with hydroxyl radical, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate. Schiffman et al. (2001) found more than 300 VOCs in swine CAFO emissions. The major chemical species are organic sulfides, disulfides, C4 to C7 aldehydes, trimethylamine, C4 amines, quinoline, dimethylpyrazine, and C3 to C6 organic acids. There are also, in lesser quantities, aromatic compounds, C4 to C7 alcohols, ketones, and aliphatic hydrocarbons (Capareda et al. 2005). VOCs may be absorbed by fine PM. A study by Cai et al. (2005) found that VOCs from swine CAFOs were preferentially bound to fine PM.

Concentrations

Concentrations of VOCs emanating from CAFOs are hard to determine for two reasons. First, VOCs are often absorbed by particulate matter, thus shielding them from many methods of analysis (Cai et al., 2005). Second, VOCs are a broad class of compounds, and whereas analytical methods exist for the precise study of individual chemical compounds, it is often more difficult to assay for such a broad category at VOCs. One study demonstrated that VOCs play an important part in perception of odor, and given the conclusions of Schiffman et al.(2001) this indicates that they may have a substantial impact on mood (Zahn et al., 2001).

Health Effects

These compounds undergo photochemical reactions in the atmosphere to generate free radicals and ozone, which cause oxidative stress on organisms. Free radical formation by VOCs has been shown to be dependent on the concentrations of nitrogen oxides (generally abbreviated as NO_x) (Baird and Cann, 2005, pg. 78). Nitrous oxide is noted as a significant pollutant from CAFOs, which would therefore potentiate health effects of VOC emissions (Konstantinos et al., 2009). This oxidative stress is equivalent to that of ozone, and ozone concentrations have been a subject of great concern, such that the federal EPA has developed ground level ozone reduction goals (Baird and Cann, 2005, pg. 78). A recent study found that ozone may have no lower threshold in its effects on human health; what this means is that at any level of ground level ozone above zero, there significant negative effects have been observed on human health (Bell et al. 2006). It stands to reason that other environmental pollutants, such as VOCs, would have the same effect on humans.

2. Particulate Matter and Aerosols, Endotoxins, and Microbes

i. Particulate Matter

Characterization

Cambra-Lòpez et al. (2009) defined particulate matter from livestock operations to be, “a complex mixture of suspended particles with different physical, chemical, and biological characteristics, which determine both its behavior, as well as its environmental and health effects.” In general, particulate matter is fine solid or liquid particles suspended in gaseous medium.[1] Particles are generally categorized according to their size: ultrafine, fine, and coarse. Each of these categories has been relatively well characterized in terms of its health effects. PM can absorb endotoxins and microbes, as well as the chemical species described above. Cai et al.

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[1] This definition is the same for aerosol: in this report, where the term particulate matter is used, bioaerosols or aerosols may be included.

(2006) found that VOCs emitted from swine CAFOs was preferentially bound to fine particulate matter. This potentiates the toxicity of PM, but also complicates measurement of pollution, as many pollutants may be contained within or on particles. Particulate matter from CAFOs can also be secondary pollutants. These are generated through reactions between gases and particles in the atmosphere. Ammonia from livestock houses forms secondary inorganic particles in the atmosphere (Erisman and Schaap, 2004, cited in Cambra-Lòpez et al., 2009). Volatile organic compounds and nitrogen oxides also engage in such reactions, and both are prevalent emissions factors from CAFOs (Cai et al., 2006, Konstantinos et al., 2009).

Concentrations

Particulate matter was measured near swine CAFOs in a recent study. Mean PM_{10}[2] concentrations were found as high as 27.3 $\mu g/m^3$ (19.38 ppb) at residences close to CAFOs, with semi-volatile PM_{10} as high as 9.2 $\mu g/m^3$ (6.53 ppb) (Wing et al., 2008). Previous studies have shown that PM_{10} routinely exceeds U.S. EPA 24-hour National Ambient Air Quality Standards (Razote et al., 2007; Sweeten et al., 1988; National Ambient Air Quality Standards, 2010; cited in Bonafacio, 2009). Razote et al.(2007) found PM_{10} concentrations of up to 1,000 $\mu g/m^3$ at the boundaries of cattle CAFOs.

Health Effects

Particulate matter is a severe public health concern. The concentration of fine PM is the air pollution parameter which correlates most strongly with rates of disease and mortality in Western nations (Baird and Cann, 2005, pg. 121). Furthermore, the concentration response

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[2] Particulate matter is characterized by aerodynamic size. PM_{10} are particles less than 10 micrometers in diameter. This is generally considered “coarse” particulate matter, as opposed to “fine” particulate matter.

relationship increases linearly for PM_{10} and $PM_{2.5}$, suggesting that there is no significant threshold for human health effects, and that risk increases monotonically with exposure (Pope et al. 2002 and Schwartz et al. 2002, cited in Bhatnagar 2006).

ii. Endotoxins

Endotoxins are lipopolysaccharide cell wall components of gram-negative bacteria. When the bacteria die, these endotoxins are released to the environment. Endotoxins have strong pro-inflammatory properties (Heederik et al. 2006).

Endotoxins, as exogenous biological material, illicit immune system reactions. Heederik et al. (2006) concluded that endotoxin is both a secondary and primary cause for asthma, via nonatopic (nonimunoglobulin E-mediated) mechanisms.

The effects of endotoxins specifically are difficult to determine in the case of CAFOs, as any effects they might illicit could be the result of microbes themselves or other irritants, like hydrogen sulfide or VOCs.

iii. Microbes

Ko et al. (2008) also found that microbes from swine CAFOs were being transported through the atmosphere. On all farms sampled, bacteria concentrations were higher at the downwind facility boundary ($p = 0.03$) and at the animal confinement buildings ($p < 0.01$), than at the upwind facility boundary. Likewise, fecal coliforms were higher at the downwind boundary than at the upwind boundary ($p = 0.005$). There were also elevated levels of fungi found downwind ($p < 0.03$). Other studies have found similar levels of total culturable bacteria and fungi around swine CAFOs (Duchaine et al. 2000, Gibbs et al. 2004, Lugauska et al. 2004).

Duchaine et al. (2000) found that temperature and relative humidity was positively correlated with culturable bacteria and fungi, while wind velocity and solar irradiation were negatively correlated. Pathogens found included *Escherichia coli, Clostridium perfringens,* bacteriophage, and *Salmonella.* The study concluded that, "airborne microbial contaminants…pose possible exposure risks to farm workers and nearby neighbors." Residents downwind of CAFOs thereby suffer from a higher pathogen load than ambient levels.

3. Health Problems by Type

One of the most important things to consider when analyzing CAFO pollution is the additive effects of pollutants (IAQS, 2002). Toxicity thresholds and dose response curves decrease when pollutants are present simultaneously. As the air pollution from CAFOs is a complex mixture of pollutants, it is difficult to determine toxicity thresholds, and established toxicological data for singular pollutants is thus insufficient to accurately regulate CAFOs. Similarly, the environmental damage posed by CAFOs is subject to such additive effects, making CAFOs unique pollution sources when compared to, say, paper mills or oil refineries (which produce large quantities of certain pollutants produced by CAFOs). Policy must take these uncertainties into account.

Upper Respiratory Problems

Sigurdson and Kline (2006) found significantly increased rates of asthma in students attending an Iowa school in close proximity to swine CAFOs, when compared with a similar control (study school, 24.7%, control school, 11.7%, $p = 0.0412$). Mirabelli et al. (2006) corroborated this in a study of students in North Carolina. They found that wheezing episodes increased in both frequency and severity among students closer to swine CAFOs. Wheezing frequency and severity also correlated more strongly with prevalence of livestock odor than with proximity to CAFOs, indicating that as air pollutant concentrations increase with decreasing distance to CAFOs, upper respiratory illness incidence increase. There was also an increase in allergies with proximity to CAFOs. Keller and Ball (2000, cited in Thu, 2002) found that upper respiratory hospital cases tripled in the period after the opening of a major swine CAFO in Utah.

Psychological Effects

Schiffman et al. (1995) found that environmental odors from swine CAFOs negatively affected the mood of nearby residents. Residents in close proximity to swine CAFOs had significantly lower scores on all factors in the Profile of Mood States (POMS) test during odor episodes compared to residents not exposed to odors. Nausea-type symptoms and respiratory symptoms were found to be higher for residents nearby swine CAFOs, and these symptoms were also associated with increased levels of psychological distress and decreased feelings of control (Bullers, 2005).

Immunosupression, Nausea, Headache, and Other Symptoms

Avery et al. (2004) correlated significantly reduced levels of secretory immunoglobulin A (an indication of immunosupression) in swine CAFOs neighbors with severity of odor. Schiffman et al. (2005) found increased reports of nausea, headache, and eye irritation from healthy volunteers exposed to diluted swine air samples, when compared to a control. Dilutions used were formulated to simulate concentrations at CAFOs themselves and at or beyond the property line, the point of exposure for neighbors.

