Environmental Impact of Industrial Farm Animal Production

A Report of the Pew Commission on Industrial Farm Animal Production

TOPIC:

Industrial Farm Animal Production, Environmental Impact of Industrial Farm Animal Production

Rolf U. Halden, MS, PhD
Kellogg J. Schwab, PhD

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PCIFAP Staff Summary Environmental Impact of Industrial Farm Animal Production

The Pew Commission on Industrial Farm Animal Production was established by a grant from The Pew Charitable Trusts to the Johns Hopkins Bloomberg School of Public Health. The two-year charge to the Commission was to study the public health, environmental, animal welfare, and rural community problems created by concentrated animal feeding operations and to recommend solutions.

Like many industries, Industrial Farm Animal Production (IFAP) results in a number of environmental impacts that affect populations both near and far. While every industry may contribute to society via production of some necessary or desired good, as our population increases, we have become more and more aware of the finite nature of our world's resources and of the impacts of our various industries upon those resources and our own human health. Industrial farm operations impact all major environmental media, including water, soil, and air. Of most concern are the pollution of ground and surface water resources with nutrients, industrial and agricultural chemicals, and microorganisms; the use of freshwater resources; the contamination and degradation of soil; and the release of toxic gases and odorous substances, as well as particulates and bioaerosols containing microorganisms and pathogens. The Commission queried the authors of this report on the magnitude and key determinants of these impacts, and the resulting impacts on both human health and ecosystems.

The major causes of the above noted environmental impacts of IFAP are the enormous amounts of waste that are produced in a very small area in this agricultural model, the inadequate systems we now have to deal with that waste, and the large energy and resource inputs required for this type of production, including feed production and transport.

The USDA Agricultural Research Services (ARS) estimated the manure output from farm animals in the United States to be nearly 1 million US short tons of dry matter per day in 2001. Eighty-six percent of this was estimated to be produced by animals held in confinement. Different groups have posited both lower and higher estimates, but the fact remains that food animals produce an enormous amount of waste every day, exceeding human sanitary waste production by at least one order of magnitude. However, disposal of this waste is far less closely regulated than disposal of human waste. Animal manure and other agricultural waste result in water and air degradation, which in turn impact both the aquatic and the terrestrial ecosystems surrounding these operations.

In addition to the enormous waste produced by industrial agriculture, this system requires major inputs of both energy and resources. Water use is more significant in these systems because it is often used for cleaning the buildings and in the waste management systems. In addition, the industrial model utilizes feed, which is grown in monocultures, often far away from the facility. Enormous quantities of both water and petroleum-based pesticides may be used in the production of this feed, leading not only to the depletion of water resources, but also to soil erosion and pollution with pesticides. Pesticide residues may remain in the animal feed, leading to the possibility of toxic residues in the food animals themselves. Feed crop monocultures also contribute to loss of biodiversity, as they are planted in place of other plants and/or animal habitats.

Finally, but growing more urgent every day, industrial agriculture may be a significant contributor to climate change, as the production of greenhouse gases from these facilities (both from the animals themselves and from the decomposition of their waste) is significant.

Taken together, these data suggest that the present industrial model of farm animal production is not sustainable for the long term. The overuse and degradation of natural resources may be too great to allow the current form of this production model to continue to be viable. The commission requested that the authors of this report investigate the scope of these environmental factors, to help grasp the breadth of the possible impacts of the IFAP system.

By releasing this technical report, the Commission acknowledges that the author/authors fulfilled the request of the Commission on the topics reviewed. This report does not reflect the position of the Commission on these, or any other, issues. The final report, and the recommendations included in it, represents the consensus position of the Commission.

Introduction

Industrial farm operations adversely impact all major environmental media, including water, soil, and air. Key issues of concern for ecological and human health include the contamination of ground and surface water resources with nutrients, industrial and agricultural chemicals, and microorganisms such as viruses, bacteria, and parasites. Unsustainable use of freshwater for feed production, animal care, and slaughterhouses contributes to water scarcity and is depleting precious resources needed by future generations (Burkholder et al., 2007; Walker et al., 2005). Contamination of soil is another pervasive problem caused by the unsustainable, year-round deposition of excess nutrients, chemicals, and pathogens on land in the vicinity of industrial feeding operations. Poor air quality results from the localized release of significant quantities of toxic gases and odorous substances, as well as particulates and bioaerosols containing a variety of microorganisms and human pathogens. Adverse ecological outcomes include excessive nutrient loading and euthrophication of surface waters resulting in oxygen-depleted dead zones in both inland and marine surface waters, recurring algal blooms, fish kills, and a decline in species populations and biodiversity.

An array of adverse human health effects have begun to be documented in conjunction with the rise of industrial farm animal production (IFAP) (Sapkota et al., 2007b; Donham et al., 2007). Health outcomes observed in farm workers and exposed rural populations include an increased prevalence in serious respiratory diseases (up to 25% for workers in the swine industry) (Heederick et al., 2007), bacterial infections that may be resistant to antimicrobials, and a general decline in physical, mental, and social wellbeing, as perceived by affected rural populations (Donham et al., 2007; Gilchrist et al., 2007; Heederick et al., 2007).

This paper explores the magnitude and key determinants of IFAP impacts on air, water, and soil, and the resulting impacts on human health and ecosystems. To gain a proper understanding of the origin of environmental and human health issues surrounding modern animal farming, it is important to define current agricultural farming practices and contrast them with traditional methods that evolved over the course of centuries in the interplay between farmers, their land, and the animals raised.

The Industrial Farming Model.

In the past few decades, American farming has undergone significant changes. Today, 54% of US food animals are concentrated on only 5% of the remaining farms. IFAP is designed to increase production yield and decrease production costs by using high-efficiency practices that rely heavily on economies of scale as well as on a standardization of processes and end products (Sapkota et al., 2007b). This model differs from traditional farming in both approach and scale. The traditionally numerous but small and independently owned and operated farms have largely been replaced with a much more limited number of large facilities for growing food animals. These large farming operations now supply most of the meat and poultry products for domestic consumption and for markets around the world. IFAP employs high-throughput farming of thousands of animals of a single breed for a single purpose, such as the large-scale production of hogs, broiler chickens, turkeys, or dairy cattle, often in confined locations under highly controlled conditions using formulated foods in lieu of access to forage. These facilities are known as animal feeding operations (AFOs). According to the US Environmental Protection

Agency (EPA), an animal feeding operation (AFO) is a lot or facility (other than an aquatic animal production facility) where the following conditions are met: (a) animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period; and (b) crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility (US EPA Compliance Assistance website).

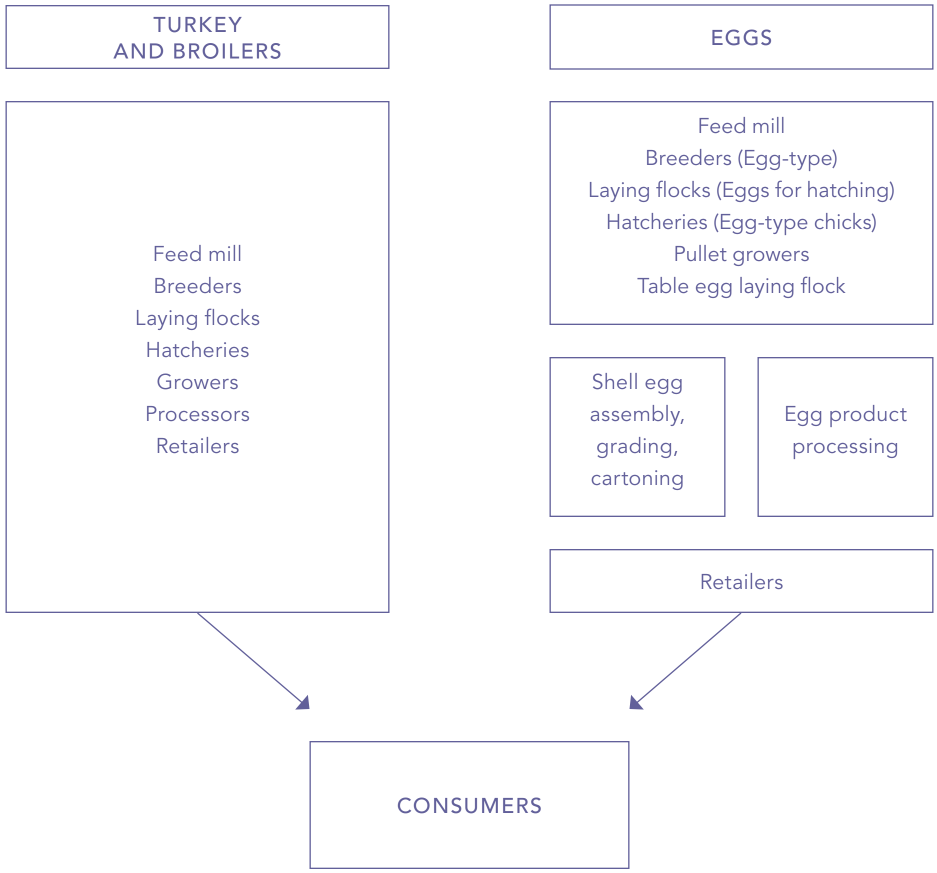
Concentrated animal feeding operations (CAFOs) are a sub-category, which previously was defined based on animal units, but now instead is determined by the actual number of animals at the operation. CAFOs can be divided into small, medium, and large operations based on the number of animals housed, as specified on the US EPA Compliance Assistance website. Presently, cows, hogs, and poultry, i.e., turkeys and chickens, are the most common food animals raised in CAFOs in the United States.

Industrialized farm animal production evolved from a change to a management structure, in which a corporation controls all aspects of production from the selective breeding of young animals to the processing of animal meat into consumer products. This organizational structure is referred to as vertical integration (Economic Research Service /USDA, undated). A distinctive feature is that most or all management and economic responsibilities of animal production lie with companies known as integrators.

The shift from traditional animal husbandry to IFAP has occurred rapidly in the United States, mostly within the last five decades. It has transformed the structure of rural communities and impacted environmental quality and public health in its wake. Today, fewer people are raising more food animals, and the traditional model of the self-employed farmer has shifted to that of a grower of animals, responsible only for raising young animals to market weight using methods prescribed by entities external to the geographic location of the animal production site (USDA/NASS, 2005). While growers may still own the land and structures used for farming, they no longer own the animals and do not grow animal feed crops. This loss of independence is offset by the perceived benefits to farmers of obtaining price stability and a multi-year contract (USDA/ERS, undated). In IFAP, growers typically perform contract work for the integrators, who provide young animals and the formulated feed. They also control the terms and conditions of animal production and set the compensation paid to the grower. Whereas it is the grower's responsibility to carry out day-to-day operations, the integrators are instrumental in determining and administering veterinary care and inspection, as well as in managing animal removal from the grower's site, mostly by using contract labor. Animals having reached market weight are then taken to integrator-owned and -managed plants that, increasingly, furnish ready-to-sell consumer products for the retail market (Figure 1).

The shift in animal production toward this industrialized business model has important environmental and public health implications. Today, more animal waste than ever before is produced by a very limited number of large farms. The disposal of these unprecedented amounts of animal waste generated in a few discrete locations poses new and significant challenges. Animal waste or manure, which traditionally has been regarded as a welcome source of nutrients for soil improvement (often referred to as amendment), in many cases, has turned into a liability and a problematic byproduct causing ecosystem degradation and public health concerns in communities surrounding IFAP facilities (Osterberg and Wallinga, 2004). High-density confinement of animals has created indoor air pollution hazards for workers and significant point sources for outdoor air pollution (Mitloehner and Schenker, 2007). Industrial animal farming practices also have promoted the use of non-traditional chemicals in agriculture, including antimicrobials for disease control, prophylaxis, and growth promotion, as well as heavy metal–containing arsenicals for control of parasitic diseases (Graham et al., 2007). The presence of these non-traditional chemicals in animal waste poses new challenges for appropriate management. Furthermore, the centralization of animal production facilities has made American agriculture more vulnerable to large-scale outbreaks of food- and waterborne diseases, thereby adversely impacting food safety and food security (Gilchrist et al., 2007). Finally, centralized meat production and animal slaughtering houses have increased energy consumption, long-distance transport of agricultural products, and the output of noxious gases suspected of contributing to air quality degradation, adverse human health effects, and climate change phenomena (Heederik et al., 2007).

Figure 1. Conceptual diagram illustrating the integrated business model extant in the poultry and egg industry. Typically, integrators own and control all aspects of production to the point of retail sale (Source: USDA ERS AER-807)



Origin and Magnitude of Environmental Impacts

In the United States, an estimated 173,000 miles of national waterways are impacted by runoff from agricultural sources (Cook, 1998). Animal farming is estimated to account for 55% of soil and sediment erosion, 37% of nationwide pesticide usage, 80% of antibiotic usage, and more than 30% of the total nitrogen and phosphorus loading to national drinking water resources (Steinfeld et al., 2006).

There are three root causes of environmental degradation from IFAP:

1. The large volumes of animal waste produced;
2. Lack of appropriate management and disposal of these materials; and
3. Unsustainable water usage and soil degradation associated with feed production.

Before these environmental issues are explored in greater detail, it is important to gain an appreciation for the scale of IFAP operations in the United States and how extensively they have penetrated the national agricultural sector.

The structural shift toward IFAP.

Contract production of meat in IFAP facilities is a national phenomenon now dominating the agricultural sector. In 1999, the IFAP business model already accounted for almost the entire broiler production, more than 60% of the hog production and about 35% of the cattle output (Donham et al., 2007; US Government Accountability Office, 2005). Today, eight years later, its role certainly is even more pronounced. (Release of updated information by the USDA is pending.)

The trend toward intensive, industrialized production of confined cattle, hogs, and poultry can be illustrated by the broiler industry. Figure 2 shows the relative increase of very large IFAP facilities producing tens of thousands of broilers per year.

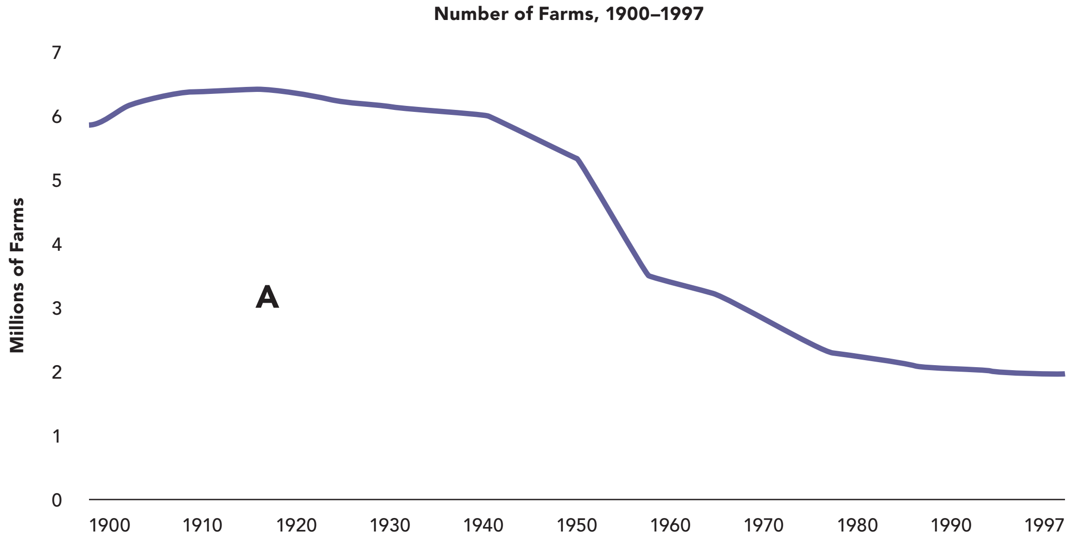
Over the course of several decades, millions of US backyard operations featuring small flocks of chickens often raised for the dual purpose of egg and meat production have been replaced with less than 50 agricultural firms that operate as highly specialized, vertically integrated businesses with most of the production coming from the top four integrators (USDA-NASS undated [http://www.usda.gov/nass/pubs/trends/broiler.htm]; USDA-ERS undated).

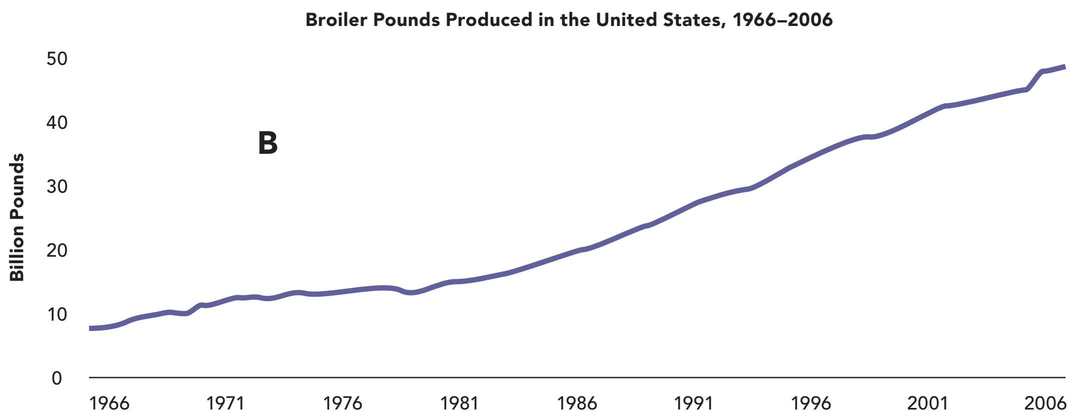
Hallmarks of new production techniques are high-density facilities in which 25,000 to 50,000 confined chickens are raised to market weight within a few weeks by automated feeding apparatuses dispensing a growth-optimized diet usually supplemented with antimicrobials that also are used as life-saving remedies in human medicine. Use of these techniques has allowed for a doubling of broiler production from 1980 to 1999 (USDA-NASS undated [http://www.usda.gov/nass/pubs/trends/livestockproduction.csv]) and has triggered a remarkable reduction in prices of broilers, now available for less than what was charged (in inflation-adjusted dollars) in the 1950s (USDA-ERS undated). However, this seemingly favorable cost comparison of meat from IFAP versus traditional farms does not account for environmental and public health costs.

Statistics for the hog industry show similar trends of a sharp decrease in the number of farms and a notable increase in their sizes. In 2005, the United States produced more than 103 million pigs at 67,000 production facilities (USDA 2006a; 2006b). Facilities housing tens of thousands of pigs accounted for more than half of the total US swine inventory, reflecting the increasing consolidation and concentration of US swine production (USDA 2006a).

Statistics for the US broiler and pork industry show today's animal production to be dominated by IFAP practices (Figure 3). This trend has resulted in the generation of large volumes of wastes in relatively confined geographical areas. For example, swine manure is typically stored in deep pits or outdoor lagoons and then applied to agricultural fields as a natural fertilizer. However, runoff events and percolation (i.e., water soaking into the ground) of manure components, including bacteria pathogenic to humans as well as chemical contaminants, have impacted surface water and groundwater proximal to swine CAFOs, thereby posing health risks to the environment and human populations (Anderson and Sobsey, 2006; Campagnolo et al., 2002; Jongbloed and Lenis, 1998; Krapac et al., 2002; Sayah et al., 2005; Thurston-Enriquez et al., 2005; Sapkota et al., 2007a).

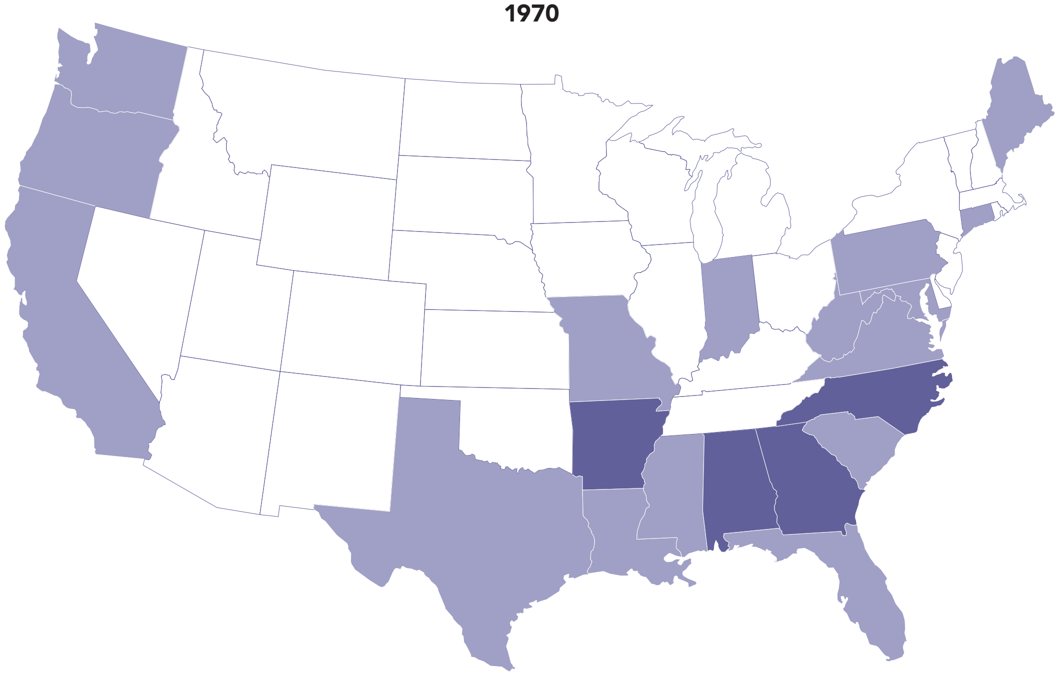
Figure 2. Between the 1940s and 1980s (A), the United States has experienced a notable shift toward a small number of larger farms. This trend is exemplified by the broiler industry, which has markedly increased its meat output (B) while reducing the number of farms, formerly spread across multiple states (C), to a small number of larger facilities concentrated in a few southeastern and south-central states. (Sources: USDA-NASS: http://www.usda.gov/nass/pubs/trends/farmnumbers.htm, and Paudel and McIntosh, 2005) (Source: Census of Agriculture)





1970

C

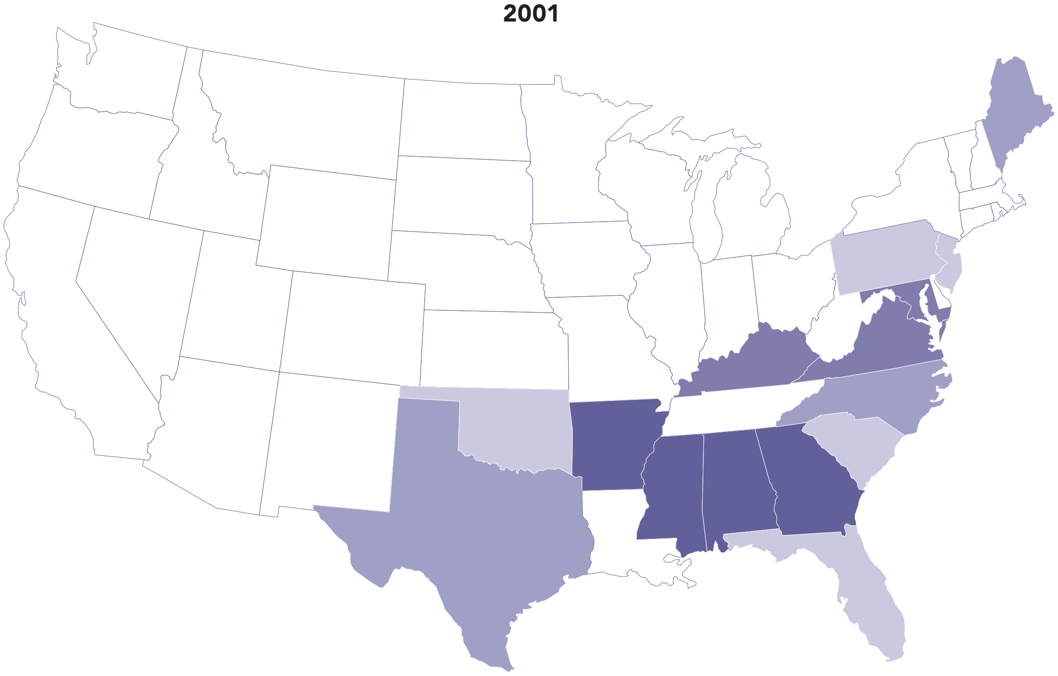


Broilers (,000)

85–5,000
5,001–8,051

2001

D



Broilers (,000)

1,607–5,000
5,001–10,000
10,001–15,000
15,001–24,543

Magnitude of animal waste produced.

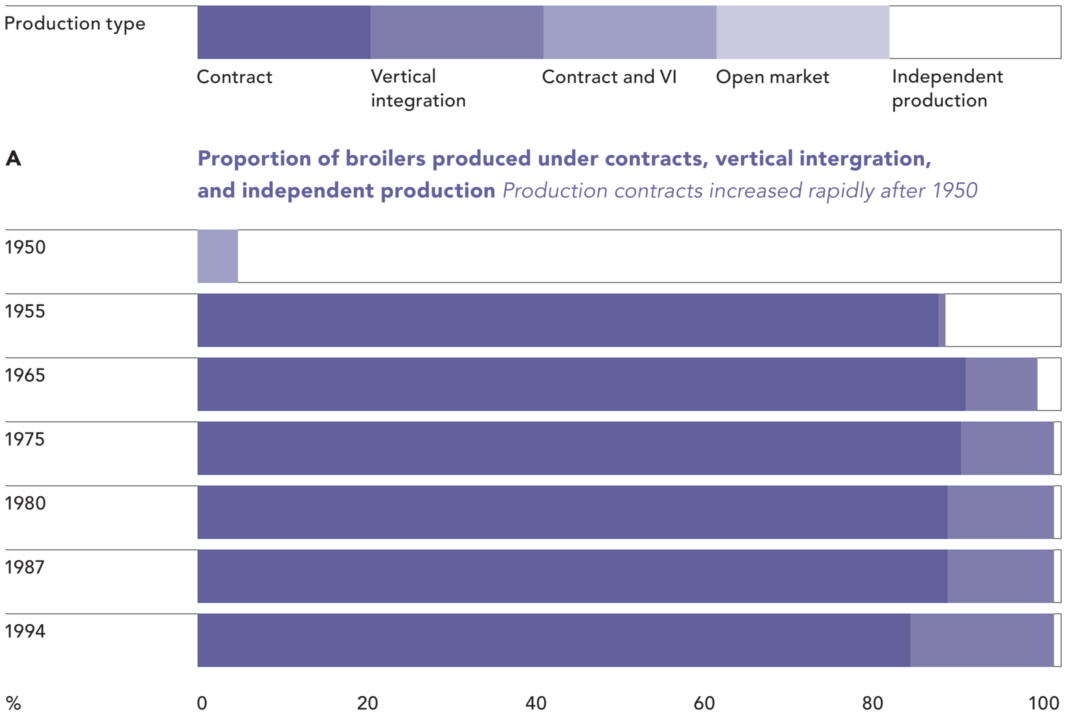
By any estimate, the total amount of farm animal waste produced annually in the United States is substantial. In its report for the year 2001, the USDA estimated the output of manure from farm animals at 920,000 US short tons of dry matter per day (USDA ARS 2002). This translates to greater than 300 million metric tons of dry mass or more than 660 billion pounds per year. Of this mass, 86% (788,000 tons per day) was projected to stem from animals held in confinement. In contrast, the American Society of Agricultural Engineers provides a higher estimate of 540 million metric tons of dry weight excreta per annum (American Society of Agricultural Engineers, 2005). Lower estimates of 133 million tons of manure per year on a dry weight basis also have been reported recently in the peer-reviewed literature using information contained in USDA online databases (Burkholder et al., 2007). Reporting the volume of excreta based on the lifespan of the food animal results again in a different set of data. Regardless of the exact amount generated, farm animal waste exceeds human sanitary waste production by at least one order of magnitude (Burkholder et al., 2007). Yet in comparison to the lesser amount of human waste, the management and disposal of animal wastes are poorly regulated. This lack of protection may have been without consequence in traditional agriculture, because animal wastes produced by traditional animal husbandry methods in rural locations did not usually present risks to local communities that relied on ecosystem services for attenuating pathogens and absorbing or diluting nutrients. However, similar to large human settlements, improper management of feces from IFAP facilities can and does overwhelm natural cleansing processes.

Resource requirements of IFAP.

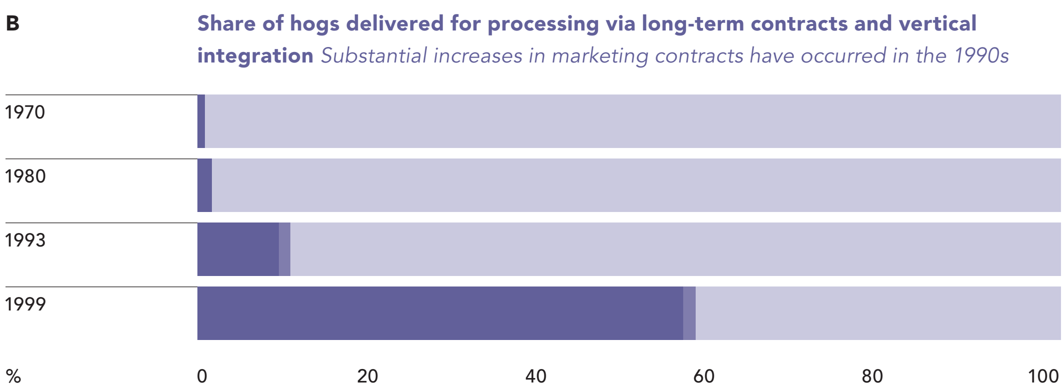
IFAP, as practiced today, is more resource intensive than the traditional practices of raising food animals (e.g., cows grazing on pastures), exhausting and eroding soils, and requiring disproportionately large inputs of fossil fuel, industrial fertilizers, and other synthetic chemicals, as well as substantial amounts of water, often withdrawn at unsustainable rates from scarce freshwater resources. Whereas the ratio of fossil fuel energy inputs per food unit produced averages 3:1 calories for all US agricultural products combined, it is substantially higher for industrially produced meat products. With a ratio as high as 35:1, beef produced in feedlots has a particularly unfavorable energy balance (Horrigan et al., 2002; these estimates exclude additional energy inputs for food processing and distribution).

Increased industrial animal production (Figures 2 and 3) implies an increase in the amount of nutrients and chemicals released to the environment. Approximately 21.3 million tons of nutrients have been applied in agriculture each year over the past three decades, with nitrogen and phosphorus contributing 11.4 and 4.6 million tons each, respectively (USDA Economic Research Service, 2007; potash accounts for the balance of the total). Pesticide inputs to the US environment from industrial meat production also are considerable (Steinfeld et al., 2006). Numbers available for the time period of 2000–2001 show the annual total pesticide usage in the United States at about 700 million pounds of active ingredient, 77% of which is applied in agriculture, with about half of this mass going to farmland used for the production of grain fed to industrial farm animals (Kiely et al., 2004; Steinfeld et al., 2006). Corn and soybeans, which now are replacing traditionally used grass as cattle feed, largely are produced in crop monocultures maintained on agricultural land that in many instances is irrigated using groundwater from aquifers whose natural recharge rates are outpaced by this intense, unsustainable usage (Horrigan et al., 2002).

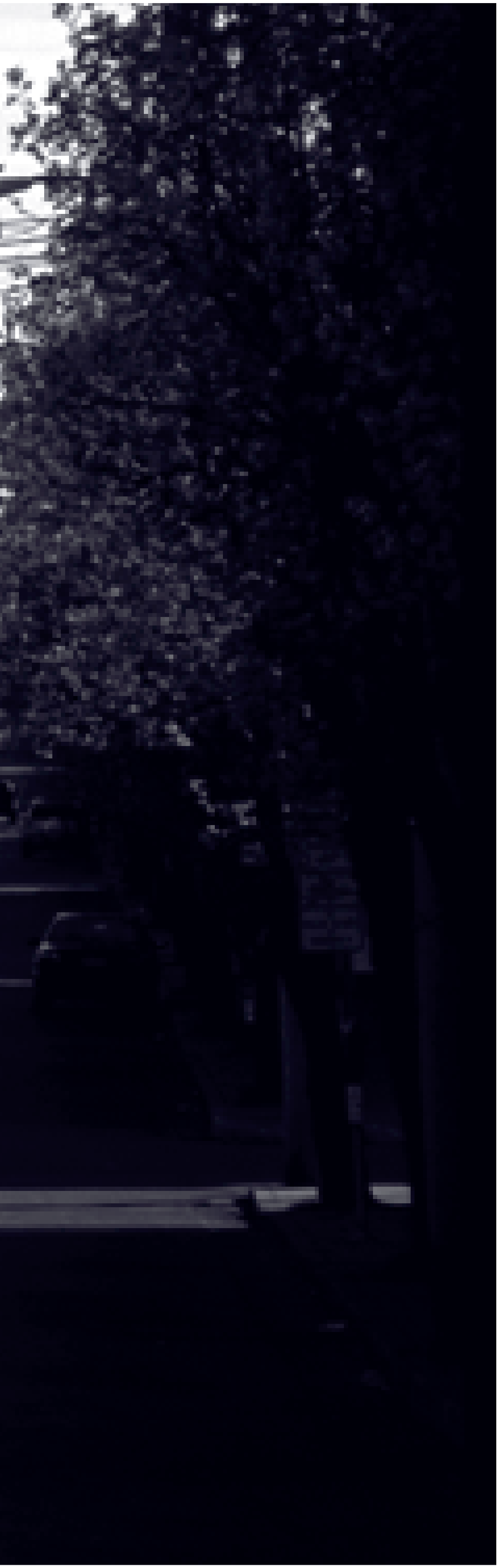
Figure 3. The number of US farm animals raised in independent production has declined at the expense of contract meat production, as illustrated by statistics for broilers (A) and hogs (B) (Source: Economic Research Service/USDA, undated)



Source: Compiled by ERS, USDA from Roy; Knutson, Penn, and Boehm; and Manchester. Note: Roy does not distinguish contracting and vertical integration in 1950.



Sources: Compiled by ERS, USDA from Hayenga, Lawrence, Rhodes, and Grimes; Marion; and University of Missouri and National Pork Producers Council.



Affected populations.

The model of contract meat production now dominating the US market has physically separated key decision makers and many employees from the locality of animal farming operations, a development that has resulted in a loss of accountability and land stewardship as well as a degradation of the quality of life in rural communities harboring IFAP facilities (Horrigan et al., 2002; Donham et al., 2007). Adverse impacts have been documented in the areas of economic health, physical health, mental health, and social health, thereby creating an environmental justice issue for rural communities (Donham et al., 2007). Reports have documented associations between IFAP facilities in rural communities and increases in self-reported respiratory diseases including asthma and bronchitis; impaired mental health including depression; anxiety and post-traumatic stress disorder; harassment of outspoken community members; and a general perception by local residents of societal neglect (Dosman et al., 2004; Thu et al., 1997; Bullers, 2005; Schiffman et al., 1995). Documented impacts of IFAP include a relative decline in retail purchases made locally, more hired farmhands versus self-employed small-acreage farmers, decreased tax revenue, degradation of the community fabric, and a decline in land and property values (Goldschmidt, 1978; Thu, 1996; Wright et al., 2001).