4. Disease Correlations Between CAFO Workers and CAFO Neighbors

Workers at CAFOs are exposed to much higher levels of air pollutants than neighboring communities or individuals. Pollutants also change as they are transported over long distances, and so not only are concentrations beyond the property line diluted, they are also a fundamentally different mixture. Nevertheless, it has been noted that worker symptoms strongly parallel neighbor symptoms (Heederik et al. 2007, Thu et al. 1997, Wing and Wolf 2000, Donham, 1990). Health problems in these workers are therefore indicative of community risks.

(b) Water pollution

Water pollution from CAFOs arises from the storage of wastes. These wastes contain nutrients, antibiotics, hormones, and pathogens. Most CAFOs store wastes in lagoons, though some store solid waste in pits. Both forms of storage can contribute to water pollution. Animal manure is also applied to agricultural land as fertilizer. Karr et al. (2001) summarize that CAFO water pollution can occur through leaking lagoons, inadvertent spills, improper discharge, atmospheric transport, and land application of the wastes. While anaerobic digestion can neutralize all the potential pollutants, the sheer quantity of waste can overwhelm normal degradative processes. Most CAFOs also use their manure to fertilize neighboring agricultural fields. Significant runoff and leachate has been recorded from these fields (Hooda et al., 2000). In addition, the centralization of CAFOs in certain states can lead to enormous quantities of water pollution that have become real public health hazards.

1. Nutrients and Chemicals

This category includes organic matter, phosphorus, nitrogen compounds including nitrates and ammonia, antibiotics, and hormones. These compounds can be transported by water to affect communities downstream. Organic matter, phosphorus, and nitrogen compounds are found in animal wastes. Ammonia and nitrate are products of microbial digestion in waste lagoons or pits. Most of these nutrients, with the exception of nitrate, are non-toxic to humans at levels generated by CAFO pollution. They can, however, play an important role as factors facilitating the rise of other environmental health risks, such as eutrophication resulting in toxic algal blooms.

i. Nutrients and Organic Matter

Characterization

The word "nutrients" is a broad category. It technically includes the general macronutrient sources of higher mammals (lipids, carbohydrates, and proteins) but it also includes nutrients that cannot be utilized for energy by higher mammals but by organisms of lower trophic levels: nitrogen, phosphorus, and in smaller quantities all the elements. The overgrowth of microbes associated with heightened levels of such nutrients is termed eutrophication (Hooda et al., 2000). The two nutrients of import for human health are nitrogen and phosphorus. Their importance is in their contributions to aquatic eutrophication (Levine and Shindler, 1989; cited in Hooda et al., 2000). Phosphorus is generally regarded as the eutrophication-limiting nutrient in most aquatic ecosystems, as some blue-green algae fix nitrogen from the atmosphere (Sims and Kleinman, 2005; cited in Gilley et al., 2007).

Organic effluents contain large proportions of solids, limiting their potential for transport through groundwater. The main routes of contamination are therefore runoff from agricultural application of manure or direct discharge from storage (Hooda et al., 2000). While nitrogen and phosphorus are the main eutrophication-limiting nutrients, organic matter contains the microorganisms responsible for eutrophication (Hooda et al., 2000). Therefore, to prevent eutrophication and its deleterious effects on human populations, it is necessary not only to limit nitrogen and phosphorus but organic effluents.

Concentrations

Nutrients are lost through leaching into the soil and subsurface water supplies, and surface runoff. These values are usually measured separately, and in terms of mass per area of land, rather than concentration in a given body of water. This is because the concentration present at any one time is highly variable with rainfall, soil characteristics such as porosity, soil conditions such as freezing, frequency, method, and time of application, and other abiotic factors such as temperature and hydrological variables such as slope of the terrain (Hooda et al., 2000). In addition, nutrient inputs from up stream can skew results, making collection directly for runoff and with catchments for leaching. Last, the flow rate of water in the area also affects the level of pollution. Given these variables, it is more effective to compare agricultural watersheds with other watersheds in terms of biological oxygen demand (BOD), since it is not nutrients but the growth of microorganisms in the aquatic environment which are of interest.[3] Organic effluents correlate positively with BOD, and so BOD is typically used as a measurement for them. This accounts for the metabolic rates of the microorganisms present, and the overall growth of micro fauna, and thus the degree of eutrophication.

Khaleel et al. (1980; cited in Hooda et al., 2000) found that BOD for runoff from animal agriculture lay between 2 mg/l and 3,450 mg/l. Maximal values for range or pasture lands were ten fold less than those for CAFOs. In conditions of accidental discharge, such as flooding, BOD have been found as high as 10,000 to 80,000 mg/l (Hooda et al., 2000). Hooda et al. (2000) cite clean river water as having a BOD of less than 5 mg/l.

It is difficult to quantify eutrophication. It is typically depicted as large expanses of water covered in algae, though it can also occur in the benthic zone. The concentrations of toxins from eutrophication is more easily measured, though data comparing CAFO-heavy watersheds with controls (matching for similar other industrial and agricultural inputs) has not yet been collected.

The toxins contained in cyanobacteria are cell-bound during the early life stages, but at later life stages as many as 70% of total toxins can be free of the cell. Seventy-five percent of algae outbreaks are accompanied by toxin production (Volterra et al., 2002).

Health Effects

The health effects of eutrophication (with the exception of associations between nitrate and certain disorders) are indirect. Two classes of aquatic microorganisms are responsible for these health effects: cyanobacteria and dinoflaggelates. These organisms produce toxins, in potentially deadly concentrations in instances of eutrophication. Cyanobacteria are most

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[3] Biological oxygen demand is measured as the amount of oxygen demanded by metabolic processes of biological cells within a given volume; in this case, the oxygen demand of microorganisms in water.

commonly found in freshwater systems, while the dinoflaggelates are found in coastal or estuarine systems (Volterra et al., 2002).

Cyanobacteria contain three classes of toxins, lipopolysaccharides, alkaloids, and cyclic peptides. These toxins work on the molecular level, causing damage to cells, tissues, and organs, including: the liver, nerve synapses and axons, skin, and gastrointestinal tract. Hepatotoxins are the most often observed cyanotoxins. They can cause death by liver haemorrhage or cardiac failure within hours of acute doses. Chronic exposures in mice caused liver injury and promoted tumor growth. Neurotoxins are less common than the hepatotoxins, and are less well studied. They can cause death in mice and aquatic birds by respiratory arrest, acting sometimes in only a few minutes. Dermatotoxins induce irritant and allergenic responses in any tissue they contact. There may also be damage to nervous, digestive, respiratory, and cutaneous systems. Amounts and classes of each toxin vary among species.

A variety of symptoms are experienced by people suffering from these toxins, including fatigue, headache, diarrhea, vomiting, sore throat, fever, and skin irritations (Volterra et al., 2002). There is a lack of data describing the long term effects of low-level exposure, though acute poisonings have been studied with animal models.

In marine waters, toxins can accumulate in the environment and in certain organisms. This is known as red tide. One of the greatest dangers comes from bioaccumulation in shellfish and other seafood. This can cause acute and potentially fatal exposures when such foods are eaten. The symptoms of diarrheal shellfish poisoning include diarrhea, vomiting, and abdominal pain. Paralytic shellfish poisoning results in muscular paralysis, difficulty breathing, shock, and, in extreme cases, death by respiratory arrest.

CAFO pollution affects any water bodies or courses downstream from them. The toxins produced by cyanobacteria and dinoflaggelates can persist for prolonged periods of time. They will therefore accumulate in coastal and estuarine environments. As time goes on, poisonings from these toxins will likely rise as environmental concentrations increase. Unfortunately, it is impossible to trace CAFO pollution and toxin build-up in specific cases, though the public health data is unequivocal.

An unexpected consequence of eutrophication is the enhanced survivability of pathogenic bacteria such as *Escherichia coli, Salmonella spp.,* and *Vibrio cholerae*. Under normal conditions, especially in seawater, these species do not survive due to lack of nutrients, damage from UV light, and osmolarity differences between sea water and the bacteria themselves, which cause the bacteria cells to rupture. During an algae bloom, these conditions are all reversed; food is abundant, light is diminished by the build-up of microorganisms, and algae produce chemicals that are osmo-protective to these bacteria.