Key Determinants of Environmental Impacts of IFAP

Swine, beef, and poultry IFAP facilities are the source of an array of chemical and biological pollutants (see Figure 4) discharged to air, water, and soil, where they have been observed to cause ecological effects and diseases in exposed individuals (Thorne, 2007; Heederik et al., 2007; Gilchrist et al., 2007). In the following, contaminant loading to all three major environmental media is discussed to emphasize that the chemical and biological agents emitted from IFAP facilities occur in multiple environmental media and migrate between them. Thereafter, key determinants of this pollution are explored in greater detail to identify opportunities for intervention and amelioration. Finally, the important role of dietary choices and their impact on environmental quality is discussed.

Water.

IFAP operations can impact the water environment by depleting limited freshwater sources and by contaminating surrounding surface and groundwater, two phenomena most frequently observed in arid regions and in floodplains, respectively (Burkholder et al., 1997; Mallin et al., 1997, 2000). Contamination of water resources occurs either directly, via intentional discharge of insufficiently treated liquid waste, or indirectly, via infiltration of contaminants into groundwater from unlined waste lagoons, as runoff from locations where solid waste is stored or has been disposed of, and from the deposition of airborne contaminants onto surface waters (Burkholder et al., 2007).

Air.

Airborne contaminant emissions arise from both ventilation and passive release. These emissions can include toxic gases and particulates (Bunton et al., 2007; Heederick et al., 2007). Decomposing animal excreta produce and release a complex mixture of dust particles, bacteria, endotoxins, and volatile organic compounds, as well as hydrogen sulfide, ammonia, and other odorous substances (Bunton et al., 2007). An association between health problems and air emissions has been reported in the literature. Some IFAP emissions such as ammonia can travel beyond the immediate CAFO location, thereby causing unwanted effects at the regional level (Aneja et al., 2003).

Soil.

The soil environment is stressed as a result of both the monoculture methods employed for producing soy and corn for animal feeds, and the disposal of animal wastes (Horrigan et al., 2002; Walker et al., 2005). Feed production in agricultural monocultures requires extensive application of pesticides and other agrichemicals, as well as irrigation, which, if not properly managed, can promote erosion and degrade terrestrial and aquatic ecosystems (Park and Egbert, 2005). Already, a significant area of US land is affected by heavy erosion, driven primarily by agricultural use, including the production of feed crops for food animals (Figure 5).

Equally important, animal wastes from IFAP are disposed of on agricultural land oftentimes year-round and without a suitable nutrient management plan. The latter practice results in over-fertilization of the soils, toxic runoff, and leaching of contaminants, which then pose additional risks to adjacent water environments and also may impact drinking water sources (Burkholder et al., 2007). While federal regulations recently have been revised (http://www.epa.gov/guide/cafo/), a lack of federal oversight and enforcement by state governments is a longstanding and continuing problem, as concluded by the US Government Accountability Office (US GAO, 2005).

None of the above issues are truly unique to industrialized farming, so why is it that IFAP plays such a critical role in the magnitude and severity of these processes and outcomes? Taking a historical view can be instructive. Many traditional animal farming methods, which evolved over more than 10,000 years, have proved to be sustainable because they strike a balance between agricultural inputs and outputs as well as the need to preserve ecosystems (one notable exception being slashand-burn agriculture, which is still practiced around the world despite its severe impacts on environmental and human health). In contrast, industrial agriculture and particularly IFAP are relatively recent phenomena, dating back less than half a century. The rapid ascent of IFAP is driving the magnitude and importance of the key determinants of environmental and human health impacts discussed hereafter.

Meat production.

US meat production is at an all-time high and projected to increase to the year 2016 and beyond (USDA 2007). The broiler industry, which has been converted almost entirely to industrial farm practices, exemplifies this trend (Figure 6). The increase in US meat consumption and in other areas of the world is due to multiple factors, including higher production capacities resulting from IFAP, a growing world population, growing exports, and a trend toward a Western diet high in animal protein (Horrigan et al., 2002). A contributing major, but frequently overlooked, factor of increased meat consumption is artificially low retail prices resulting from government agricultural subsidies as well as the exclusion of external costs, i.e., costs resulting from current business practices that are excluded from the price of food (Walker et al., 2005); specifically, these external costs include the adverse environmental and human health impacts triggered by the release of insufficiently treated agricultural waste. The increased production of food animals has triggered an increase in feed crop production. Today, 66% of the grain produced in the US is fed to livestock (World Resource Institute, 2000). This simultaneous increase in feed and meat production has caused additional ecological impacts, including the need for disposal of increasing amounts of animal wastes. These wastes are produced in highly concentrated areas that have insufficient crop fertilizer needs to absorb the massive burden of nutrients and contaminants that are continuously generated.

Figure 4. Source-to-effect diagram illustrating the role of IFAP facilities as a source of hazardous agents whose emission adversely impacts the environmental quality of air, water, and soil, and creates conditions for biological exposure and unwanted health outcomes in affected animal and human populations (VOCs, volatile organic compounds; figure adapted from Walker et al., 2005)

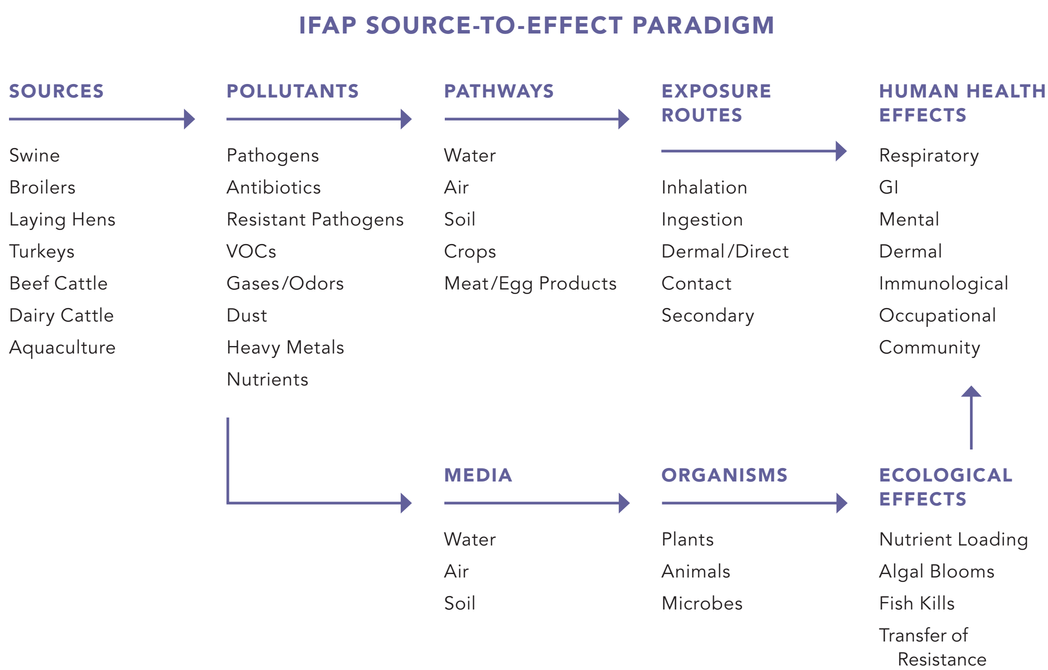


Figure 5. Map of the United States showing the rate of soil loss due to sheet and rill erosion resulting, in part, from the agricultural production of corn and other feed crops used in IFAP. Shown is the average value of soil erosion in units of pounds per acre calculated according to the Universal Soil Loss Equation (USLE) for cultivated cropland and pastureland (Taken from Kellogg, 2000)

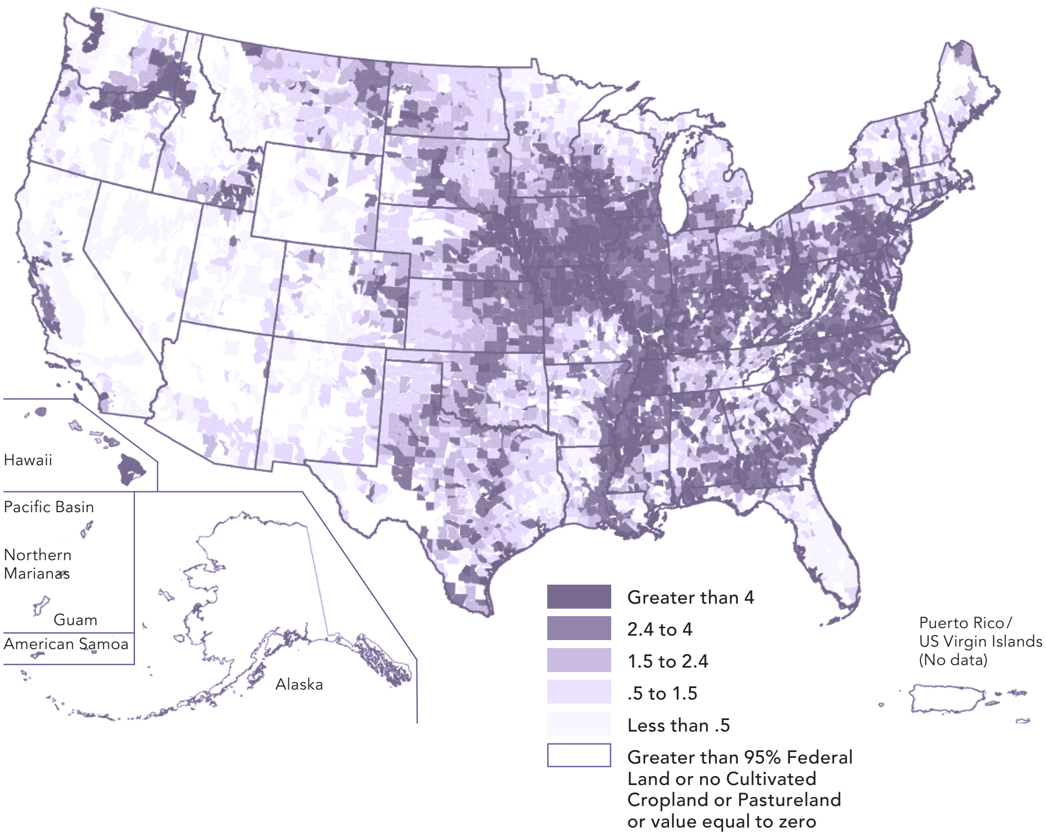
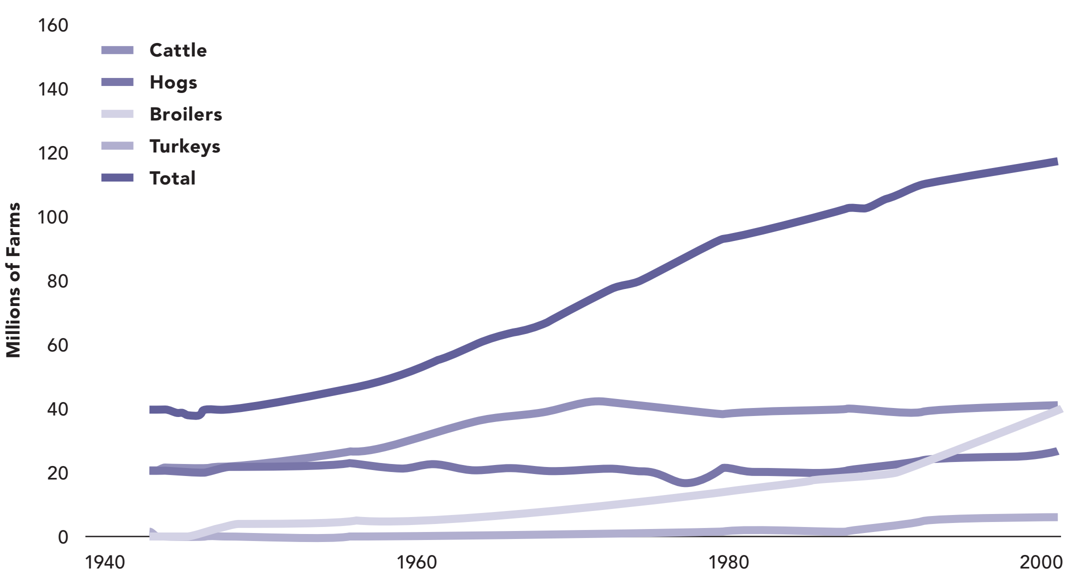


Figure 6. Trends in US meat production for the years 1945 through 1999 (Source: USDA)



Nutrients.

Chief among the ecological concerns regarding current management practices of animal wastes are excess nutrients, including nitrogen and phosphorus. These elements control the fertility of soils and aquatic environments. Another important parameter is the so-called biochemical oxygen demand or BOD, a lump measure of organic and inorganic substances that readily undergo aerobic microbial metabolism. As discussed later in greater detail, excess BOD originating from IFAP facilities can cause dangerous drops in dissolved oxygen levels in surface waters, a condition threatening the survival of most aquatic life.

Nitrogen-containing pollutants, principally ammonium, nitrate and nitrite, pose both ecological and human health threats. Constituents of animal waste applied on fields for feed crop production frequently find their way into surface waters as a result of leaching and surface runoff (Burkholder et al., 2007). Nitrogen in animal waste, present largely as ammonium, is quickly converted by microorganisms to nitrate in aerobic conditions. Nitrate is highly soluble and hence moves with water into rivers or groundwater. The problem is that nitrogen (as nitrate or ammonia) represents the limiting nutrient in marine and estuarine environments. As a result, an increased loading of nitrogen-containing compounds to surface waters can dramatically change these downstream coastal ecosystems. Discharge of excess nitrogen into streams and rivers, such as the Mississippi River and its tributaries (Figure 7), also is known to contribute to both eutrophication in freshwater as well as annually recurring large dead zones in marine waters of the Gulf of Mexico (Figure 8). It is important to note that this phenomenon is driven not only by the land application of CAFO waste but also by an increased reliance on fertilizer used for the production of grain fed to animals held in distant CAFOs.

The resultant increased incidence of hypoxia, or lack of oxygen (Figure 9), is responsible for massive fish kills. This phenomenon is a direct result of excessive use of fertilizers and improper disposal of animal wastes in agriculture.

Nitrate also is a key drinking water contaminant, regulated under EPA's Safe Drinking Water Act at a level of 10 mg per liter as nitrogen (10 mg/L NO_3^--N). Exposure to nitrate of infants under six months of age can result in blue baby syndrome or methemoglobinemia, a potentially deadly condition triggered via the conversion of ingested nitrate (NO_3^-) to toxic nitrite (NO_2^-) by commensal microorganisms within the human digestive tract (Ward et al., 2005). Adults also can be affected by nitrate-contaminated drinking water. Documented outcomes of human exposure to nitrates in drinking water are cancer and non-cancer diseases, including hyperthyroidism, insulin-dependent diabetes, and increased risk of adverse reproductive outcomes and neurodevelopmental defects. A recent review of public health issues related to IFAP summarizes the controversial issue of health outcomes from nitrate exposure (Burkholder et al., 2007).

Phosphorus is another major water contaminant that can originate from CAFOs. Similar to nitrogen in marine and coastal environments, phosphorus is the limiting nutrient for the productivity of freshwater environments.