CAFOs are at least in part responsible for the rise of eutrophication and the consequent public health dangers of cyanotoxin intoxication. Obviously, a pollution concern as far-reaching as this is difficult to regulate, tax, or mitigate. The public health problems could only be circumvented by protective measures for the public, but even these efforts can only prevent acute intoxication.

ii. Nitrate

Characterization

The two major forms of inorganic nitrogen in manure are nitrate and ammonia. Ammonia inter converts with ammonium, and at typical soil and surface water pH, the ammonium ion is predominant (Hooda et al., 2000). Ammonium undergoes cation exchange in the soil. This prevents its transport via water. However, nitrifying bacteria convert ammonium to nitrate (Karr et al., 2001). Nitrate is freely mobile in the soil solution (Hooda et al., 2000).

Concentrations

Nitrate, as it is freely mobile in the soil solution and has a lower threshold of toxicity, is more likely to be of concern to neighboring populations. Ritter and Chirnside (1987; cited in Hooda et al., 2000) found that the mean level of nitrate in wells in a poultry farming area was 21.9 mg/l. Forty four percent of wells near a buried dairy waste lagoon had nitrate levels over the maximum contaminant level (MCL) in the United States (Cantor, 1997; cited in Showers et al., 2007). Karr et al. (2001) traced elevated nitrate levels in waters to a nearby swine CAFO, though they did not measure levels in municipal water sources. The U.S. Geological survey found that 22% of all domestic wells in agricultural areas of the United States exceed the MCL for nitrate (Ward et al., 2005).

Health Effects

The U.S. EPA has set a MCL for nitrate (as nitrate-N) of 10 mg/l, and the World Health Organization guideline is for 11 mg/l. These levels were set to prevent methemoglobinemia (Burkholder et al., 2007). Nitrate ingestion is associated with risk for methemoglobinemia (blue-baby syndrome), which affects infants under 6 months old. Other factors, such as diarrhea and respiratory disease, are also associated with methemoglobinemia (Ward, et al., 2005).

Nitrate has been the subject of intensive study after it was reported to be a carcinogen. Nitrates form N-nitroso compounds (NOC), known genotoxins. A comprehensive review of the literature by Burkholder et al. (2007) concluded that "clear epidemiologic findings are lacking on the possible association of nitrate in drinking water with cancer risk." Mixed results were found for cancers of the stomach, bladder, esophagus (Barret et al., 1998; Cantor, 1997; Eicholzer and Gutzwiller, 1990; Morales-Suarez-Varela et al., 1993, 1995), and non-Hodgkin lymphoma (Jensen, 1982; Thouez et al., 1981). Whatever the exact findings of clinical studies, Ward et al. (2005) concluded that, "NOC cause tumors in every animal species tested, and it is unlikely that humans are unaffected" (citing Lijinsky, 1986).

Indeed, positive findings have been found for chronic exposures to greater than 10 mg/l of nitrate in drinking water, but again the literature is unclear (Burkholder et al., 2007). Burkholder et al. (2007) summarize that there have been mixed results for stomach cancer (Cuello et al., 1976; Rademacher et al., 1992; Yang et al., 1998), positive results for non-Hodgkin lymphoma at greater than 4 mg/l nitrate (Ward et al., 1996) and colon cancer at greater than 5 mg/l (De Roos et al., 2003). Negative results have been found 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), at levels of nitrate greater than 10 mg/l. A cohort study by Van Loon et al. (1998) found no associations between nitrate in drinking water and stomach cancer. Weyer et al. (2001) found a positive association with cancers of the bladder and ovary at chronic exposures of greater than 2.5 mg/l, but inverse associations with cancers of the rectum and uterus at the same levels.

There are several other negative health outcomes associated with nitrates. Incidence of hypothyroidism was increased (Seffner, 1995) at chronic exposures to levels between 11 and 61 mg/l (Tajtakova et al., 2006). Nitrate has been associated with insulin-dependent diabetes, though results are seemingly contradictory. Levels of nitrate in drinking water less than 10 mg/l were associated with insulin-dependent diabetes (Kostraba et al., 1992), but other studies associated levels higher than 15 mg/l (Parslow et al., 1997) and 25 mg/l (van Maanen et al., 2000) with insulin-dependent diabetes. Nitrates have also been implicated as a cause of reproductive and developmental toxicity, though the levels of nitrate are much higher than the current MCLs (Fan and Steinberg, 1996). Adverse reproductive outcomes have been associated with drinking water nitrate levels of less than 10 mg/l. Arbuckle et al. (1988) found central nervous system malformations, though the results were not statistically significant. Brender et al. (2004) and Croen et al. (2001) found neural tube defects. There is anecdotal evidence that high levels of nitrate in drinking water (19-26 mg/l) cause spontaneous abortion (Morbidity and Mortality Weekly Report, 1996; cited in Burkholder et al., 2007). For comprehensive reviews, see Burkholder et al. (2007) and Ward et al. (2005).

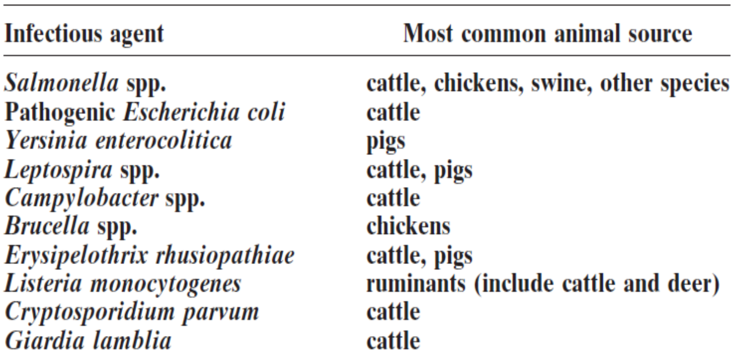
2. Antibiotics and Hormones

The literature on health effects of antibiotics and hormones is far less well established than that for other pollutants. Only the recent improvement in analytical methods has begun to allow for their investigation when present only in very low concentrations, concentrations in which they may nevertheless have significant biological effects. Furthermore, little has been done to determine the effects of these agents at chronic low dosages. Experts in the field have posited that these agents may have far reaching and long term effects on public health (Daughton and Ternes, 1999; Daughton, 2008).

3. Pathogenic Microbes

Characteristics

Several important pathogens are found in animal manure, including *Escherichia coli, Campylobacter jejuni, Yersinia enterocolitica, Listeria monocytogenes, Clostridium perfringens, Cryptosporidium*, *Salmonellae*, and *Giardia* (Venglovsky, et al., 2006; Hooda, et al., 2000). These pathogens are responsible for much of the food and water born illness in the United States each year (Mead, et al., 1999). Bacteria and parasites can contaminate meat, poultry, and milk before it is butchered or collected (as the case may be) or can contaminate it sometime en route to consumption, or the pathogens can be transported via water into municipal or recreational waters. Determining the etiology of food and water born illness can be very difficult when food may have changed hands several times from production to consumption. Pathogens can be present in the animal and survive the passage to the consumer. This area of food sanitation already receives significant public and governmental attention. Other routes of infection exist, however, some of them unique to CAFOs. Thus, while many aspects of CAFO production promote contamination of CAFO products with foodborne illnesses, only direct exposures through water pollution will be dealt with.



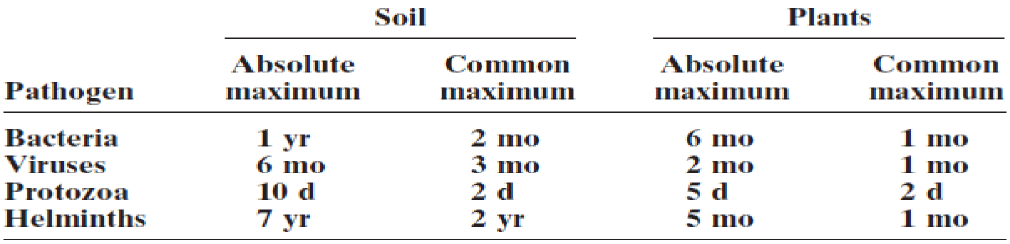
Infectious agent	**Most common animal source**
***Salmonella* spp.**	**cattle, chickens, swine, other species**
Pathogenic *Escherichia coli*	**cattle**
Yersinia enterocolitica	**pigs**
***Leptospira* spp.**	**cattle, pigs**
***Campylobacter* spp.**	**cattle**
***Brucella* spp.**	**chickens**
Erysipelothrix rhusiopathiae	**cattle, pigs**
Listeria monocytogenes	**ruminants (include cattle and deer)**
Cryptosporidium parvum	**cattle**
Giardia lamblia	**cattle**

Figure 2: Common zoonotic diseases transmitted by farm animals. Source: Cole et al., 1999; cited in Gerba and Smith, 2005.