Figure 7. Fertilizers, whose use has increased six-fold since the 1950s, represent a major source of nitrogen (purple trend line) annually released in the Mississippi Basin (Taken from Goolsby and Battaglin, 2000)

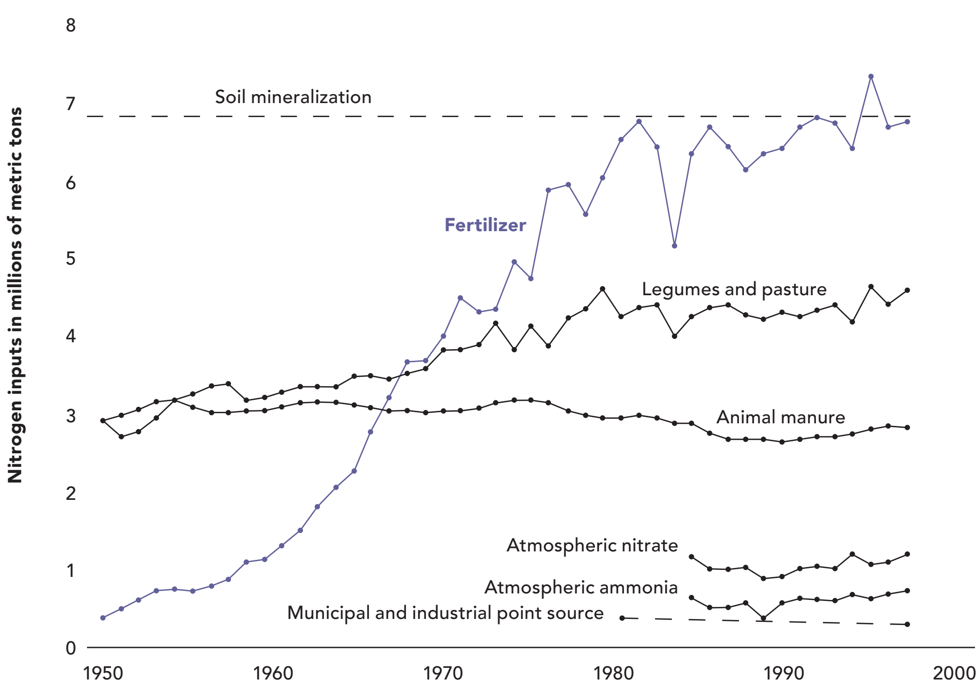


Figure 8. Excess nutrients flushed from agricultural soils into the Mississippi Delta create annually recurring dead zones in the Gulf of Mexico (Source: NOAA: www.noaanews.noaa.gov/stories/s2004.htm)

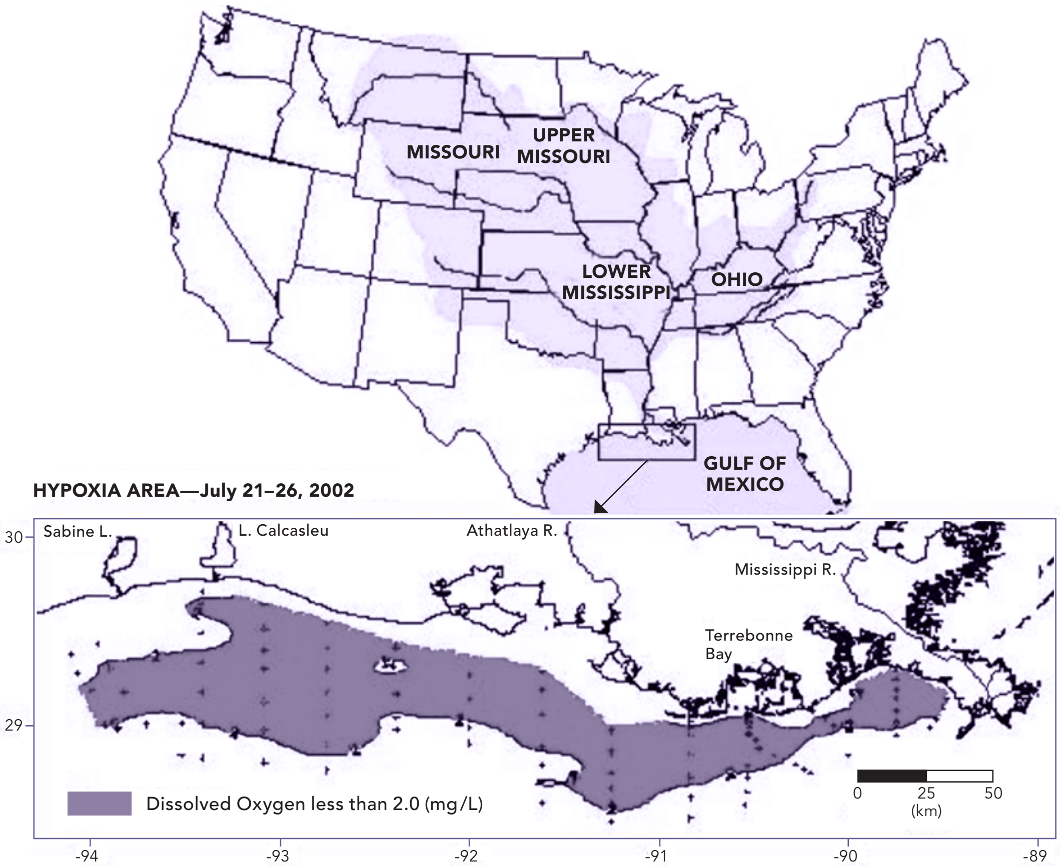
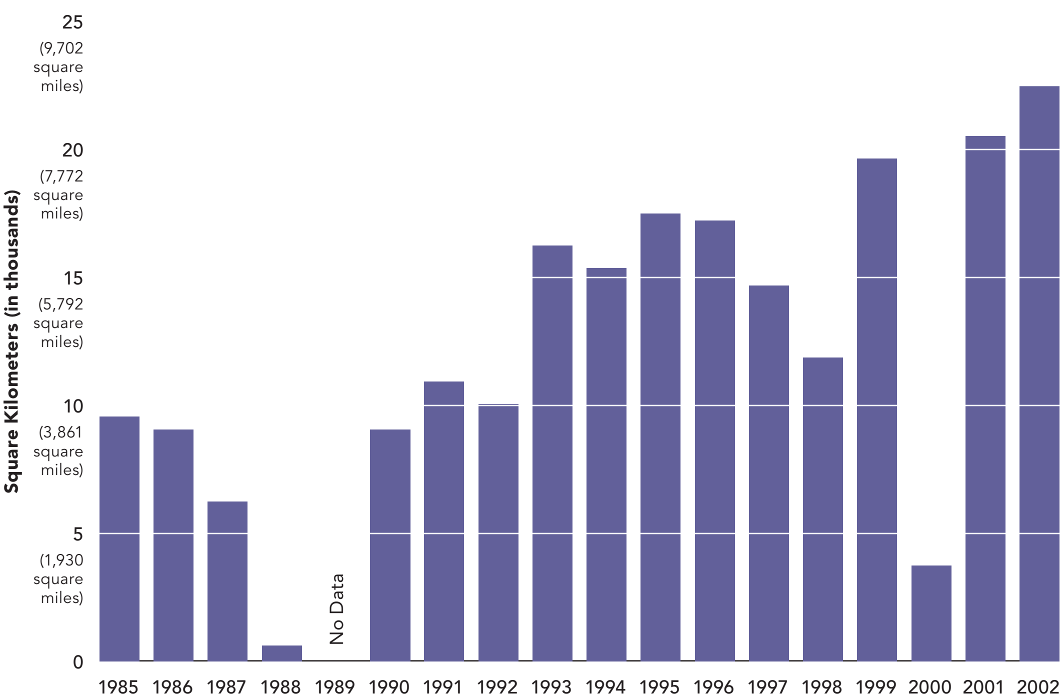


Figure 9. Hypoxic conditions in the Gulf of Mexico have increased from 1985 to 2002 (Source: US EPA: www.epa.gov/indicate/roe/html/roeWaterW2.htm)



Note: Hypoxia in the Gulf is defined as less than 2.0 parts per million (ppm).

Annual midsummer cruises have been conducted systematically over the past 15 years (with the exception of 1989). Hypoxia in bottom waters covered an average of 8,000–9,000 km^2 in 1985–92 but increased to 16,000–20,000 km^2 in 1993–99.

Source: For 1985–1999 data years: Rabalais, Nancy N. et al. *Characterization of Hypoxia: Topic 1 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico*. May 1999, updated July 2000; for 2000–2002 data years: Rabalais, Nancy N., Lousiana Universities Marine Consortium. Unpublished data, personal communication. February 11, 2003.

Agricultural fertilizers employed in feed crop production and animal wastes from livestock operations contain large quantities of phosphorus, mostly in the form of inorganic phosphate (PO_4^{3-}). Disposal, leaching, and runoff of agricultural phosphorus compounds into freshwater resources form the principal cause for eutrophication of US surface freshwaters. Eutrophication is known to spawn excessive aquatic productivity and the development of recurring toxic algal blooms (Schindler, 1990) (Figure 10).

The burden of nitrogen and phosphorus from animal waste is considerable. As shown in Table 1, the estimated inventory of 9.6 billion food animals in the United States excretes a combined total of 9.2 million metric tons of nitrogen and 857,000 tons of phosphorus. Deposition of these materials on agricultural soils vulnerable to runoff and leaching creates environmental and human health risks (Figure 2).

As stated in the nutrient overview, biochemical oxygen demand (BOD) is another important parameter closely related to the issues of excess nutrient burden. It is a simple measure of the amount of oxygen required to aerobically digest compostable matter (mostly organics) in a given period of time, typically 5 days. Swine waste slurries exhibit a BOD of 20,000 to 30,000 mg per liter (Webb and Archer, 1994), which is about 75 times and 500 times more concentrated, respectively, than raw sewage and treated effluent discharged by the average municipal wastewater treatment facility in the United States. The contribution of raw or marginally treated animal manure to surface waters has been implicated with depressed oxygen levels and fish kills, particularly during storm events. Many IFAP facilities are susceptible to extreme weather events because they have been sited in flood plains, a practice that, albeit in accordance with existing regulations, is creating significant problems.

Figure 10. Nutrient-rich freshwater (bottom of picture) is subject to eutrophication and algal blooms, a condition of excessive aquatic photosynthetic activity that frequently is followed by severe depletion of dissolved oxygen, thereby resulting in fish kills (Source: http://www.umanitoba.ca/institutes/fisheries/eutro.html)

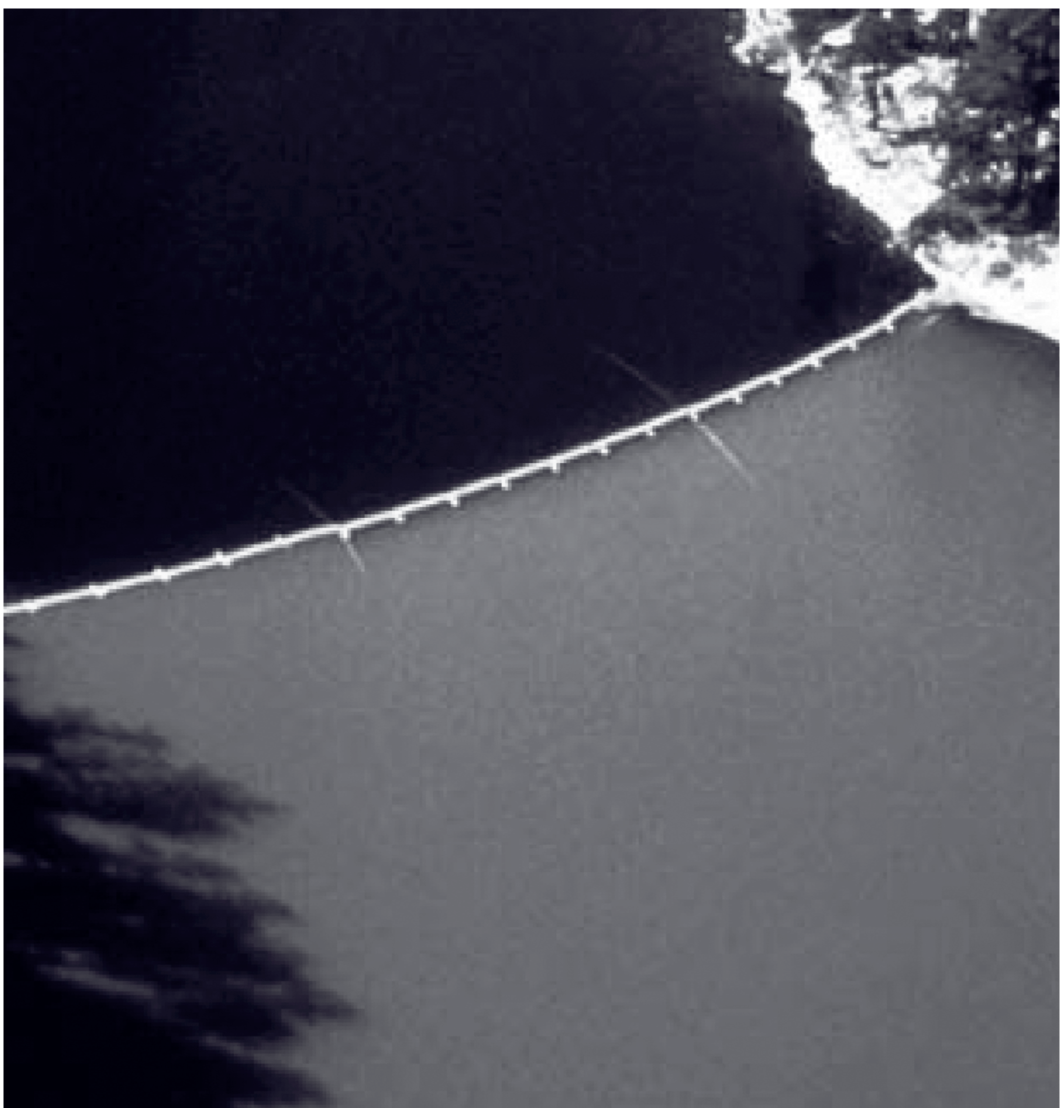
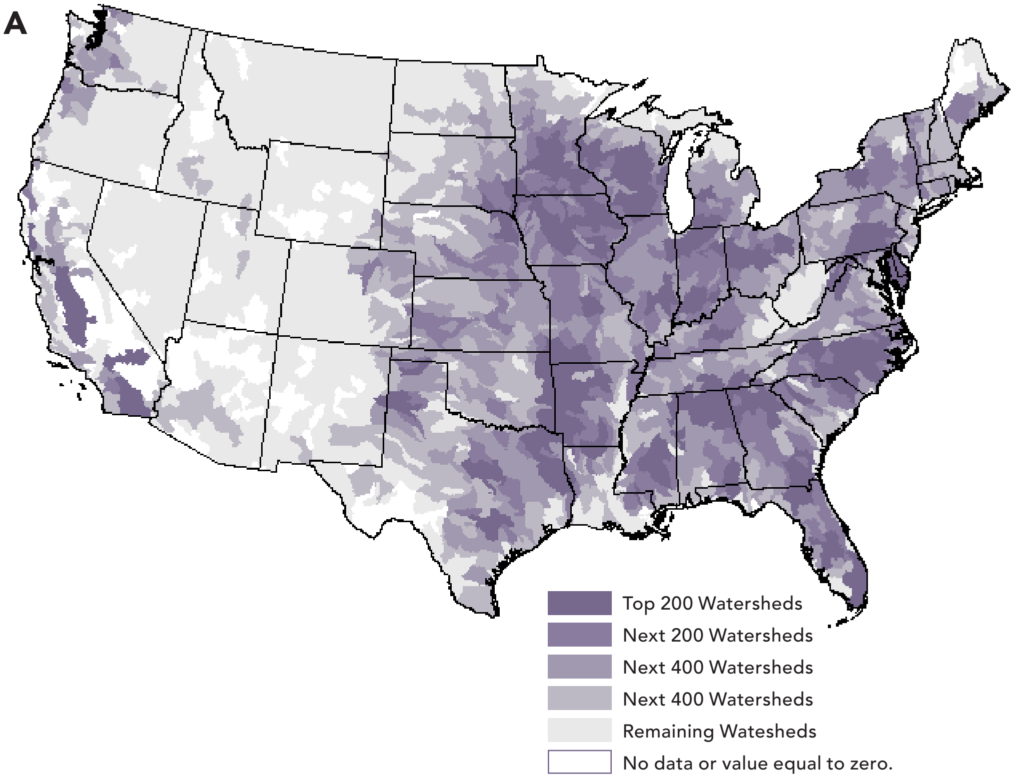


Figure 11. Map of the United States showing areas identified for the year 1997 as being vulnerable to runoff (A) and leaching (B) of manure nitrogen (Taken from Kellogg et al., 2000)

A



B

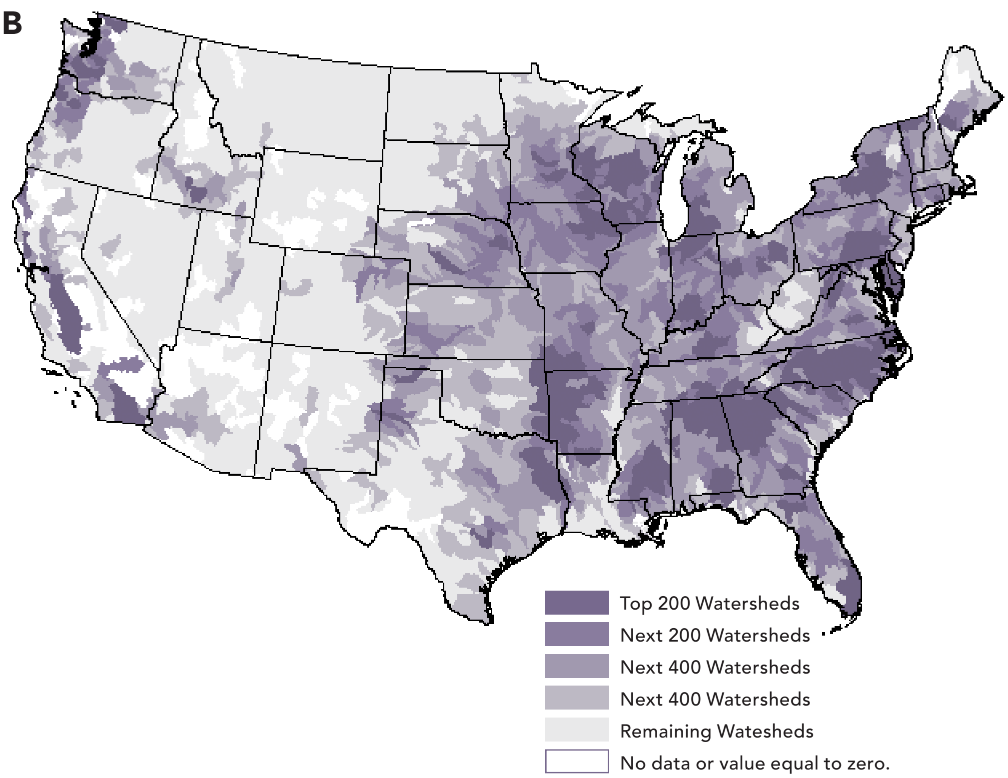


Table 1. Estimated manure and nutrient mass produced in the United States and excreted by food animals. Average amounts of manure and nutrients are reported as either kg per finished animal (kg/f.a.) or kg per day per animal (kg/d-a).