In order to pose a public health threat, pathogens must be transmitted from manure to humans. This can happen in one of two ways. Workers in close proximity to the pathogens may be exposed through viable routes of infection to infectious levels of a pathogen. This individual may then become a vector for infecting other members of the public. Alternatively, and arguably of greater significance, pathogens may be transported through the environment or through a zoonotic vector to infect a human host. Venglovsky et al. (2009) summarize that in the case of using manure as fertilizer:

> The application of livestock faeces and waste water in agriculture may result in a public health threat only if all of the following prerequisites concur: a) an infective dose of an excreted pathogen reaches the pond or natural water body, or if the pathogen multiplies in an intermediate host residing in the pond or in the aquatic environment to form an infective dose; b) if this infective dose reaches a human host through contact or consumption of the aquacultural products; c) if this host subsequently becomes infected.

Many factors, both biotic and abiotic, affect pathogen mobility and survival, and therefore their potential to reach a human host. Pathogens can enter the water from land application as fertilizer, as seepage or leachate from manure storage, as airborne particles, or as the result of accidental discharges such as flooding. Pathogens can enter ground water, affecting wells, or into riparian zones, and then to municipal water sources or individuals utilizing water supplies independently. Pathogen mobility through the soil matrix takes on both vertical and horizontal parameters and affects the likelihood of pathogens entering ground water (Venglovsky et al., 2006).



	Soil		Plants	
Pathogen	**Absolute maximum**	**Common maximum**	**Absolute maximum**	**Common maximum**
Bacteria	**1 yr**	**2 mo**	**6 mo**	**1 mo**
Viruses	**6 mo**	**3 mo**	**2 mo**	**1 mo**
Protozoa	**10 d**	**2 d**	**5 d**	**2 d**
Helminths	**7 yr**	**2 yr**	**5 mo**	**1 mo**

Figure 3: Survival Times of Common Pathogens in Soil and Plants. Source: Gerba and Smith, 2005.

Pathogen levels in manure depend on three factors: the source animal, the animal's health, and how the manure was stored or treated before use (Venglovsky et al., 2006). Pathogens are typically eliminated from animal wastes through proper treatment, including facultative lagoons and storage, air-drying, composting, anaerobic digestion, aerobic digestion, and lime stabilization (Gerba and Smith, 2005). Three major phylogenetic categories of pathogen are present in CAFO wastes, and since pathogen survival and pathogenicity are much the same within these phylogenic categories, they will be dealt with as such (Venglovsky et al., 2009; Gerba and Smith, 2005). The potential for public exposure comes when these procedures are not followed correctly and viable microbes are released into the environment.

i. Bacteria

Bacteria are currently the most numerous of the possible human pathogens in animal wastes. The infective species include *Campylobacter* spp*, E. coli, Clostridium perfringens, Listeria monocytogenes, Salmonella* (Typhi and non-typhoidal), and *Yersinia enterocolitica* (Mead et al., 1999; Cole et al., 1999; cited in Gerba and Smith, 2005).

ii. Parasites

Parasites transmitted by CAFO animals include both macroparasites, notably helminth worms, and microparasites, which contain the two parasites of greatest concern: *Cryptosporidium parvum* and *Giardia lamblia*. Other, less common microparasites include *Toxoplasma gondii* and *Entamoeba* sp., in particular *Entamoeba histolytica* (Gerba and Smith, 1995; Venglovsky et al., 2009; Bowman et al., 2000).

iii. Viruses

Viruses have significantly shorter life spans in the environment than bacteria or parasites. They are obligate parasites, meaning that they cannot survive and replicate outside of their host. Viruses that can be harbored by animals and are pathogenic to humans include poliovirus, coxsackievirus, echovirus, hepatitus A virus, rotavirus, human caliciviruses, reovirus, hepatitis E virus, TT hepatitis, astrovirus, and adenoviruses (Gerba and Smith, 2005; Venglovsky et al., 2009).

Concentrations

Aquatic pathogen levels are often measured in terms of total coliform bacteria. The EPA has set its maximum coliform level at zero, and public water suppliers are required to test water routinely for coliforms. The EPA notes that any level of coliform poses a public health risk (Basic information, EPA, 2009).

Runoff from agricultural applications is the largest non-accidental pathogen input from CAFOs. Pathogen levels are usually equated to coliforms, which is the group of bacteria which inhabit human and higher vertebrate digestive tracts. High levels of coliforms have been recorded in runoff from animal manures. Total coliforms have been recorded as high as 137,000 colony forming units (CFU) per 100 ml in cattle manure , 18,400 CFU per 100 ml in liquid dairy manure, and 12,900 CFU per 100 ml in turkey litter (Soupir et al., 2005). In Brazil, a study found fecal coliforms as high as 4,479 CFU per ml, and in every catchment but the control (no animal agriculture) fecal coliforms were significantly elevated (Sigua et al., 2009). A study at the University of Nebraska modeled fecal indicator organism runoff during rainfall events. They used manure from swine, and fresh manure and aged manure from cattle. They found indicator organisms (*E. coli, Enterococci, Clostridium,* and Coliphage) in runoff in concentrations as high as 3,330,000 CFU per gram of manure (for *E. coli only*) or 1.61 x 10^{11} CFU per 1.5 meters square plot. The lowest value was for *Clostridium* in aged cattle manure, which was still 801 CFU per gram or 1.18 x 10^{8} CFU per 1.5 square meters (Thurston-Enriquez, Gilley, and Eghball, 2005). It is therefore clear that current CAFO manure disposal practices are releasing large quantities of pathogens into the environment.

Whether or not pathogens are present in manure is, in terms of public health, irrelevant if they are not making their way into contact with the public. However, given that even a minimal amount of coliform can pose a public health threat, and given that CAFOs may be present in rural areas with drinking wells rather than monitored municipal water supplies, there may be significant public exposure that is not reported to authorities. The fate of pathogens, notably their dispersion and survival, once in an aquatic environment must be examined.

In general, concentrations of fecal coliforms drop dramatically as the distance to their source increases. Natural factors like ultraviolet radiation dramatically reduce pathogen survival in the environment, and concentrations of viable pathogens decrease as water courses mix and sediments settle out of the flow. In a major study of Tillamook Bay, Oregon, Shanks et al. (2006) examined basin-wide dynamics of fecal contamination, with a focus on animal agriculture. There are 185 dairy CAFOs in the basin, housing 30,000 animals. The study concluded that *E. coli* were more prevalent near and more closely linked to ruminant than human sources, though results were not consistent. As *E. coli* levels rose to exceptionally high levels, chances of detecting ruminant sourced *E. coli* neared 100%. These analyses were checked against probably feral inputs, with conclusive evidence that sources were ruminant (dairy cattle) rather than feral animals (in this case, elk). The study concluded that significant *E. coli* pollution was entering the watershed from CAFOs, and that a watershed manager's best strategy for reducing fecal pollution would be to mitigate ruminant pollution.

Pathogens have different survival times in the environment. Survival time is a critical parameter for whether or not pathogens may reach human populations. A study of *E. coli* and *Salmonella* in a tropical freshwater estuary showed that both organisms remained viable after five days in water, and implicating that *E. coli* is not a useful indicator for fecal contamination given its persistence (Jimenez et al., 1988). In another study, water samples in *Salmonella* contaminated aquaria remained culture positive for 54 days, and sediment samples were culture positive for 119 days. In addition, transmission of *Salmonella* via an aquatic midge (*Chironomus* tentans) was also studied, and the authors concluded that while the midges may not contaminate other sediments, they are possible vectors for *Salmonella* (Moore et al., 2003). Another study found the *E. coli* persisted in reservoir waters for 30 days after exposure, and that factors like native heterotrophic microflora and better nutritional conditions significantly increased bacteria survival (Wcislo and Chrost, 2000). Bitton et al. (1983) found that pathogenic bacteria and viruses were relatively stable in groundwater, under both field and laboratory conditions. This implies that populations downstream from CAFOs using well water (which are significant populations given the rural siting of CAFOs) could be severely affected by CAFO water pollution.

Another questions is pathogen survival in sediments. Davies et al. (1995) found that 90% of the fecal streptococci *Clostridium perfringens* died within 85 days in both freshwater and marine sediments. However, once pathogens have settled into sediment, there is little real possibility that they will reenter the water, but such exposures are conceivable, however unlikely, for recreational waters, especially if pathogens can survive long periods in sediment. The only other means for pathogens to reenter the water would be natural disturbances such as storms or flooding.

Flooding presents one of the greatest public health threats of CAFOs. Eastern North Carolina, where much of the nation's swine industry is concentrated, is subject to frequent hurricanes and is also an area with a high density of CAFOs. In 1995, 25 million gallons of raw sewage entered the New River from a swine CAFO lagoon that had burst. Twenty-two miles of the river were polluted, along with much of the upper estuary, with manure pathogens (Burkholder et al., 2007; cited in Mallin and Cahoon, 2003). While no infections were reported as a result of the disaster, the prospect of such in the future is not unrealistic, especially as animal agriculture continues to expand and population densities rise. One of the problems is that CAFOs are concentrated geographically, significantly increasing pollution from flooding (Wing et al., 2002).