Major US Animal Welfare Standards (Source: Mench et al., 2008)

Animal type	Number of animals in 2005	Avg. amount of nitrogen per finished animal (kg/f.a.)	Average amount of phosphorus per finished animal (kg/f.a.)	Total dry wt. of manure per finished animal (kg/f.a.)	Total nitrogen per animal type (Mg‡)	Total phosphorus per animal type (Mg‡)	Total dry wt. of manure per animal type (Mg‡)
Poultry							
Broilers	8,870,000,000	0.53	0.016	1.274	4,701,100	141,920	11,300,380
Turkeys	264,874,000						
Females	132,437,000	0.26	0.074	4.42	34,434	9,800	585,372
Males	132,437,000	0.55	0.16	9.36	72,840	21,190	1,239,610
Layers	343,501,000	0.0016	0.00048	0.022	200,605	60,181	2,758,313
Beef–finishing cattle†	101,400,500	25	3.3	360	2,535,013	334,622	36,504,180
Swine							
Nursery pig (<40lbs)	19,988,000	0.41	0.06	4.8	8,195	1,359	95,942
Grow–finish	40,188,000	4.7	0.76	56	188,884	30,543	2,250,528
Dairy cows (lactating)	9,041,000	.45	0.078	8.84	1,484,984	257,397	29,171,691
Total	9,648,992,500				9,226,054	857,013	83,906,016

†Average US cattle herd between January 1, 2006 and July 1, 2006 ‡Mg or one metric ton equals 1,000 Kg

Endocrine disruptors.

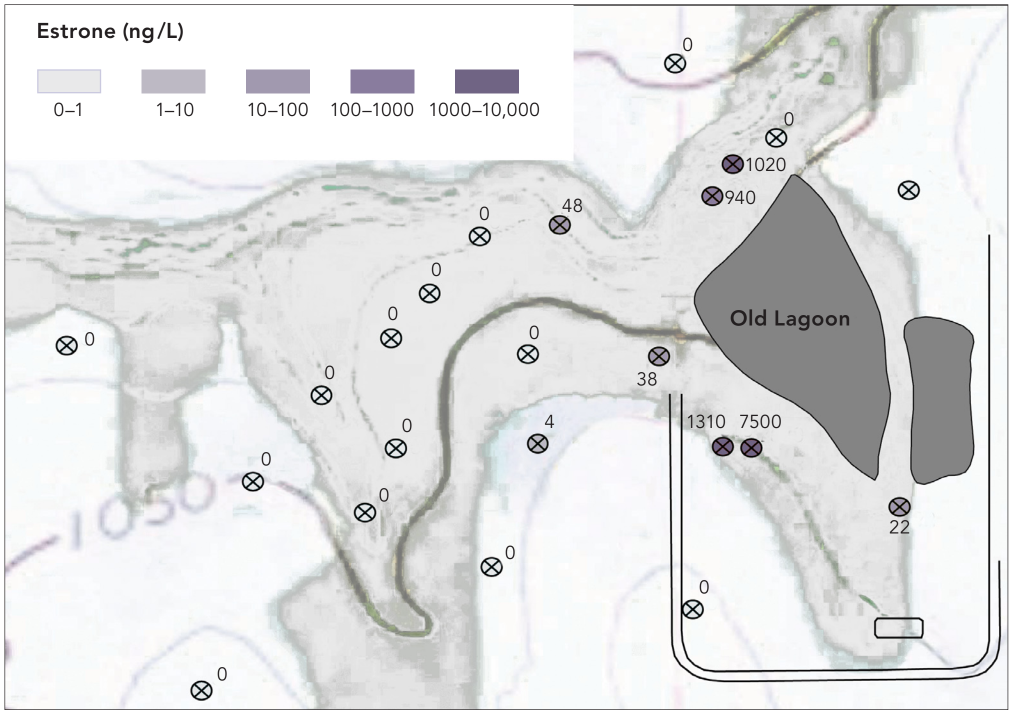
An important but somewhat loosely defined group of chemicals found in animal waste are endocrine disrupting compounds or EDCs. They can occur as natural constituents of animal excreta or represent drugs added to the feed of certain food animals, such as beef cattle. They are of both organic and inorganic nature and share the ability to interfere with hormonal signaling in animals and humans, thereby possessing the potential for causing adverse health effects in the exposed organism or its progeny (European Union, 2007). EDCs can mimic the function of estrogenic or androgenic hormones, or they can interfere with hormone receptors to alter the outcome of internal signaling events. A major concern of EDCs is that some may display activity at very low concentrations in the parts-per-trillion or nanogram-per-liter range (Porter et al., 1999). Examples of EDCs in animal wastes include steroids and possibly arsenic in the form of arsenate (Liu et al., 2006). Endocrine-disrupting steroids include the natural estrogens 17alpha-estradiol, 17beta-estradiol, estrone, and estriol; all are common constituents of farm animal waste (Sarmah et al., 2006b). Figure 12 illustrates the transport of estrone from hog waste into groundwater.

Another indirect but important source of EDCs from IFAP facilities is the use of pesticides for production of crops grown as animal feed. Pesticides that have been implicated with endocrine disruption are numerous and include alachlor and atrazine, the latter being applied extensively in the production of corn and other feed crops. Atrazine, which is regulated under the Safe Drinking Water Act (SDWA), has endocrine-disrupting activity in fish and amphibia (Freeman et al., 2005; Hayes et al., 2002, 2006; Thomas and Daughty, 2004). Environmental transformation products of atrazine and alachlor are also toxic and have been included on EPA's current chemical Contaminant Candidate List (CCL) (USEPA, 2005). Chemicals on the CCL are under consideration for regulation by the SDWA.

Water stress.

IFAP operations can create water stress in a number of ways. The production of animal protein requires 100 times more water than for vegetable protein (Pimentel and Pimentel, 1996). For example, it takes 3,500 liters of water to produce 1 kg of grain-fed broiler chicken (Pimentel et al., 1997). Therefore, siting of CAFOs in arid or semi-arid regions or in any area with water supply limitations is problematic due to the limited amount of water available and the substantial quantities needed for IFAP. Eighty-seven percent of freshwater withdrawn in the United States from surface and groundwater resources is used in agriculture (Pimentel et al., 1997). Agriculture withdraws water from rivers and freshwater aquifers for irrigation of farmland used in feed crop production. This practice reduces the availability of water for riparian water users downstream and, in some locations, has resulted in unsustainable water use and

Figure 12. Map of a farm site, illustrating the movement of estrone, a natural hormone and potential endocrine-disrupting contaminant, from a hog waste lagoon into underlying groundwater (Source: Data by Hutchins et al., contained in a presentation by Mills, 2007)



a dramatic decline in the groundwater table in some locations. For example, the large Ogallala Aquifer, which underlies parts of Nebraska, Kansas, Colorado, Oklahoma, New Mexico, and Texas, is severely stressed by overwithdrawal and has been depleted by half, with water levels dropping at a rate of 1 meter per year (Soule and Piper, 1992; McMichael, 1993) (Figure 13).

Pesticides and fertilizers applied to farmland also degrade the quality of surface and groundwater not used directly by farming operations. Animal husbandry requires additional water and is more demanding for IFAP, where water consumption per animal can exceed that of traditional animal raising practices by up to a factor of five (Chapagain and Hoekstra, 2003).

Finally, pollution from animal waste disposal further reduces the availability of safe drinking water and impairs environmental and ecological health (Burkholder et al., 2007); EPA's 2000 national water quality inventory identifies agriculture as the leading cause for water quality impairment in rivers, streams, lakes, and reservoirs (EPA, 2002).

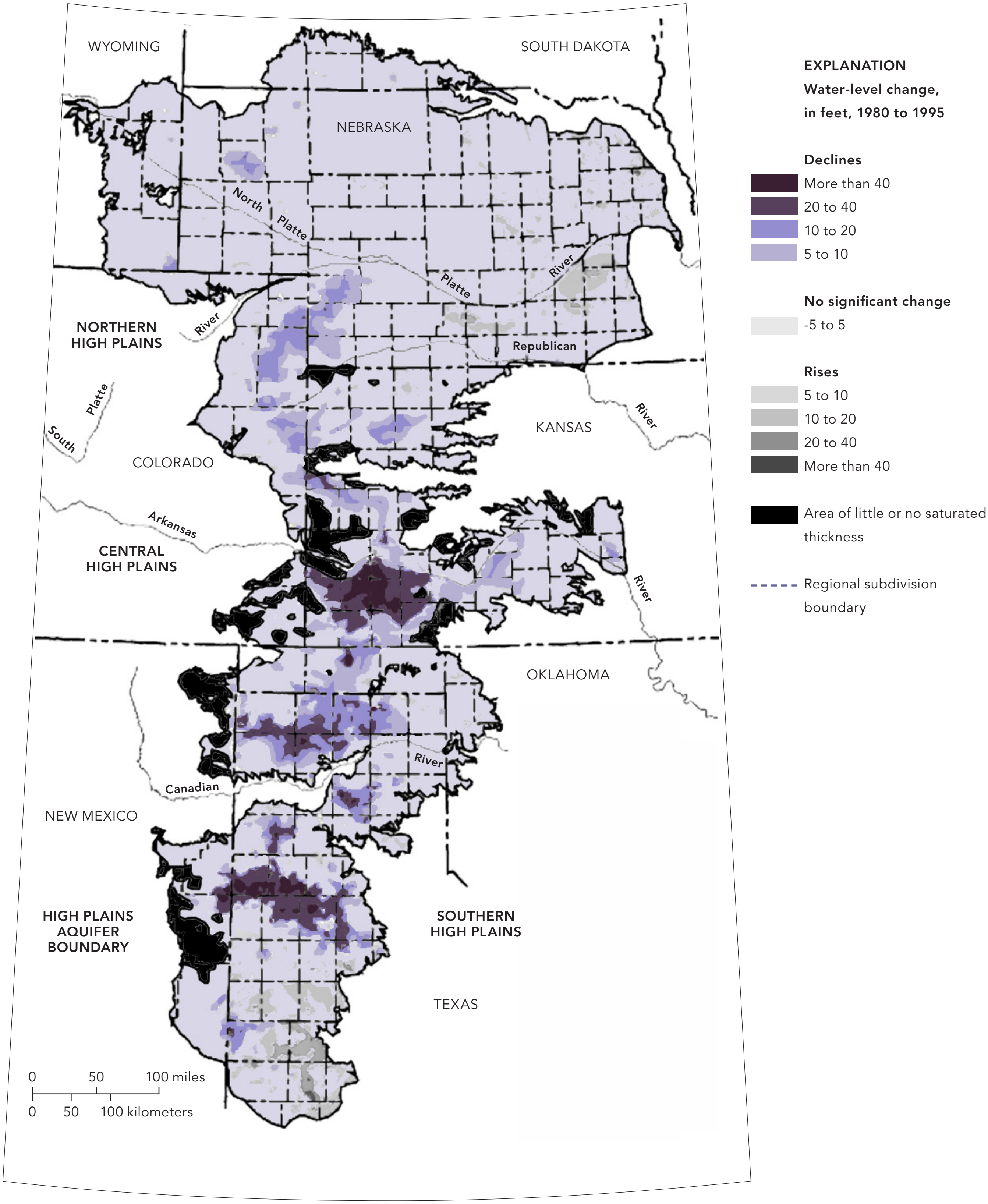
Climate.

Greenhouse gas emissions from livestock operations are significant. At 18% on a global scale, they even exceed the emissions caused by the transportation sector (Steinfeld et al., 2006). Greenhouse gases, primarily methane, carbon dioxide, and nitrous oxide, are given off by the animals during the digestion process in the gut. Additional emissions result from degradation processes occurring in uncovered waste lagoons and anaerobic digesters. Deforestation for feed grain crops represents a major source of greenhouse gas emission. More detailed information on this issue is provided later in the paragraph on air emissions. Emission control solutions are now being examined by the EPA along with potential opportunities for carbon credits and credit trading (Jensen, 2006). North Carolina has also recently passed legislation that sets strong performance standards for permits for new hog AFOs with substantial reductions required in emissions of ammonia, odors, and pathogens (General Assembly of North Carolina, 2007).

Antimicrobials.

Antibiotics and related antimicrobial compounds are widely administered for animal health and management and are used to treat diseases, promote growth, and improve feed efficiency (Sarmah et al., 2006a). Many antimicrobials used in the animal food-producing industry are provided in the feed throughout the lifetime. Much of this intake, between 30 and 90% of the initial dose, is being excreted. Therefore, antimicrobials applied in farming operations can and do find their way into the receiving environment, where they can be present either as the parent compound or as a metabolite (Sarmah et al., 2006a). Once in the environment, their efficacy and persistence depends on their physio-chemical properties, prevailing climatic conditions, and soil types and variety, as well as other environmental factors. In many instances, these

Figure 13. The Ogallala aquifer, at 174,000 square miles representing one of the largest aquifers in the world, has experienced substantial drops in water levels in many regions as a result of unsustainable agricultural water use (Source: USGS image downloadable at: http://water.usgs.gov/GIS/browse/ofr99-197_wlc80_95.gif)

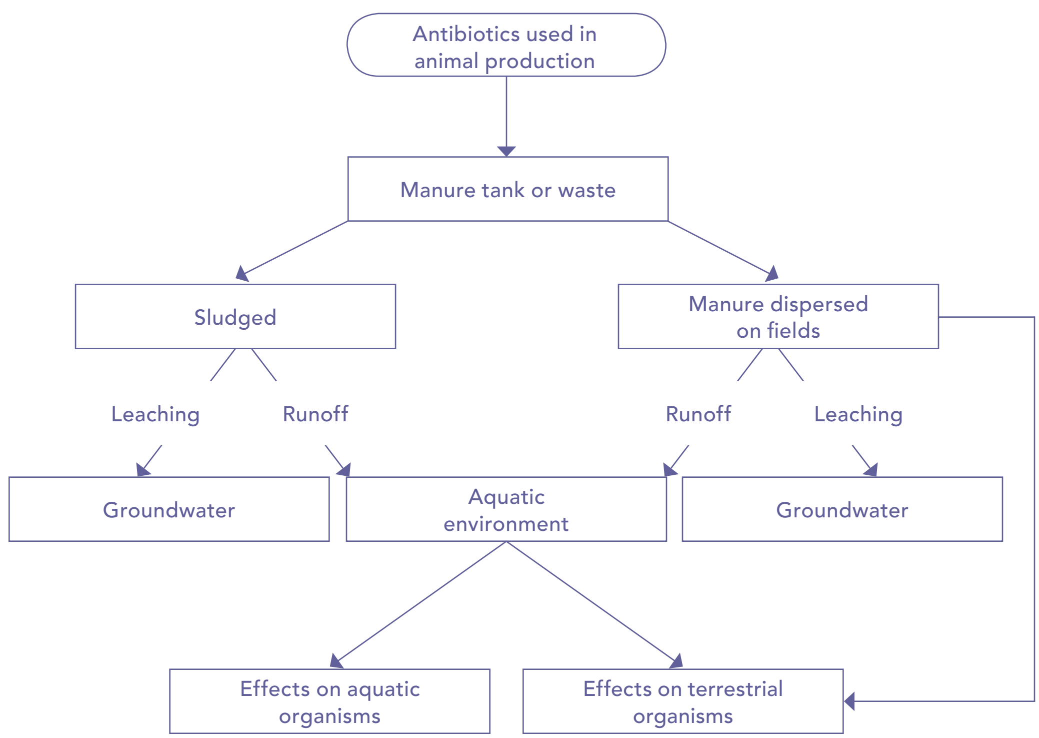


excreted antibiotics are not efficiently degraded, and the resulting residues can promote both maintenance and development of antibiotic-resistant microbial populations. Thus, cyclic application of manure on the same location may result in the continuous exposure of soil microbes to antibiotic residues, thereby fostering the potential development of drug-resistant microbial populations. Release of antimicrobials contained in manure also can have additional deleterious effects on aquatic life and human health, especially if the residues are transported by surface runoff or leaching through soil and reach nearby rivers or lakes (Sarmah et al., 2006a).

The Union of Concerned Scientists estimates that 10.3, 10.5, and 3.7 million pounds of antibiotics are used annually in the United States, respectively, in swine, poultry, and cattle production for non-therapeutic purposes such as promoting growth and improving feed efficiency (Mellon et al., 2001). These antibiotics are the same, or in the same family of, drugs that are used in human clinical medicine and include tetracycline, erythromycin, lincomycin, virginiamycin, and ampicillin, to name a few (FDA, 2004). The Animal Health Institute (AHI) issued a press release in 2000 on antimicrobial production based on a 1998 survey of AHI members. Although the absence of detail in terms of methodology hampers interpretation, AHI reported 17.8 million pounds of antimicrobial production, apparently for all animal uses, therapeutic and non-therapeutic. Of the 17.8 million pounds, 14.7 million were attributed to therapeutic use and disease prevention, and 3.1 million pounds were attributed to growth promotion (Mellon et al., 2001).

Veterinary antibiotics can enter terrestrial and aquatic environments through spilled or excreted feed additives, overland flow runoff, unsaturated zone transport from fields to which agricultural waste has been applied, and leaky waste-storage structures (Figure 14) (Sarmah et al., 2006a).

Figure 14. Anticipated exposure pathways for veterinary antibiotics in the environment (Source: Sarmah et al., 2006a)



Bacteria in waste.