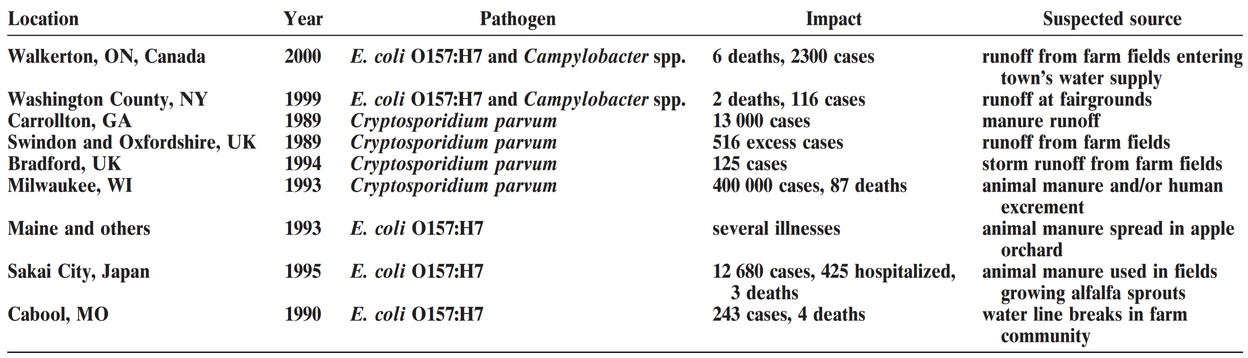
It is also worth noting that areas without livestock manure inputs can still have high coliform counts. Doran and Linn (1979) reported faecal coliform concentrations from ungrazed grassland in the range of 150 - 50,000 CFU per 100 ml (cited in Tyrrel and Quinton, 2003). Noble et al. (2003) found that coastal waters near Santa Monica, California, frequently failed the same coliform test standards used for drinking water, especially following storms. Mallin et al. (2000) found that percentage watershed-impervious surface area (i.e. the land area covered in impermeable surfaces) accounted for 95% of variability in watershed fecal coliform abundance. The study area was an estuary in Eastern North Carolina (New Hanover County), and no comparison was made to watersheds with significant CAFO density. Such cases do not make CAFO pollution any less harmful, but do highlight the need for regulation based on actual pollutant inputs rather than categorizing industries as polluting or non-polluting.

Another important route of infection is through food sources fertilized or irrigated with manure or manure contaminated water. Islam et al. (2004) found that the most significant pathogenic form of *E. coli* (the study used a non-virulent strain) could persist in lettuce and parsley from 77 up to 177 days after manure application, and the *E. coli* strain in question survived longer than 5 months after application of manure or irrigation water. Another study simulated exposure to *Salmonella* in tomato plants, and found 37% of plants harbored *Salmonella* at harvest (Guo et al., 2001). Islam et al. (2004) found that onions and carrots could harbor *E. coli* for up 74 to 168 days after inoculation by irrigation water or manure, with similar results for both sources of contamination.

Health Effects

There has been some question over the exact health effects of many of the pollutants discussed herein. This debate does not exist for pathogens, which by definition are already recognized as agents of human disease. The bacteria, viruses, and parasites in question cause severe gastrointestinal disease, most notably (for more detail, please refer to Gerba and Smith, 2005; Hooda et al., 2000; Venglovsky et al., 2006). A section on health effects would be redundant to much more significant works by more qualified authors. That pathogens are surviving in the environment and are finding routes of infection is what is relevant to this thesis.

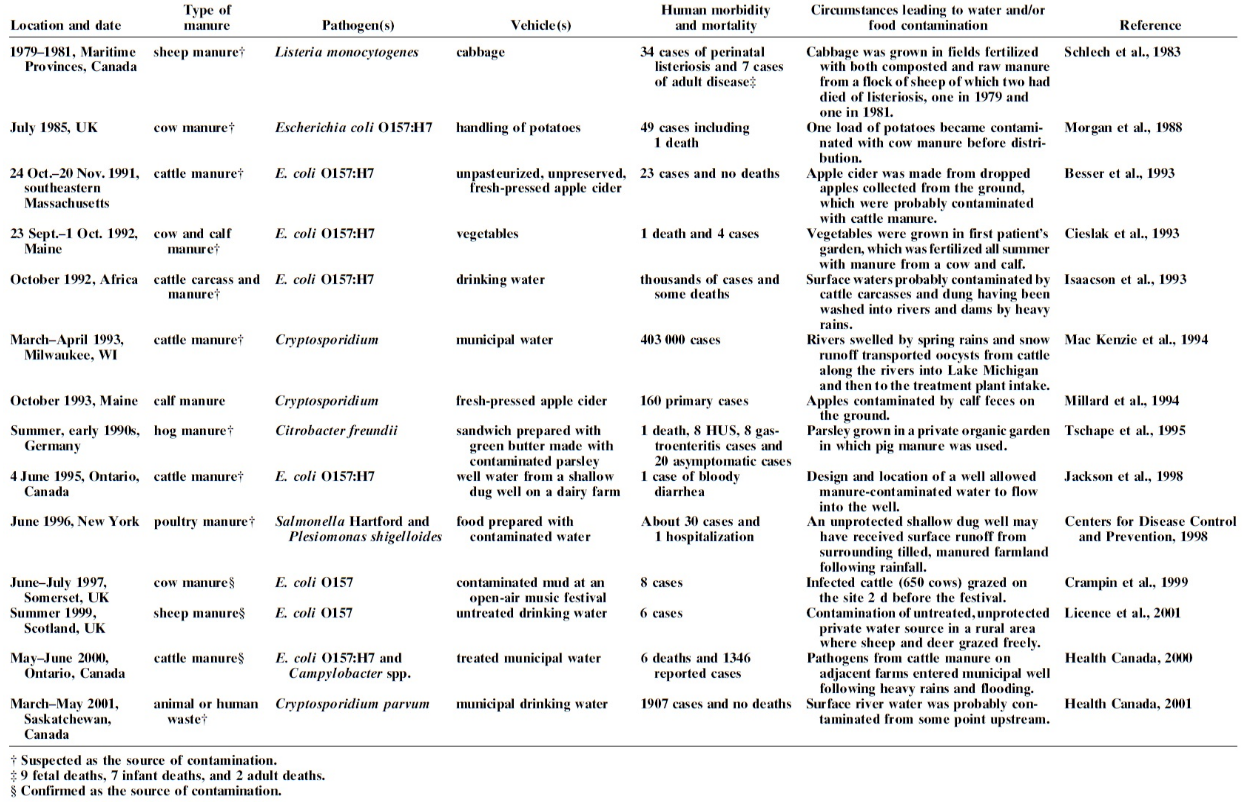
4. Health Effects by Event



Location	Year	Pathogen	Impact	Suspected source
Walkerton, ON, Canada	**2000**	***E. coli* O157:H7 and *Campylobacter* spp.**	**6 deaths, 2300 cases**	**runoff from farm fields entering town's water supply**
Washington County, NY	**1999**	***E. coli* O157:H7 and *Campylobacter* spp.**	**2 deaths, 116 cases**	**runoff at fairgrounds**
Carrollton, GA	**1989**	***Cryptosporidium parvum***	**13 000 cases**	**manure runoff**
Swindon and Oxfordshire, UK	**1989**	***Cryptosporidium parvum***	**516 excess cases**	**runoff from farm fields**
Bradford, UK	**1994**	***Cryptosporidium parvum***	**125 cases**	**storm runoff from farm fields**
Milwaukee, WI	**1993**	***Cryptosporidium parvum***	**400 000 cases, 87 deaths**	**animal manure and/or human excrement**
Maine and others	**1993**	***E. coli* O157:H7**	**several illnesses**	**animal manure spread in apple orchard**
Sakai City, Japan	**1995**	***E. coli* O157:H7**	**12 680 cases, 425 hospitalized, 3 deaths**	**animal manure used in fields growing alfalfa sprouts**
Cabool, MO	**1990**	***E. coli* O157:H7**	**243 cases, 4 deaths**	**water line breaks in farm community**

Figure 4: Manure-related Disease Outbreaks, 1990-2005. Source: Gerba and Smith, 2005.

As can be seen, a number of contamination events have occurred with confirmed etiology of animal agriculture (excepting the Milwaukee case). These cases do not include other possible events caused by routes such as food contaminated by manure or irrigation water, or aquatic contamination with algal toxins. A summary from another review is listed below, and shows more incidences of contamination across the world, especially in Europe (there are significant numbers of CAFOs in Europe), where population densities and animal agriculture exist much more closely, as they someday (presummably) will in America.



Location and date	Type of manure	Pathogen(s)	Vehicle(s)	Human morbidity and mortality	Circumstances leading to water and/or food contamination	Reference
1979–1981, Maritime Provinces, Canada	sheep manure†	*Listeria monocytogenes*	cabbage	34 cases of perinatal listeriosis and 7 cases of adult disease‡	Cabbage was grown in fields fertilized with both composted and raw manure from a flock of sheep of which two had died of listeriosis, one in 1979 and one in 1981.	Schlech et al., 1983
July 1985, UK	cow manure†	*Escherichia coli* O157:H7	handling of potatoes	49 cases including 1 death	One load of potatoes became contaminated with cow manure before distribution.	Morgan et al., 1988
24 Oct.–20 Nov. 1991, southeastern Massachusetts	cattle manure†	*E. coli* O157:H7	unpasteurized, unpreserved, fresh-pressed apple cider	23 cases and no deaths	Apple cider was made from dropped apples collected from the ground, which were probably contaminated with cattle manure.	Besser et al., 1993
23 Sept.–1 Oct. 1992, Maine	cow and calf manure†	*E. coli* O157:H7	vegetables	1 death and 4 cases	Vegetables were grown in first patient's garden, which was fertilized all summer with manure from a cow and calf.	Cieslak et al., 1993
October 1992, Africa	cattle carcass and manure†	*E. coli* O157:H7	drinking water	thousands of cases and some deaths	Surface waters probably contaminated by cattle carcasses and dung having been washed into rivers and dams by heavy rains.	Isaacson et al., 1993
March–April 1993, Milwaukee, WI	cattle manure†	*Cryptosporidium*	municipal water	403 000 cases	Rivers swelled by spring rains and snow runoff transported oocysts from cattle along the rivers into Lake Michigan and then to the treatment plant intake.	Mac Kenzie et al., 1994
October 1993, Maine	calf manure	*Cryptosporidium*	fresh-pressed apple cider	160 primary cases	Apples contaminated by calf feces on the ground.	Millard et al., 1994
Summer, early 1990s, Germany	hog manure†	*Citrobacter freundii*	sandwich prepared with green butter made with contaminated parsley	1 death, 8 HUS, 8 gastroenteritis cases and 20 asymptomatic cases	Parsley grown in a private organic garden in which pig manure was used.	Tschape et al., 1995
4 June 1995, Ontario, Canada	cattle manure†	*E. coli* O157:H7	well water from a shallow dug well on a dairy farm	1 case of bloody diarrhea	Design and location of a well allowed manure-contaminated water to flow into the well.	Jackson et al., 1998
June 1996, New York	poultry manure†	*Salmonella* Hartford and *Plesiomonas shigelloides*	food prepared with contaminated water	About 30 cases and 1 hospitalization	An unprotected shallow dug well may have received surface runoff from surrounding tilled, manured farmland following rainfall.	Centers for Disease Control and Prevention, 1998
June–July 1997, Somerset, UK	cow manure§	*E. coli* O157	contaminated mud at an open-air music festival	8 cases	Infected cattle (650 cows) grazed on the site 2 d before the festival.	Crampin et al., 1999
Summer 1999, Scotland, UK	sheep manure§	*E. coli* O157	untreated drinking water	6 cases	Contamination of untreated, unprotected private water source in a rural area where sheep and deer grazed freely.	Licence et al., 2001
May–June 2000, Ontario, Canada	cattle manure§	*E. coli* O157:H7 and *Campylobacter* spp.	treated municipal water	6 deaths and 1346 reported cases	Pathogens from cattle manure on adjacent farms entered municipal well following heavy rains and flooding.	Health Canada, 2000
March–May 2001, Saskatchewan, Canada	animal or human waste†	*Cryptosporidium parvum*	municipal drinking water	1907 cases and no deaths	Surface river water was probably contaminated from some point upstream.	Health Canada, 2001

† Suspected as the source of contamination.
‡ 9 fetal deaths, 7 infant deaths, and 2 adult deaths.
§ Confirmed as the source of contamination.

Figure 5: Manure-related disease outbreaks world wide, 1979-2003. Source: Guan and Holley, 2003.

One study by Keller and Ball (2000; cited in Thu, Neighbor Health) found that diarrheal hospital cases in a Utah community quadrupled after the opening of a swine CAFO. The Utah Department of Environmental Quality found that diarrheal illnesses in Milford, Utah, increased upon the opening of a very large swine CAFO (An Evaluation of Health Concerns in Milford, Utah and the Possible Relationship of Circle Four Farms to Those Concerns, 2001).

It should be noted that these are only confirmed events of poisoinings from animal agriculture. Poisonings or epidemics from eutrophication or pharmaceuticals, for example, may never been fully known. To give some scale to this issue, 329 documented manure spills from livestock facilities occurred from 1992 to 2002, killing 2.6 million fish and poisoning groundwater (Economic Research Service, 2005; cited in Gurian-Sherman, 2007).

(c) Summary of Health Effects and Desired Policy

CAFOs have been conclusively associated with increased incidence of numerous diseases. Immediate neighbors are at increased risk for upper respiratory illness, including asthma, psychological harm, airborne microbial infection, immunosuppression, and other health problems such as headache and nausea. Immediate neighbors and downstream communities are subjected to increased levels of nutrients, with concordantly increased risks of algal blooms, and nitrate poisoning. They are also subjected to elevated (and, as in the case of floods, potentially extreme) pathogen loads. Last, they are exposed to increased levels of antibiotics and hormones, the health effects of which are unknown but may be significant.

The literature is conclusive in calling for policy changes to protect public health. The question for policy becomes what level of protection is required, or what level is best for the nation, state, or county, depending on the level of policy in question.

Needless to say, the most desirable policy for animal agriculture in general would eliminate the public health problems posed by air and water pollution. But while stringent policies to protect the public health might seem the best course given the literature, there are economic and social realities that preclude such regulation. Farmers must be able to make a living, and added costs of pollution abatement measures could drive them out of business. One of the complaints of farmers is that the current economic situation has already driven them into CAFO production methods, without paying for environmental and public health externalities, and increased regulation could raise the cost of production such that they would go out of business (private communication).

Ultimately, someone will raise livestock to meet public demand. The ideal is a system where livestock are raised without posing major dangers to public health but where farmers can make a reasonable living. The challenge lies in determining where public health must yield to economic constraints, if in the end it must. Having established the public health threats posed by CAFOs, in order to make policy recommendations it is necessary to determine the economic realities of modern animal agriculture. For policy to be implemented, it must be practical not only for public health but for the economy. And just as the ideal system would eliminate the public health threats covered previously, it would also maximize economic productivity. Such a system seems a pipe-dream to most modern day activists and environmentalists, and an impossibility to economists and free-marketeers.

But despite the traditional antagonism between these two groups, a growing body of evidence suggests that such a system can be achieved. The movement for "free market environmentalism" posits that free markets are the best safeguard for environmental quality, and by extension (in this case in particular) public health. CAFOs provide an excellent example in which these principles propose an ideal solution.

III. The Economics of Concentrated Animal Feeding Operations: An Economic Problem and an Economic Solution

(a) The Economic Rise of CAFOs and the Challenges Confronting Policy Changes

As public health improvements are balanced by economic concerns, it is important to explore what exactly those economic concerns are. Policy recommendations to protect the public health can then be formulated in light of these concerns.

In February of 2003, Nigel Key and William McBride provided the following abstract in a paper entitled, “Economic and Structural Relationships in U.S. Hog Production” (2003):

> Rapid change in the size and ownership structure of U.S. hog production has created new and varied challenges for the industry. This report describes an industry becoming increasingly concentrated among fewer and larger farms, and becoming more economically efficient. These changes have not come without problems. The increasing market control and power concentrated among packers and large hog operations, and the manure management problem posed by an increasing concentration of hog manure on fewer operations, are paramount concerns. Addressing these concerns through regulations would likely impose economic costs that could be passed on to consumers. In addition, the relative mobility of the hog industry means that regulations could result in significant changes in the location of hog production facilities, with ripple effects in local economies. Balancing environmental and economic interests will challenge policymakers dealing with the implications of structural change in U.S. Hog production.

This is a succinct analysis of the overriding economic trends in hog production, and in livestock production in general, in the U.S. Several key points arise in the abstract that are pertinent to policy.

First, the concentration of livestock into fewer and fewer operations outlines the major issue of contention, both economic and environmental, regarding CAFOs. Economically, it is more profitable to centralize production. Environmentally, this has been a disaster, not only in the hog farming industry but in the livestock industry and all industry in general. Concentrations of industrial pollutants achieved by centralized production have always posed a public health threat. This outlines the major problem of presenting an economic argument against CAFOs; how can one make CAFOs less profitable than more sustainable alternatives?