The practice of administering non-therapeutic levels of antimicrobials in swine feed selects for antibiotic resistance among commensal and pathogenic bacteria in swine (Aarestrup et al., 2000; Bager et al., 1997; Wegener, 2003), resulting in high prevalence of resistant bacteria and resistance genes in swine waste (Chee-Sanford et al., 2001; Haack and Andrews, 2000; Parveen et al., 2006; Koike et al., 2007). Monitoring results showed 1.6×10^7 (16,000,000) colony forming units (CFU)/ml of total tetracycline-resistant bacteria and 2.1×10^5 (210,000) CFU/ml of tetracycline-resistant *enterococci* in swine waste (Haack and Andrews, 2000). Another study determined resistance to at least one antibiotic in 85% of *Escherichia coli* isolates recovered from a swine lagoon (Parveen et al., 2006). Other researchers detected up to eight known tetracycline resistance genes in total DNA extracted from swine lagoon samples (Chee-Sanford et al., 2001). In the same study, a broad range of tetracycline resistance determinants were found in groundwater samples collected downstream of swine lagoons. One study also detected higher percentages of antibiotic-resistant *E. coli* in groundwater collected in the vicinity of large-scale swine facilities versus groundwater collected at reference sites (Anderson and Sobsey, 2006). In another study, 80.6% of *E. coli* isolates collected from surface waters located near swine and other livestock facilities were found to be resistant to at least one antibiotic (Sayah et al., 2005).

The presence of swine-associated resistant bacteria in rural surface water and groundwater sources is important to human health because exposure to these sources could enable the transfer of resistant bacteria from swine to humans, thereby contributing to the spread and persistence of antibiotic resistance. However, there are few studies in the peer-reviewed literature regarding the presence of antibiotic-resistant bacteria in surface waters and groundwater from the vicinity of swine CAFOs (Chee-Sanford et al., 2001; Anderson and Sobsey, 2006; Sayah et al., 2005; Sapkota et al., 2007a). Moreover, there are few data available comparing concentrations of fecal indicators in groundwater and surface waters impacted by swine CAFOs versus unaffected waters.

The widespread practice of using sub-therapeutic doses of antimicrobials to promote growth and improve feed efficiency has become one of the most controversial practices in CAFO management. Recent studies have shown that antibiotic compounds administered to food-producing animals subsequently can be detected in liquid and solid manure of CAFOs. Upon application of these materials to fields, residues can persist in the soil and may be transported to surface and groundwater, as described in a white paper on antibiotic-resistant bacteria (Silbergeld et al., 2007).

Arsenic.

More than 8 billion broiler chickens are produced annually in the United States (USDA-NASS, 2004). For the purposes of promoting growth and improving feed efficiency, broilers are fed non-therapeutic levels of antimicrobials, including arsenic, which is usually in the form of the organoarsenical compound roxarsone (Chapman and Johnson, 2002; National Research Council, 1999). Roxarsone is added to poultry feed at concentrations ranging from 22.7 to 45.4 g/ton (Mellon et al., 2001). Approximately 70% of the US broiler industry utilizes roxarsone (Chapman and Johnson, 2002) and researchers have calculated that 9×10^5 kg of roxarsone is excreted in poultry litter each year (Garbarino et al., 2003). Once roxarsone is excreted, it degrades into metabolites such as arsenite (As^{III}) and arsenate (As^{V}) (Bednar et al., 2003). Since these inorganic metabolites are classified as human carcinogens, researchers have begun to investigate the fate of arsenic in poultry meat, poultry litter, soil, and water (Chapman and Johnson, 2002; Garbarino et al., 2003; Han et al., 2004; Lasky et al., 2004; Rutherford et al., 2003). Meanwhile, some large producers of animal products have announced a cessation of the use of arsenicals, a commendable but voluntary and therefore easily reversible action.

Microbial contaminants.

The production of food has always involved microbiological risks, which have been well recognized by farmers, government, industry, and other stakeholders. Microbiological issues in food safety are not unique to IFAP. However, the scale and methods of IFAP can both contribute to and prevent pathogen contamination of consumer food products. In particular, zoonotic (animal to human) transmission can be exacerbated by current IFAP practices. All segments of livestock production potentially contribute to zoonotic disease, including manure handling practices, meat processing, transportation of livestock, and animal rendering (Gilchrist et al., 2007). The leading causes of bacterial illness listed above all have predominant zoonotic transmission routes. Viruses, including hepatitis E virus and nipah virus, have also been directly transmitted from animals to humans (Gilchrist et al., 2007; Leblanc et al., 2007; Feagins et al., 2007; Bellini et al., 2005). Because of the mass of animals produced in each herd or flock, a microbiological issue can affect thousands of animals. Large-scale production and high-throughput processing can increase the magnitude of pathogen contamination when control systems fail because of the large volume of production and processing; on the other hand, the concentration of production and processing in fewer large facilities can result in more consistent practice, more extensive regulatory coverage, and the use of more advanced control technologies. Newer technologies for pathogen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control include food irradiation, extensively used in Europe and approved by the FDA for certain meat and poultry products.

While food-borne pathogens are of general concern in food production, the risks of human exposure to *antibiotic resistant bacterial pathogens* is of particular relevance to IFAP because of the use of antibiotics in feed for growth promotion, which is distinct from disease treatment and prevention. This use results in low doses of growth-promoting antibiotics (GPAs) to each animal, thereby contributing to the selection and proliferation of antibiotic-resistant strains of bacteria, as does the administration of higher doses for disease prevention. Antibiotic resistance can be transferred among bacteria from non-pathogenic to pathogenic organisms, which increases the complexity and challenge of understanding and preventing this problem (Silbergeld et al., 2007). The potential for resistance reservoirs and interspecies transfer of resistance determinants is a high priority issue in the federal government's program to reduce the threat of antibiotic-resistant infections (Silbergeld et al., 2007).

Recent studies have found that the air inside large-scale swine feeding operations and downwind can also be contaminated with high levels of multidrug-resistant bacteria (Gibbs et al., 2004, 2006; Chapin et al., 2005). Airborne bacteria (*Staphylococcus aureus*, *Salmonella spp.*, fecal coliforms, and total coliforms) collected inside and downwind of two large-scale swine operations were found to be resistant to two or more antibiotics, including ampicillin, penicillin, erythromycin, tylosin, tetracycline, and/or oxytetracycline (Gibbs et al., 2004). Airborne bacteria collected upwind of the swine operations were significantly more susceptible to all of the antibiotics evaluated, suggesting that releases from the swine facilities were the likely sources of airborne multidrug-resistant bacteria recovered downwind (Gibbs et al., 2004). One study involved the collection of air samples via liquid impingers in a swine CAFO and analysis for viable isolates of antibiotic-resistant bacteria (Chapin et al., 2005). *Enterococci*, *staphylococci,* and *streptococci* were analyzed for resistance to erythromycin, clindamycin, virginiamycin, tetracycline, and vancomycin. None of the isolates were resistant to vancomycin, which has never been approved for use in livestock in the United States. In contrast, 98% of these Gram-positive bacterial isolates were resistant to two or more, and 29% were resistant to all of the other four antibiotics that are commonly used as growth promoters in swine (Chapin et al., 2005). The high prevalence of antibiotic-resistant bacteria in swine facility air is relevant to swine growers and workers, as well as to other individuals who live or work close to these facilities. In addition, airborne antibiotic-resistant bacteria found within and around large-scale swine feeding operations could contribute to environmental reservoirs of antibiotic-resistance genes, participating in the genetic exchange of these genes among bacterial populations in animals, humans, and the environment. For this reason, understanding the prevalence of antibiotic-resistance genes in airborne bacteria emitted from large-scale swine operations is important in terms of both public health and bacterial ecology.

Air emissions.

Air emissions from livestock facilities are complex and of growing concern. Emissions from CAFOs and the spraying of animal waste on surrounding fields can result in environmental exposure to gases, organic dusts, bacteria, fungi, endotoxins, and residues of veterinary antibiotics (Radon et al., 2007; Mirabelli et al., 2006). In particular, large IFAP facilities emit significant levels of several compounds, including endotoxins, particulate matter, ammonia, hydrogen sulfide, nitrous oxide, methane, and volatile organic compounds (NRC, 2003). Exposures to these compounds are associated with a wide range of airway diseases, including mucous membrane irritation, bronchitis, asthma, asthma-like syndrome, and chronic obstructive pulmonary disease, as demonstrated in studies of farm workers (Heederik et al., 2007). Organic aerosols, combined with inflammatory agents and endotoxins, have been associated with the development of respiratory illness among swine workers (Donham, 2000, Von Essen and Donham, 1999) and the community surrounding the CAFO (Donham et al., 2007, Donham, 1995; Cole et al., 2000, Sapkota et al., 2007a). Table 2 lists potential respiratory diseases associated with swine production (Osterberg and Wallinga, 2004).

A variety of analytical methods are available for measuring toxic gases, particulates, and odor (Bunton et al., 2007). Air pollution problems caused by emissions from CAFOs, such as hydrogen sulfide, particulate matter, and odor, are more generally local in scale because neighbors living near the CAFO are affected. In contrast, pollutants such as oxides of nitrogen (NO_x) and ammonia are causing concerns on a regional scale. Nitrogen-containing pollutants can affect the quality of life in a multi-state area (Bunton et al., 2007). The quantitation of odor is more challenging because it represents a complex and variable mixture of free and particle-bound compounds. Ideally, odor characterization would involve analysis of each of the chemical constituents associated with a particular offensive odor. However, the correlation between human response and specific compounds identified by instrumental methods such as gas chromatography remains quite poor (Bunton et al., 2007).

Anaerobic lagoons are commonly used to store and treat manure from large-scale swine production facilities. Ultimate by-products of anaerobic digestion are methane (CH_4) and carbon dioxide (CO_2), with CH_4 making up between 60 and 70% of the biogas (DeSutter and Ham, 2005). Although some facilities have engineered systems to utilize the CH_4 for energy (Lusk, 1998), most farms using anaerobic lagoons permit the CH_4 to escape into the atmosphere. Lagoons are commonly 2 to 6 m deep with surface areas between 0.5 and 5.0 ha or 1.2 to 12 acres (Ham and DeSutter, 2000). The primary objective

Table 2. Respiratory Diseases Associated with Swine Production (Source: Adopted from Donham, 2000)

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

of anaerobic digestion is to stabilize organic matter and, thus, reduce odors, pathogens, and the overall mass of organic solids; however, this process is often not adequately controlled in CAFO lagoons (Parkin and Owen, 1986). The waste is converted to CH_4 and CO_2 by two groups of bacteria, methanogens and acetogens, and by a three-stage process called methanogenesis (Figure 15) (Lusk, 1998).

Greenhouse gases (GHG) produced from agriculture account for 6.8% of all US emissions (US EPA, 2004), and global efforts are being directed to reduce the emissions of these gases from agricultural sources (DeSutter and Ham, 2005; Lusk, 1998). When the entire commodity chain is taken into consideration (including the production of feed grain), greenhouse gas emissions from livestock operations are significant.

Recently, a carbon budget was conducted by using a mass-balance approach as a way to quantify and trace various forms of carbon through agricultural systems (DeSutter and Ham, 2005). A total carbon balance analysis of animal production facilities is a mechanism that can provide valuable information about the quantity of GHG produced from the facility per mass of animal produced (i.e., emission factors). This information then can be extrapolated to regional sites with similar animal production practices and climates, and provide research-based information needed to model GHG emissions in the United States. Past analyses involved the measurement of biogas and CH_4 fluxes from an anaerobic-swine lagoon, and a mass balance of carbon from the entire swine production facility (DeSutter and Ham, 2005). The contribution of CH_4 from both lagoon and animal respiration to GHG inventories was about 2,132 mg of CO_2 equivalents, of which 85% was from lagoon emissions. Thus, even though swine are not considered large contributors of CH_4 through respiration or flatulence, there is a potential for substantial GHG contributions when animal waste is stored and treated in anaerobic lagoons (DeSutter and Ham, 2005).

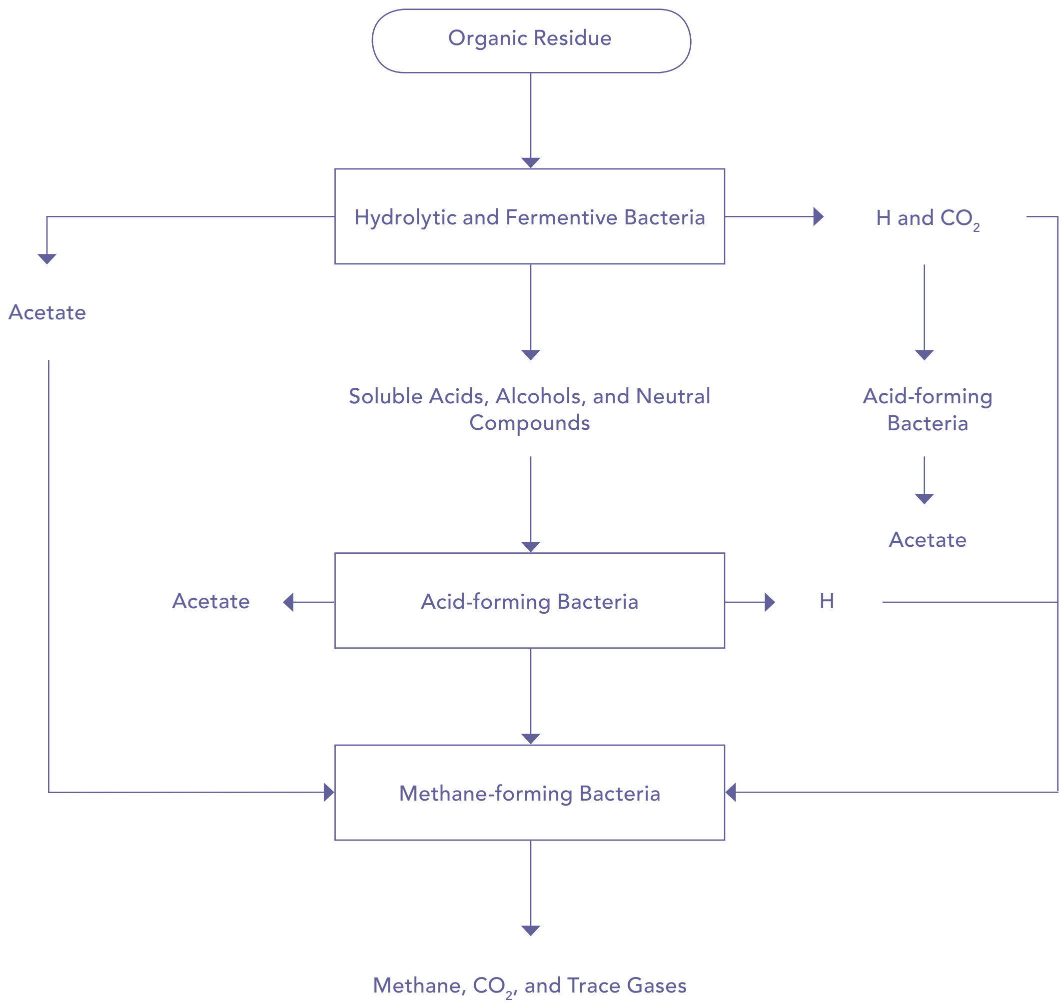
Because of the complex environment created within CAFOs and the potential airborne releases into the surrounding environment and any proximal communities, research and development in hazard abatement is being actively pursued in order to explore opportunities for emission reduction. A number of different strategies have been examined, including air filtration to control emissions, replacing dry feed with liquid, and spraying vegetable oil inside the barn (Martens et al., 2001; Takai and Pedersen, 2000).

Figure 16 summarizes the major elements in agricultural air quality that need to be addressed by environmental managers and researchers. Accurate estimates of air emissions from CAFOs are needed to gauge their possible primary and secondary adverse impacts and the subsequent implementation of control measures (Aneja et al., 2006; Cole et al., 1997; Oenema et al., 2001).

Biodiversity.

Loss of biodiversity is known to be intimately linked to agricultural development. Policy reform can be an important driver of changes in agricultural land-use, but there is considerable spatial variation in response to policy and its potential impact on biodiversity (Mattison and Norris, 2005; Butler et al., 2007). Industrial agriculture limits biodiversity by favoring monoculture crop production, i.e., planting the same crop over a large land area, which diminishes diverse habitats and increases vulnerability to large-scale damage from pests. These monocultures can stretch over thousands of acres, leading to more chemical use, pesticide resistance in insects, and pollution of surface and groundwater by herbicides and insecticides (Horrigan et al., 2002). IFAP facilities play an important role in the reduction of biodiversity as they contribute directly or indirectly to a loss of biodiversity via habitat change, climate change, invasive alien species, and pollution. Typically, biodiversity loss is caused by a combination of various processes of environmental degradation. This makes it hard to single out the specific contribution of IFAP, particularly since the animal food product chain features many steps from which environmental impact may occur (Steinfeld et al., 2006).

Figure 15. The anaerobic digestion process (Source: Lusk 1998)



The role of the Western diet.

Environmental stress from chemical and biological agents is amplified by dietary choices of the American population. The standard Western diet, which is heavy on meat and light on vegetable intake, is taking a significant toll on the environment, public health, and the nation's economy. In the United States, meat is produced and consumed at unprecedented rates, with future increases projected (USDA, 2005). Excess meat consumption has been linked to adverse human health outcomes, including obesity and an increased risk of mortality from cardiovascular disease (Kelemen et al., 2005). Thus, health impairments from a high-meat diet create a significant strain on the US economy, this representing only one of many unaccounted for externalities.

It has been suggested that the dietary model of the United States is environmentally unsustainable both nationally and globally (reviewed in Horrigan et al., 2002). Americans are among the top meat consumers in the world. Whereas animal protein constitutes only about one-third of dietary protein intake worldwide, Americans average more than two-thirds (UN FAOSTAT, 2005). Excessive meat consumption takes a toll on human health and the environment. Contrary to farm animals raised by grazing on pastures, industrial farm animals are fed grains in confinement. Environmental consequences of this shift in agriculture already have been described. National natural resources, including water and farmland, are too limited to sustain the perpetual production of millions of tons of feed grain for the 10+ billion farm animals slaughtered each year in the United States (UN FAOSTAT, 2005). In an average American household of four people, more than 120 chickens, four pigs and one cow are consumed annually (UN FAOSTAT, 2005). US consumption rates for lean meat are above 100 kg per person per year and thus exceed the American Heart Association's recommended upper limit by more than 60% (calculated from data presented in Walker et al., 2005). Continuation of this unhealthy and environmentally unsustainable consumption is undesirable nationally and sets a poor example internationally.

But even if national meat production and consumption in future years were adjusted downward to match the recommendation of the American Heart Association (2005), current practices in IFAP would still continue to inflict significant harm to public health and the environment. This is due to the spatial concentration of animal wastes and public health threats of IFAP facilities. A single CAFO routinely discharges to the environment untreated or minimally processed animal waste at a rate equivalent to the sewage flow of a small American city. Since waste excretion by pigs exceeds that of humans by a factor of four, a single CAFO housing 5,000 pigs produces an environmental footprint similar to 20,000 residents of a city having no sewage treatment plant (Walker et al., 2005).

Figure 16. Interactions and assessment of agricultural air quality (Source: Aneja et al., 2006)

Conclusions

Current IFAP practices in the United States are unsustainable. Although some data gaps exist regarding the impact of IFAP on human health, a body of peer-reviewed literature clearly outlines an expanding array of deleterious environmental effects on local and regional water, air, and soil resources. Already, more than a million people are estimated to consume groundwater showing moderate or severe contamination with nitrogen-containing pollutants (Nolan and Hitt, 2006), caused primarily by heavy use of agricultural fertilizers and unsustainably high application rates of animal waste. In addition, existing federal environmental laws and most local zoning regulations allow for CAFOs to be operated and new ones to be built across the nation, in regions vulnerable to natural disasters such as flooding or arid ones lacking appropriate water resources. These practices run counter to environmental conservation, public health protection, and the goals of the Clean Air Act and the Clean Water Act.

In the face of this challenge, there is a need for more protective zoning as well as for better management practices, regulations, enforcement, and monitoring of IFAP facilities (Burkholder et al., 2007; Horrigan et al., 2002; Aneja et al., 2006; Donham et al., 2007; Sarmah et al., 2006b). The US Government Accountability Office recently concluded that as many as 60% of animal feeding operations in the United States are unregulated and that the few existing federal regulations are not enforced by state governments due to a lack of federal oversight (US GAO 2005). Right-to-farm legislation, originally designed to shield family farms from getting forced out of business by encroaching development, in some states prevents zoning laws that could serve as a mechanism to preclude siting of IFAP facilities in locations where detrimental effects to the environment and human populations are likely (Chapin et al., 1998; Hamilton, 1998).

To prevent further environmental degradation, greater accountability and land stewardship are needed, and due diligence should be placed on evaluating the environmental, financial, societal, and health effects of food animal production. To reach this goal, restrictive actions will be required, and further research should be conducted to define state-of-the-art animal husbandry practices that can adequately address environmental, health, and animal welfare criteria (Burkholder et al., 2007; Thorne, 2007; Sapkota et al., 2007b; Donham et al., 2007; Bunton et al., 2007).

Figure 17. Spraying of manure on frozen soil, as shown here in Yakima, WA, can trigger runoff of nutrients, pollutants, and pathogens during snow melt and heavy rain events (Photo source: Anonymous)

References

Aarestrup FM, Kruse H, Tast E, Hammerum AM, Jensen LB (2000). Associations between the use of antimicrobial agents for growth promotion and the occurrence of resistance among *Enterococcus faecium* from broilers and pigs in Denmark, Finland, and Norway. *Microb Drug Resist* 6: 63-70.

American Heart Association (2005). An Eating Plan for Healthy Americans. Available at http://www.americanheart.org/presenter.jhtml?identifier_1088.

Accessed at CHECK.

American Society of Agricultural Engineers (2005). Manure production and characteristics, St. Joseph, Michigan.

Anderson ME, Sobsey MD (2006). Detection and occurrence of antimicrobially resistant *E. coli* in groundwater on or near swine farms in eastern North Carolina. *Water Sci Technol* 54(3): 211-8.

Aneja VP, Nelson DR, Roelle PA, Walker JT (2003). Agricultural ammonia emissions and ammonium concentrations associated with aerosols and precipitation in the southeast United States. *J Geophys Res* 108(D4): ACH 12-1, 12-11.

Aneja VP, Schlesinger WH, Niyogi D., Jennings G., Gilliam W., Knighton RE, Duke CS, Blunden J, and Krishnan S (2006). Emerging national research needs for agricultural air quality. EOS, Volume 87: 25-29.

Bager F, Madsen M, Christensen J, Aarestrup FM (1997). Avoparcin used as a growth promoter is associated with the occurrence of vancomycin-resistant *Enterococcus faecium* on Danish poultry and pig farms. *Prev Vet Med* 31: 95-112.

Bednar AJ, Garbarino JR, Ferrer I, Rutherford DW, Wershaw RL, Ranville JF, and Wildeman TR (2003). Photodegradation of roxarsone in poultry litter leachates. *Sci Total Environ* 302: 237-245.

Bellini WJ, Harcourt BH, Bowden N, Rota PA (2005). Nipah virus: an emergent paramyxovirus causing severe encephalitis in humans. *J Neurovirol* 11: 481-487.

Bender A (1992). Meat and Meat Products in Human Nutrition in the Developing World. Food and Nutrition Paper No. 53. Food and Agriculture Organization of the United Nations, Rome, Italy.

Bullers S (2005). Environmental stressors, perceived control, and health: the case of residents near large-scale hog farms in eastern North Carolina. *Hum Ecol* 33: 1-16.

Bunton B, O'Shaughnessy P, Fitzsimmons S, et al. (2007). Monitoring and modeling of emissions from concentrated animal feeding operations: overview of methods. *Environ Health Perspect* 115: 303-307.

Burkholder JM, Mallin MA, Glasgow HB, Larsen LM, McIver MR, Shank GC, et al. (1997). Impacts to a coastal river and estuary from rupture of a large swine waste holding lagoon. *J Environ Qual* 26: 1451-1466.

Burkholder J, Libra B, Weyer P, Heathcote S, Kolpin D, Thorne PS, and Wichman M (2007). Impacts of waste from concentrated animal feeding operations on water quality. *Environ Health Perspect* 115(2): 308-12.

Butler SJ, Vickery JA, and Norris K (2007). Farmland Biodiversity and the Footprint of Agriculture. *Science* 315: 381-384.

Campagnolo ER, Johnson KR, Karpati A, Rubin CS, Kolpin DW, Meyer MT, Esteban JE, Currier RW, Smith K, Thu KM, McGeehin M (2002). Antimicrobial residues in animal waste and water resources proximal to large-scale swine and poultry feeding operations. *Sci Total Environ* 299: 89-95.

Chapagain AK and Hoekstra AY (2003). Virtual water flows between nations in relation to trade in livestock and livestock products. Value of Water Research Report Series No. 13. UNESCO-IHE.

Chapin AC Boulind, and Moore A (1998). Controlling Odor and Gaseous Emission Problems from Industrial Swine Facilities: A Handbook for All Interested Parties. Yale Environmental Protection Clinic. Online at: http://www.yale.edu/envirocenter/clinic/swine/swine.html [accessed May 18, 2007].

Chapin A, Rule A, Gibson K, Buckley T, and Schwab K (2005). Airborne multi-drug resistant bacteria isolated from a concentrated swine feeding operation. *Environ Health Perspect* 113: 137-142.

Chapman HD and Johnson ZB (2002). Use of antibiotics and roxarsone in broiler chickens in the USA: Analysis of the years 1995 to 2000. *Poultry Sci* 81: 356-364.

Chee-Sanford JC, Aminov RI, Krapac IJ, Garrigues-Jeanjean N, Mackie RI (2001). Occurrence and diversity of tetracycline resistance genes in lagoons and groundwater underlying two swine production facilities. *Appl Environ Microbiol* 67: 1494-1502.

Cole CV, Duxbury J, Freney J, Heinemeyer O, Minami K, Mosier A, Paustian K, Rosenberg N, Sampson N, Sauerbeck D, and Zhao Q (1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutr Cycling Agroecosyst* 49: 221-228.

Cole D, Todd L, Wing S. Concentrated swine feeding operations and public health: A review of occupational and community health effects. *Environmental Health Perspectives* (2000) 108: 685-699.

Cook M (1998). Reducing Water Pollution from Animal Feeding Operations. Testimony before Subcommittee on Forestry, Resource Conservation, and Research of the Committee on Agriculture, US House of Representatives, 13 May 1998. Available: http://www.epa.gov/ocirpage/hearings/testimony/105_1997_1998/051398.htm; accessed on April 14, 2007.

DeSutter TM, Ham JM (2005). Lagoon-biogas emissions and carbon balance estimates of a swine production facility. *J Environ Qual* 34: 198-206.

Donham KJ, Wing S, Osterberg D, JL Flora, Hodne C, KM Thu, and PS Thorne (2007). Community health and socioeconomic issues surrounding concentrated animal feeding operations. *Environ Health Perspect* 115(2): 317-20.

Donham KJ, Reynolds SJ, Whitten P, Merchant JA, Burmeister L, Popendorf WJ. Respiratory Dysfunction in Swine Production Facility Workers—Dose-Response Relationships of Environmental Exposures and Pulmonary-Function. *American Journal of Industrial Medicine* (1995) 27: 405-418.

Donham KJ (2000). The concentration of swine production—Effects on swine health, productivity, human health, and the environment. *Veterinary Clinics of North America-Food Animal Practice* 16: 559-597.

Dosman JA, JA Lawson, SP Kirychuk, Cormier Y, Biem J, and Koehncke N (2004). Occupational asthma in newly employed workers in intensive swine confinement facilities. *Eur Respir J* 24(4): 698-702.

European Union. 2007. Endocrine Disruptors Website: How the European Union Uses the Precautionary Principle to Tackle Endocrine Disruptors. Online at http://ec.europa.eu/environment/endocrine/definitions/endodis_en.htm (Accessed May 19, 2007).

Feagins AR, Opriessnig T, Guenette DK, et al. (2007). Detection and characterization of infectious Hepatitis E virus from commercial pig livers sold in local grocery stores in the USA. *J Gen Virol* 88: 912-917.

Federal Registrar (2003). 40 CFR Parts 9, 122, 123, and 412 National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs); Final Rule Federal Register / Vol. 68, No. 29 / Wednesday, February 12, 2003 / Rules and Regulations http://www.epa.gov/npdes/regulations/cafo_fedrgstr.pdf

Food and Drug Administration. 2004. FDA approved animal drug products. Blacksburg, Virginia: Drug Information Laboratory, Virginia/Maryland Regional College of Veterinary Medicine.

Freeman JL, Beccue N, and Rayburn AL (2005). Differential metamorphosis alters the endocrine response in anuran larvae exposed to T3 and atrazine. *Aquat Toxicol* 75(3): 263-76.

Garbarino JR, Bednar AJ, Rutherford DW, Beyer RS, and Wershaw RL (2003). Environmental fate of roxarsone in poultry litter. 1. Degradation of roxarsone during composting. *Environ. Sci. Tech.* 37: 1509-1514.

General Assembly of North Carolina (2007). SESSION LAW 2007-523, SENATE BILL 1465. http://www.ncga.state.nc.us/Sessions/2007/Bills/Senate/HTML/S1465v7.html

Gibbs SG, Green CF, Tarwater PM and Scarpino PV (2004) Airborne antibiotic resistant and nonresistant bacteria and fungi recovered from two swine herd confined animal feeding operations. *J Occup Environ Hyg 1*: 699-706.

Gibbs SG, Green CF, Tarwater PM, Mota LC, Mena KD and Scarpino VD (2006). Isolation of antibiotic resistant bacteria from the air plume downwind of a swine confined or concentrated animal feeding operation. *Environ Health Perspect* 114(7): 1032-1037.

Gilchrist MJ, Greko C, Wallinga DB et al. (2007) The potential role of concentrated animal feeding operations in infectious disease epidemics and antibiotic resistance. *Environ Health Perspect* 115: 313-316.

Goldschmidt, WR (1978). As You Sow: Three Studies in the Social Consequence of Agribusiness. Rowman & Littlefield Publishers, Inc., ISBN-10: 0916672115.

Goolsby DA and WA Battaglin (2000). Nitrogen in the Mississippi Basin-Estimating Sources and Predicting Flux to the Gulf of Mexico. Online at: http://ks.water.usgs.gov/Kansas/pubs/fact-sheets/fs.135-00.html#HDR3

Graham JP, Boland JJ, Silbergeld E (2007) Growth promoting antibiotics in food animal production: an economic analysis. *Public Health Rep* 122(1): 79-87.

Haack BJ, Andrews RE Jr (2000). Isolation of Tn916-like conjugal elements from swine lot effluent. *Can J Microbiol* 46: 542-549.

Ham, JM, and TM DeSutter (2000). Toward site-specific design standards for animal-waste lagoons: Protecting ground water quality. *J Environ Qual* 29: 1721-1732.

Hamilton ND (1998). Right-to-farm laws reconsidered: ten reasons why legislative efforts to resolve agricultural nuisances may be ineffective. *Drake J Agric Law* 3(1): 104.

Han FX, Kingery WL, Selim HM, Gerard PD, Cox MS, and Oldham JL (2004). Arsenic solubility and distribution in poultry waste and long-term amended soil. *Sci Total Environ* 320: 51-61.

Hayes TB, Haston K, Tsui M, Hoang A, Haeffele C, Vonk A. Herbicides: feminization of male frogs in the wild. *Nature* (2002) Oct 31; 419(6910): 895-6.

Hayes TB, Stuart AA, Mendoza M, Collins A, Noriega N, Vonk A, Johnston G, Liu R, Kpodzo D. Characterization of atrazine-induced gonadal malformations in African clawed frogs (Xenopus laevis) and comparisons with effects of an androgen antagonist (cyproterone acetate) and exogenous estrogen (17beta-estradiol): Support for the demasculinization/feminization hypothesis. *Environ Health Perspect* (2006) 114 *Suppl* 1: 134-41.

Heederik D, Sigsgaard T, Thorne P et al. (2007). Health effects of airborne exposures from concentrated animal feeding operations. *Environ Health Perspect* 115: 298-302.

Hirsch RM, Hamilton PA, and Timothy L. Miller (2006). The Increasing Need for Science to Inform Policy—More than 30 Years after Passage of the Clean Water Act. *Water Environ Res* 78(9): 899-900.

Horrigan L, Lawrence RS, and Walker P (2002). How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture. *Environ Health Perspect* 110(5): 45-456.

Hutchins SR, White MV, Hudson FM, Fine DD 2007. Analysis of lagoon samples from different concentrated animal feeding operations for estrogens and estrogen conjugates. *Environ Sci Technol* 41: 738-44.

Jensen J (2006). Carbon Credits: New Opportunities for US Livestock Industry. Online at: http://www.epa.gov/agstar/pdf/conf06/jensen.pdf. (Accessed May, 2007).

Jongbloed AW, Lenis NP (1998). Environmental concerns about animal manure. *J Anim Sci* 76: 2641-8.

Kelemen LE, LH Kushi DR. Jacobs Jr., and Cerhan JR. Associations of dietary protein with disease and mortality in a prospective study of postmenopausal women. *American Journal of Epidemiology* (2005); 161(3): 239-49.

Kellogg RL (2000). Potential Priority Watersheds for Protection of Water Quality from Contamination by Manure Nutrients. A paper presented at the Animal Residuals Management Conference 2000, November 12-14, Kansas City, Missouri. Online at: http://www.nrcs.usda.gov/TECHNICAL/land/pubs/wshedpap_w.pdf

Kellogg RL, Lander CH, Moffitt DC and Gollehon N (2000). Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States. United States Department of Agriculture, Natural Resources Conservation Service. Online at: http://www.nrcs.usda.gov/technical/land/pubs/manntr.html

Kiely T, Donaldson D, and Grube A (2004). Pesticides Industry Sales and Usage, 2000 and 2001 Market Estimates. Biological and Economic Analysis Division

Krapac IG, Dey WS, Roy WR, Smyth CA, Storment E, Sargent SL, Steele JD (2002). Impacts of swine manure pits on groundwater quality. *Environ Pollut* 120: 475-92.

Lasky T, Sun W, Kadry A, and Hoffman MK (2004) Mean total arsenic concentrations in chicken 1989-2000 and estimated exposures for consumers of chicken. *Environ Health Perspect* 112: 18-21.

Koike S, Krapac IG, Oliver HD, Yannarell AC, Chee-Sanford JC, Aminov RI, Mackie RI (2007). Monitoring and source tracking of tetracycline resistance genes in lagoons and groundwater adjacent to swine production facilities over a 3-year period. *Appl Environ.Microbiol* 73(15): 4813-23.

Leblanc D, Ward P, Gagne MJ, et al. (2007). Presence of hepatitis E virus in a naturally infected swine herd from nursery to slaughter. *Int J Food Microbiol* 2007 Mar 30; [Epub ahead of print].

Liu FJ, Wang JS, and Theodorakis CW (2006). Thyrotoxicity of sodium arsenate, sodium perchlorate, and their mixture in zebrafish Danio rerio. *Environ Sci Technol* 40(10): 3429-36.

Lusk P (1998). Methane Recovery from Animal Manures: A Current Opportunities Casebook. 3rd Edition. NREL/SR-25145. Golden, Colorado: National Renewable Energy Laboratory. Work performed by Resource Development Associates, Washington, DC.