The obvious answer, and the second point brought up by this abstract, is to impose regulations. This is the answer proposed by Pigou in *The Economics of Social Welfare,* and has remained the reigning paradigm of government environmental regulation since such regulatory agencies were established. There are a number of conceivable ways to regulate CAFOs to protect public health.

The most important goal of regulation is to contain wastes. Discharge and seepage, as well as agricultural application (as fertilizer), of wastes can be regulated and taxed. Emissions can also be regulated and taxed. Zoning measures can be taken to prevent large densities of CAFOs in certain areas, in particular in watersheds, where pollutants are concentrated through water flow. Best management practices to minimize pollution can be included in regulatory frameworks.

But all of these measures leave something to be desired. The enforcement alone would be very costly to the government and thus the consumer, and monitoring would likewise be very costly and possibly unreliable. Zoning measures, while potentially very effective, do not fundamentally deal with the problem that CAFOs concentrate wastes in small areas. Best management practices have not advanced to mitigate pollution sufficiently. So while regulation may be effective in controlling CAFO pollution, it will inherently have loopholes and flaws.

There are other reasons to shy away from increasing regulations. In 2003, Bruce Yandle and Sean Blacklocke published a paper entitled “Regulating Concentrated Animal Feeding Operations: Internalization or Cartelization?” (Meiners and Yandle, 2003). They concluded that environmental regulation of CAFOs in particular (and industry in general) would cartelize upon the institution of government regulations. The result would be increased costs for industry and thus for consumers. The challenge of how to balance economics and public health then becomes the central debate of public health policy reform. A more desirable outcome would be one in which policy both improved public health and economic efficiency.

Furthermore, Yandle and Blacklocke (2003) concluded that the political interests necessary to mobilize effective regulation would result in formulation of regulations favoring the industry supporters of those political interests - in this case, the CAFO industry.

The bottom line is that there is little economic efficiency in instituting a regulatory framework, and such a framework might in the end prove counterproductive. A regulatory scheme would be sub-optimal in an economic sense. However, there are costs being imposed on others by pollution from CAFOs, and ideally a compensatory mechanism would exist that reassigned these costs to the CAFOs that incur them. The question is then, what is the most efficient means to assign the costs of these externalities to CAFOs?

The last point is that changing the current regulatory framework may cause significant economic upset in communities dependent upon CAFOs. Taking drastic regulatory measures would undercut farmers who have built their operations assuming that their methods would remain economically viable. To suddenly render CAFOs economically inviable with heavy taxes, fines, or subsidies to their competitors would put many farmers out of business. The question posed by this point is, how can policy changes be made without causing undue economic harm?

These are the key issues that must be taken into consideration by any policy recommendation regarding CAFOs. Policy recommendations must consider the economic circumstances discussed by McBride and Key. Likewise, they cannot be watered down to pad the blow to industry at the expense to public health. As mentioned previously, the ideal would be a market based solution. Such a solution would improve economic efficiency while also eliminating the problems posed by CAFO pollution.

This may seem contradictory. Decreased regulation would result in increased pollution, and thus increased public health threats. This assumes, however, that in a free market (or in one with minimal regulation), CAFOs would remain the most efficient form of animal agriculture. In fact, small, diversified farms are a more efficient alternative, in both scientific and economic terms. CAFOs are the result of market interference and government regulation. Decreasing government regulation would eliminate CAFOs by allowing more efficient forms of agriculture to out compete them.

(b) Subsidies and Externalities: Making CAFOs Pay the Full Social Cost

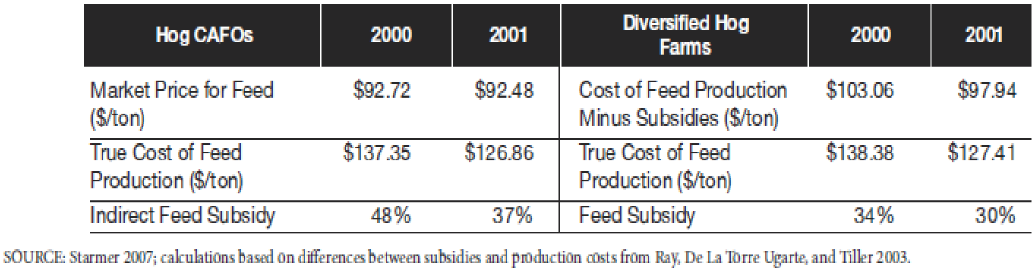
If small, diversified farms are more efficient than CAFOs, then the problem for policy lies in eliminating the economic advantages arising from government regulation that CAFOs enjoy over these smaller farms. The reason CAFOs have become the predominant form of animal agriculture in the United States is that their production costs do not match their social costs. This is known as market failure. Market failure is defined as when a market fails to allocate resources efficiently, and can be caused by externalities and subsidies (as is the case with CAFOs) (Economics A-Z, 2010a). Social cost is defined as the total costs associated with an economic activity, regardless of who bears those costs (Economics A-Z, 2010b). In the case of CAFOs, this would include the costs of production and the costs of externalities, including those whose costs are not born by CAFOs. Whether CAFOs or the public bear these costs, the net social cost is theoretically the same. Devising a system that makes CAFOs bear the full cost of production, the social cost, would allow for free competition and a solution to the problem.

Many of the costs of CAFO production are subsidized by federal and state governments. These subsidies are both direct and indirect. Direct subsidies include Environmental Quality Incentive Program funding at both state and federal levels. Indirect subsidies include grain subsidies and even public roads which allow for cheap transport of manure (which would not be transported off smaller farms) and feed.

In 2008, the Union of Concerned Scientists commissioned a paper on CAFOs. The paper evaluated the environmental, public health, and social concerns of CAFOs, as well as the economics of CAFO production. In his analysis, the author, Dr. Doug Gurian-Sherman, estimated that more than $5 billion in subsidies were given to CAFOs per year for grain subsidies and manure disposal alone. Smaller farms do not generally benefit to the same extent from these subsidies, as smaller farms often grow their own feed and their manure is kept on-farm for fertilizer.

Figure 6: Taxpayer Costs for Externalities and Subsidies of CAFOs. Source: Gurian-Sherman, 2008.

The elimination of government subsidies, or at least providing their equivalents to smaller farms, would go a long way in reestablishing healthy competition and allowing for smaller operations to reenter the market.



Hog CAFOs	2000	2001	Diversified Hog Farms	2000	2001
Market Price for Feed ($/ton)	$92.72	$92.48	Cost of Feed Production Minus Subsidies ($/ton)	$103.06	$97.94
True Cost of Feed Production ($/ton)	$137.35	$126.86	True Cost of Feed Production ($/ton)	$138.38	$127.41
Indirect Feed Subsidy	48%	37%	Feed Subsidy	34%	30%

SOURCE: Starmer 2007; calculations based on differences between subsidies and production costs from Ray, De La Torre Ugarte, and Tiller 2003.

Figure 7: Comparison of Feed Costs and Subsidies for Hog CAFOs and Diversified Hog Farms. Source: Gurian-Sherman, 2008.

In 1960 Ronald H. Coase published a paper entitled, “The Problem of Social Cost.” This seminal paper challenged the reigning view of policy makers that externalities must be dealt with by governmental regulation rather than market mechanisms. This paper has in part formed the basis for modern arguments for free market environmentalism and such fields of study as ecological economics.

Modern American public policy still embodies a Pigovian view of externalities. That is to say that, as proposed by Pigou in *The Economics of Welfare*, businesses whose operations involve the harm of others are taxed or regulated to curtail such externalities or at least to compensate for the damage caused. The result is large government regulatory agencies and a limitation of the free market. In “The Problem of Social Cost” Ronald H. Coase challenges the Pigovian analysis on externalities, and then presents an alternative scenario in which these externalities were dealt with through market mechanisms, leading to the most efficient outcome. The importance of the Coase Theorem is that it allows for free markets while still offering protection against externalities. The theorem states, in summary, that if property rights are are well established and transaction costs are zero, then parties could negotiate an efficient outcome through the market, rather than through government mediation. The key to obtaining an efficient solution without government intervention would be the establishment of property rights. These rights should extend to protected the environmental quality of a person's property, and in the case of personal health, the environmental quality of a person's living space, regardless of ownership.