Mallin MA (2000). Impacts of industrial-scale swine and poultry production on rivers and estuaries. *Am Sci* 88: 26-37.

Mallin MA, Burkholder JM, Shank GC, McIver MR, Glasgow, HB Springer J, et al. (1997). Comparative impacts of effluent from poultry and swine waste holding lagoon spills on receiving rivers and tidal creeks. *J Environ Qual* 26: 1622-1631.

Martens W, Martinec M, Zapirain R, Stark M, Hartung E, Palmgren U. Reduction potential of microbial, odour and ammonia emissions from a pig facility by biofilters. *International Journal of Hygiene and Environmental Health* (2001) 203: 335-345.

Mattison EH, Norris K (2005) Bridging the gaps between agricultural policy, land-use and biodiversity. *Trends Ecol Evol* 20: 610-616.

McMichael AJ (1993). *Planetary Overload: Global Environmental Change and the Health of the Human Species*. Cambridge, England, Cambridge University Press.

Mead PS, Slutsker L, Dietz V, McCaig LF, Bresee JS, Shapiro C, Griffin PM, Tauxe RV (1999). Food-related illness and death in the United States. *Emerg Infect Dis* 5: 607-625.

Mellon M, Benbrook C, Benbrook KL (2001). Hogging It: Estimates of Antimicrobial Abuse in Livestock. Cambridge, Massachussetts: Union of Concerned Scientists Publications. Available: http://www.ucsusa.org/food_and_environment/antibiotics_and_food/margaret-mellon-on-hogging-it.html [accessed 15 September 2006].

Mills M (2007). Endocrine Disrupting Chemicals and other Fluorochemicals in Wastewater Treatment Technologies. New England Interstate Water Pollution Control Commission (NEIWPCC) Northeast Water Science Forum Pharmaceuticals and Personal Care Products: State of the Science Conference, Portland, Maine, August 8–9, 2007. http://www.neiwpcc.org/ppcpconference/ppcp-docs/MarcMills.pdf. (Slide 27). Accessed 15 December 2007.

Mitloehner FM, Schenker MB (2007). Environmental exposure and health effects from concentrated animal feeding operations. *Epidemiology* 18: 309-311.

Mirabelli M, Wing S, Marshall SW et al. (2006). Race, poverty, and potential exposure of middle-school students to air emissions from confined swine feeding operations. *Environ Health Perspect* 114: 591-596.

MMWR (2006). Surveillance for Foodborne-Disease Outbreaks—United States, 1998/2002. November 10, 2006/Vol. 55/No. SS/10.

National Research Council 2003 Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs. Washington DC: Committee on Animal Nutrition, National Research Council. National Academy Press.

National Research Council (1999). The use of drugs in food animals: Benefits and risks. National Academy of Sciences, Washington, DC.

Nolan BT, Hitt KJ (2006). Vulnerability of shallow groundwater and drinking-water wells to nitrate in the United States. *Environ Sci Technol* 40: 7834-40.

Oenema O, Velthof G, and Kuikman P (2001). Technical and policy aspects of strategies to decrease greenhouse gas emissions from agriculture. *Nutr Cycling Agroecosyst* 60: 301-315.

Office of Pesticide Programs, Office of Prevention, Pesticides, and Toxic Substances, US Environmental Protection Agency, Washington, DC. Accessible online at: http://www.epa.gov/oppbead1/pestsales/01pestsales/market_estimates2001.pdf; accessed on April 14, 2007.

Osterberg D, and Wallinga D (2004). Addressing Externalities From Swine Production to Reduce Public Health and Environmental Impacts. *American Journal of Public Health* 94: 1703-1708.

Park S, Egbert SL (2005). Assessment of soil erodibility indices for conservation reserve program lands in southwestern Kansas using satellite imagery and GIS techniques. *Environ Manage* 36(6): 886-98.

Parkin GF, and Owen WF (1986). Fundamentals of anaerobic digestion of wastewater sludges. *J Environ Eng* 112: 867-920.

Parveen S, Lukasik J, Scott TM, Tamplin ML, Portier KM, Sheperd S, et al. (2006). Geographical variation in antibiotic resistance profiles of *Escherichia coli* isolated from swine, poultry, beef and dairy cattle farm water retention ponds in Florida. *J Appl Microbiol* 10050-57.

Paudel KP and McIntosh CS (2005). Country report: Broiler industry and broiler litter-related problems in the southeastern United States. *Waste Management* 25: 1083-1088.

Pimentel D, Houser J, Preiss E, White O, Fang H, Mesnick L, Barsky T, Tariche S, Schreck J, and Alpert S (1997). Water Resources: Agriculture, the Environment, and Society. *BioScience* 47(2): 97-106.

Pimentel D and Pimentel M (1996). Food, energy and society. Niwot, Colorado. University Press of Colorado.

Porter WP, Jaeger J and Carlson I (Part 1) (Part 2) Endocrine, immune and behavioral effects of aldicarb (carbamate), atrazine (triazine) and nitrate (fertilizer) mixtures at ground water concentrations. *Toxicology and Industrial Health* (1999) 15(1-2): 133-150.

Radon K, Schulze A, Ehrenstein V et al. (2007) Environmental exposure to confined animal feeding operations and respiratory health of neighboring residents. *Epidemiology* 18: 300-308.

Rutherford DW, Bednar AJ, Garbarino JR, Needham R, Staver KW, and Wershaw RL (2003). Environmental fate of roxarsone in poultry litter. Part 2. Mobility of arsenic in soils amended with poultry litter. *Environ Sci Tech* 37: 1515-1520.

Sapkota AR, Curriero FC, Gibson KE, and Schwab KJ (2007a). Antibiotic-resistant *enterococci* and fecal indicators in surface water and groundwater impacted by a concentrated Swine feeding operation. *Environ Health Perspect* 115(7): 1040-5.

Sapkota AR, Lefferts LY, McKenzie S, and Walker P (2007b). What do we feed to food-production animals? A review of animal feed ingredients and their potential impacts on human health. *Environ Health Perspect* 115(5): 663-70.

Sarmah AK, Meyer MT, Boxall AB (2006a). A global perspective on the use, sales, exposure pathways, occurrence, fate and effects of veterinary antibiotics (VAS) in the environment. *Chemosphere* 65(5): 725-59.

Sarmah AK, Northcott GL, Leusch FD, and Tremblay, LA (2006b). A survey of endocrine disrupting chemicals (EDCS) in municipal sewage and animal waste effluents in the Waikato region of New Zealand. *Sci Total Environ* 355(1-3): 135-44.

Sayah RS, Kaneene JB, Johnson Y, and Miller R (2005). Patterns of antimicrobial resistance observed in *Escherichia coli* isolates obtained from domestic- and wild-animal fecal samples, human septage, and surface water. *Appl Environ Microbiol* 71: 1394-1404.

Schiffman SS, Miller EA, Suggs MS, Graham BG (1995). The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. *Brain Res Bull* 37: 369-375.

Schindler DW (1990). Experimental Perturbations of Whole Lakes as Tests of Hypotheses Concerning Ecosystem Structure and Function. *Oikos* 57(1): 25-41.

Schulze RH (1993). The 20-Year History of the Evolution of Air-Pollution Control Legislation in the USA. *Atmospheric Environment Part B-Urban Atmosphere* 27(1): 15-22.

Silbergeld EK, Graham J, Price LB (2007). Industrial Food Animal Production, Antimcirobial Resistance, and Human Health. White Paper solicited by the National Commission on Industrial Farm Animal Production.

Soule JD, and Piper D (1992). Farming in Nature's Image: *An Ecological Approach to Agriculture*. Washington, DC, Island Press.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006). Livestock's Long Shadow _ Environmental Issues and Options. 390 pp. Food and Agriculture Organization of the United Nations, Rome, Italy.

Takai H, Pedersen S, Johnsen JO, Metz JHM, Koerkamp PWGG, Uenk GH, Phillips VR, Holden MR, Sneath RW, Short JL, White RP, Hartung J, Seedorf J, Schroder M, Linkert KH, Wathes CM. Concentrations and emissions of airborne dust in livestock buildings in Northern Europe. *J of Agric Eng Research* (1998) 70: 59-77.

Takai H, Pedersen S. A comparison study of different dust control methods in pig buildings. *Applied Engineering in Agriculture* (2000) 16: 269-277.

Thomas P, and Doughty K (2004). Disruption of rapid, nongenomic steroid actions by environmental chemicals: interference with progestin stimulation of sperm motility in Atlantic croaker. *Environ Sci Technol* 38(23): 6328-32.

Thorne PS (2007). Environmental health impacts of concentrated animal feeding operations: anticipating hazards searching for solutions. *Environ Health Perspect* 115: 296-7.

Thu K, (Editor) (1996). Understanding the Impacts of Large-Scale Swine Production: Proceedings from an Interdisciplinary Scientific Workshop. Iowa City, Iowa: The University of Iowa.

Thu K, Donham K, Ziegenhorn R, Reynolds S, PS Thorne, Subramanian P et al. (1997). A control study of the physical and mental health of residents living near a large-scale swine operation. *J Agric Saf Health* 3: 13-26.

Thurston-Enriquez JA, Gilley JE, Eghball B (2005). Microbial quality of runoff following land application of cattle manure and swine slurry. *J Water Health* 3: 157-71.

United Nations Food and Agriculture Organization. FAOSTAT

Database [online], (2005) Data. Query at http://faostat.fao.org/Core Consumption Data. Accessed April 4, 2007.

University of Mannitoba (2007). Experimental Lakes Area homepage: Eutrophication. http://www.umanitoba.ca/institutes/fisheries/eutro.html

USDA (United States Department of Agriculture), 2005. USDA Agricultural Baseline

Projections to 2014. Baseline Report OCE-2005-1, 116 pp. Available at http://www.usda.gov/oce/waob.

USDA, (2006a). Farms, Land in Farms, and Livestock Operations: 2005 Summary. Washington, DC: US Department of Agriculture. http://usda.mannlib.cornell.edu/nass/FarmLandIn/2000s/2005/FarmLandIn-01-31-2005.pdf. Accessed 15 December, 2007.

USDA, (2006b). Meat Animals Production, Disposition, and Income: 2005 Summary. Washington, DC: US Department of Agriculture. http://usda.mannlib.cornell.edu/usda/nass/MeatAnimPr//2000s/2006/MeatAnimPr-04-27-2006.pdf. Accessed 15 December, 2007.

USDA (2007). Rise in meat production. http://usda.mannlib.cornell.edu/MannUsda/viewStaticPage.do?url=http://usda.mannlib.cornell.edu/usda/ers/94005/./2007/index.html

USDA Economic Research Service (ERS), 2007. Numbers calculated from Table 1 posted online at: http://www.ers.usda.gov/Data/FertilizerUse/Tables/Table1.xls; accessed April 14, 2007.

USDA-ERS, undated. The Role of Changing Vertical Coordination in the Broiler and Pork Industries. http://www.ers.usda.gov/publications/aer777/aer777b.pdf. Accessed 15 December 2007.

USDA National Agricultural Statistics Service (NASS), 2004. Poultry--production and value: 2003 Summary. Pou 3-1. [Online] http://usda.mannlib.cornell.edu/reports/nassr/poultry/pbh-bbp/plva0404.pdf Accessed 17 August, 2005.

USDA-NASS, undated. Trends in US Agriculture. http://www.usda.gov/nass/pubs/trends/broiler.htm and http://www.usda.gov/nass/pubs/trends/livestockproduction.csv

USDA Agricultural Research Service (ARS), 2002. National Programs Manure and Byproduct Utilization,

National Program Annual Report: FY 2001. http://www.ars.usda.gov/research/programs/programs.htm?np_code=206&docid=1076

USDA-ARS, 2005. Available: http://www.nass.usda.gov/index.asp [accessed 2007].

United States Environmental Protection Agency (USEPA) (2002). 2000 National water quality inventory. Office of Water, Washington, DC, Chapter 2, p 14 and 3, p. 22. Accessible at: http://www.epa.gov/305b/2000report.

USEPA (2004). Inventory of the US greenhouse gas emissions and sinks: 1990-2002 USEPA, Washington, DC.

USEPA Compliance Assistance webpage. http://www.epa.gov/oecaerth/assistance/bystatute/cwa/afo.html. Accessed 15 December, 2007.

USEPA (2005). Fact sheet: The drinking water contaminant candidate list the source of priority contaminants for the drinking water program. Office of Water. EPA 815-F-05-001.

USEPA (2007). Draft Report on the Environment: Water and Watersheds. http://www.epa.gov/indicate/roe/html/roeWaterW2.htm

United States Geological Survey (USGS) (1997). Digital data set of water-level changes in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 1980 to 1995. http://water.usgs.gov/GIS/metadata/usgswrd/XML/ofr99-197_wlc80_95.xml

US Government Accountability Office (US GOA) (2005). Livestock Market Reporting: USDA Has Taken Some Steps to Ensure Quality, but Additional Efforts Are Needed. GAO-06-202, 9 December 2005. Available at: http://www.gao.gov/new.items/d06202.pdf. Accessed 17 August, 2007].

Von Essen S, Donham K (1999). Illness and injury in animal confinement workers. Occupational Medicine-State of the Art Reviews; 14: 337-350

Walker P, Rhubart-Berg P, McKenzie S, Kelling K and Lawrence RS (2005). Public health implications of meat production and consumption. *Public Health Nutr* 8(4): 348-356.

Ward MH, deKok TM, Levallois P, Brender J, Gulis G, Nolan BT, et al. (2005). Workgroup report: drinking-water nitrate and health recent findings and research needs. *Environ Health Perspect* 113: 1607-1614.

Webb J, Archer JR 1994. Pollution of soils and watercourses by wastes from livestock production systems. In: *Pollution in Livestock Production Systems* (Dewi IA, Axford RFE, Marai IFM, Omed HM, eds). Oxfordshire, UK, CABI Publishing, 189-204.

Wegener HC (2003). Antibiotics in animal feed and their role in resistance development. *Curr Opin Microbiol* 6: 439-445.

WHO (World Health Organization) (2003). Diet, Nutrition, and the Prevention of Chronic Disease. WHO Technical Report Series No. 913, Geneva.

World Resources Institute (2000). World Resources 2000-2001: People and Ecosystems—The Fraying Web of Life. Washington, DC.

Wright W, Flora CB, Kremer KS, Goudy W, Hinrichs CP, Lasley et al. (2001). Social and Community Impacts. Technical work paper. Prepared for the Generic Environmental Impact Statement on Animal Agriculture and the Minnesota Environmental Quality Board., St. Paul, Minnesota. Available online at: http://www.eqb.state.mn.us/geis/TWP_Social.pdf [accessed April 14, 2007].

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PCIFAP Commissioners

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Executive-in-Residence
Kansas State University

Michael Blackwell, DVM, MPH, Vice Chair
Assistant Surgeon General, USPHS (ret.)
President and CEO
Blackwell Consulting, LLC

Brother David Andrews, CSC, JD
Former Executive Director
National Catholic Rural Life Conference

Fedele Bauccio, MBA
Co-founder and CEO
Bon Appétit Management Company

Tom Dempster
State Senator, South Dakota

Dan Glickman, JD
Former US Secretary of Agriculture
Chairman and CEO
Motion Picture Association of America

Alan M. Goldberg, PhD
Professor
Johns Hopkins Bloomberg School of Public Health

John Hatch, DrPH
Kenan Professor Emeritus
University of North Carolina at Chapel Hill
School of Public Health

Dan Jackson
Cattle Rancher

Frederick Kirschenmann, PhD
Distinguished Fellow
Leopold Center for Sustainable Agriculture
Iowa State University

James Merchant, MD, DrPH
Dean
University of Iowa College of Public Health

Marion Nestle, PhD, MPH
Paulette Goddard Professor
Department of Nutrition, Food Studies,
and Public Health
New York University

Bill Niman
Cattle Rancher and Founder of Niman Ranch, Inc.

Bernard Rollin, PhD
Distinguished Professor of Philosophy
Colorado State University

Mary Wilson, MD
Associate Professor
Harvard School of Public Health
Associate Clinical Professor of Medicine
Harvard Medical School

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PCIFAP Staff

Robert P. Martin
Executive Director

Ralph Loglisci
Communications Director

Paul Wolfe
Policy Analyst

Emily A. McVey, PhD
Science Director

Lisa Bertelson
Research Associate

The Commission gratefully acknowledges the contribution of Dr. Amira Roess during her tenure as Science Director with the Commission.

Report Authors

Rolf U. Halden, MS, PhD
Associate Professor
Certified Professional Engineer
Center for Water and Health
Johns Hopkins Bloomberg School of Public Health
Baltimore, Maryland
and
Center for Environmental Biotechnology
Arizona State University
Tempe, Arizona

Kellogg J. Schwab, PhD
Associate Professor
Director, Center for Water and Health
Department of Environmental Health Sciences
Johns Hopkins Bloomberg School of Public Health
Baltimore, Maryland

Peer Reviewers

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David Pimentel
Professor
Cornell University
Ithaca, New York

Joe Rudek, PhD
Senior Scientist
Environmental Defense
Raleigh, North Carolina

Lars B. Jensen, MSc, PhD
Senior Scientist
National Food Institute
Technical University of Denmark
Danish Institute for Food and Veterinary Research
Copenhagen, Denmark

Joseph M. Blondeau, MSc, PhD, RSM(CCM), SM(AAM), SM(ASCP), FCCP
Head, Clinical Microbiology
Royal University Hospital and Saskatoon Health Region
Adjunct Professor of Microbiology and Immunology
Clinical Associate Professor of Pathology
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

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