Steven C. Medema cites three major challenges which Coase presents to Pigou's analysis. First, that Pigovian solutions are unnecessary to reach efficient outcomes in a zero transaction cost world. That is to say that individuals can negotiate and find an efficient solution without interference from government; all that is needed is the proper delimitation of rights. Second, that Pigovian solutions would have harmful spillover effects, i.e. would be brought to bear in situations where they were not the optimal solution. Third, that Pigou ignores the reciprocal nature of externalities. A Pigovian analysis would yield that if the polluter had not polluted, no injury would have been done. A Coasian analysis would add that if the injured party had absented themselves from the place of pollution, then the polluter would not have caused any harm. When regulation is put in place, it limits the possibility for negotiations between private parties as to externalities. The most significant conclusion of Coase's paper, “The Problem of Social Cost,” was that private parties could obtain more efficient and mutually satisfactory outcomes than those afforded by government regulation. Of course, in all cases property rights are paramount for a Coasian system to work properly.

Property rights have always been recognized to be an arbitrary institution of humanity. It is in this case that property rights are something to be assigned and delimited. In the popular conception of property rights, they might be said to extend only to physical material that can be held - definitions vary, but generally this is the case. They could also be extended to someone's health and physical body, and should be extended to those who do not own but rent property near CAFOs. Most people would agree that if someone opens a sewage treatment plant in their front yard, the odor would constitute a violation of their neighbors' property rights, in that it impairs their use of their property. The sewage plant is but one (highly unlikely) example of incompatible land use.

Concentrated Animal Feeding Operations (CAFOs) present an example for analysis with the Coase Theorem. CAFOs generate enormous quantities of animal waste, which pollutes both air and water. Neighbors are subjected to unbearable odors, and water contamination. A Pigovian analysis would conclude that the CAFO had to curtail its odors and its water pollution. The problem presented by this absolutist proposition is that ultimately if all neighbors of animal production facilities have rights to absolutely clean air and water. Arguably, they do, but the problem with a Pigovian solution is summarized will by the dissent of J. Jasen in the case, “Boomer vs. Atlantic Cement Company,” (taken from Miceli, 2008) a nuisance suit in which an injunction against the polluting cement company was denied. Jasen says:

> I see grave dangers in overruling our long-established rule of granting an injunction where a nuisance results in substantial continuing damage. In permitting the injunction to become inoperative upon the payment of permanent damages, the majority is, in effect, licensing a continuing wrong. It is the same as saying to the cement company, you may continue to do harm to your neighbors so long as you pay a fee for it. Furthermore, once such permanent damages are assessed and paid, the incentive to alleviate the wrong would be eliminated, thereby continuing air pollution of an area without abatement.

Indeed, Jasen presents a Pigovian case against the cement company. But what is to happen if all methods of animal production are, by the same logic as above, rendered illegal? One might quickly imagine that someone would be willing to bear the nuisance of the pollution for a fee. People have always put up with pollution from agriculture, be it flies, odor, or water pollution. In “The Problem of Social Cost,” Coase describes a situation in which a cattle rancher and a farmer negotiate the damages caused by cattle eating the farmer's crops. It is easy to imagine a similar scenario in which crop damages are replaced by odor or other externalities of CAFOs. People could thus negotiate for the nuisances caused by CAFOs, while property rights would Ideally, however, pollution would be minimal, and so such arrangements would rarely be necessary.

Fortunately, there are methods of animal production that do not entail severe odor and water pollution. But the point is not that the above situation can be avoided; it is that the Coasian system allows for the resolution of an otherwise intractable problem without costly government agencies and regulations by contractual arrangements between individuals. There are certain amounts of pollution inherent in some industries. The benefit of the Coasian system is that it allows for contractual agreements permitting pollution so long as those suffering it consent to do so, while those who do not agree can obtain injunctions against industry activity. The result is market efficiency and the protection of the public health.

This is what makes the Coase Theorem attractive as a policy option for resolving issues of CAFO pollution. Studies have shown that livestock can be raised on smaller scales, avoiding the problems of CAFOs, for only slightly higher prices (Gurian-Sherman, 2008). This may surprise some people, who in considering the quantity of meat required to feed the world might consider CAFOs economically advantageous. They are only so because of the current economic circumstances. The obvious advantages they maintain over smaller operations are that they are economies of scale. But there are many hidden costs that they do not assume but are arguably responsible for, and many subsidies which they receive that do not similarly benefit smaller operations.

CAFOs currently pollute ground water and air but are not held responsible for remediation or damages in many cases (Gurian-Sherman, 2008). There have been some nuisance cases decided in favor of plaintiffs, with damages awarded at the expense of CAFOs (Yandle and Blacklocke, 2003). But there are also catastrophes like the floods in North Carolina which poisoned the Neuse River and resulted in a 19 mile fish kill (Gurian-Sherman, 2008). And the effects of the pollution is far reaching. Consider that the Chesapeake shellfish industry is suffering from eutrophication of the watershed. The cost of eutrophication from CAFOs to other fishing industries, across the nation and, as CAFOs globalize, the world, would be difficult if not impossible to estimate accurately. If these damages where in part or whole paid for by CAFOs directly, rather than the taxpayer, or, worse, left unpaid, they might alone make CAFOs economically less favorable than smaller alternative farms.

In the case of the externalities alone (in other words, assuming government subsides will remain unchanged, as is likely given the mammoth political interests invested in them), the Coase Theorem can lead to an efficient outcome in the case of CAFOs. If neighbors are accorded property rights to their air and water, either on the grounds of public health or nuisance, then CAFOs can be reined in without the costs and inefficiency of the state or federal EPA. Besides which, these agencies have been years and decades late in mandating effective CAFO policies, in some cases being hindered by politically bribed legislatures, and in others simply not formulating policy quickly enough, always in violation of the precautionary principle. It is unlikely that they will suddenly rise to the challenge in the future.

Two of the foremost economic analysts of animal agriculture, Elanor Starmer and Timothy Wise, published a paper in 2007 which concluded that without subsidies and with assessment for just one externality, CAFOs would eventually be out competed by smaller, more sustainable forms of animal agriculture. Their research, along with that of Yandle and Blacklocke (2003), Gurian-Sherman (2008), and the Pew Commission on Industrial Farm

Animal Production (2008), all point to a free market solution that will see CAFOs gradually phased out of the market as more sustainable and cheaper forms of animal agriculture replace them. With the American Public Health Association's 2003 recommendation for a moratorium on CAFO construction, eliminating CAFOs rather than mitigating their pollution is arguably the most desirable outcome.

IV. Conclusion: Final Recommendations and Summary of Research Findings

CAFOs represent a severe hazard to the public health. Previous attempts at regulation have only curtailed symptoms rather than eliminating core problems. Yet neither scientists nor economists, who often oppose one another in such debates, believe CAFOs are the best method of animal agriculture. Decades of research have shown the CAFOs are not only unsustainable and wasteful in scientific terms, but economically as well. All that is required is a dismantling of current policies that enable the CAFO industry to out compete smaller operations.

But as Nigel and Key (2003) note, changes to policy must be gradual or compensated so that farmers and other industry workers, and society at large, do not suffer from bankruptcy, unemployment, and sudden shortages in food products. To that end, it is recommended that government subsidies which would otherwise directly benefit CAFOs should be used to transition these operations to diversified farms. Indirect subsidies should be, if not cut altogether, then assessed to CAFOs at purchase; feed in the form of grain is the principle example of this.

Regarding externalities, the same gradual and compensated approach should be taken. A Coasian approach should be incorporated into the current regulatory frameworks, both to ease the regulatory burden and to allow individuals to reach efficient solutions of their own volition. Property rights should be delimited closely and firmly, with specific regards to farming, and keeping in mind that a certain amount of pollution, from noise to odor to runoff, is inevitable from agricultural processes.

These measures would take effect over the course of years. In the meantime, the American Public Health Association's recommendation for a moratorium on CAFO permits should be honored by state and federal government, regardless of industry complaints. Furthermore, attention should be paid to specific populations at risk, populations in CAFO dense areas. If CAFO densities are seen to pose an acute public health risk in these areas, officials should identify key operations to shut down, if necessary.

For decades, scientists, citizens, government officials, and industry professionals have recognized the problems posed by CAFO production methods. Free markets and well established property rights provide a solution that allows for efficient markets and protects public health. Hopefully, policy will catch up to the scientific research and recognize the expediency of this solution, and policy makers will put the public first and make the necessary changes. Hopefully, CAFOs will be a thing of the past in a few years, agriculture will have returned to its idyllic roots.

V. Acknowledgments

I would like to thank Professor Marc Zimmer, Professor Jessica Mulligan, and Michael Reder, who helped me with the formatting and content of my thesis. I would like to thank Steven

Hennenfent, for giving me the idea that led to this project. I would also like to thank Professor James Otteson of Yeshiva University, who gave me my first exposure to moral philosophy and the merits of free market economics, and also recommended me to Jane Shaw, and through her Bruce Yandle, Blake Hurst, and Roger Meiners. These last four directed me to resources that proved instrumental in formulating the policy recommendations of my thesis.

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