PEW COMMISSION ON INDUSTRIAL FARM ANIMAL PRODUCTION

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, *Putting Meat on the Table: Industrial Farm Animal Production in America,* and the recommendations included in it, represents the consensus position of the Commission.

Farm Animal Waste Management

Introduction:
Recent Changes in Food Animal Production and
Impacts on Animal Waste Management

During the past half-century, US production of human food of animal origin has increased in response to greater demand not only domestically but globally. Meat production has grown by over 250 percent and milk production by over 40 percent, in response to both increases in population and changes in per capita consumption. Production growth is particularly evident in the larger numbers of broiler chickens—from 280,000 to 8.2 billion—to accommodate the nearly 1,000 percent increase in per capita broiler meat consumption between 1950 and 2000 (Havenstein 2007; Havenstein et al. 2003). In contrast, beef and pork production has risen with only modest increases in numbers of animals (and in some years actually reduced numbers). And a 16 percent growth in milk production was achieved with only about 35 percent of the number of cows in 2000 that were involved in production in 1950 (7.8 million in 2000 vs. 21.9 million in 1950) (USDA 2007).

These remarkable productivity changes are the result of a combination of improved genetics, management, and especially nutrition, all of which have increased the productivity of each animal. For example, the time to reach market weight for a broiler in 1957 was 101 days with a feed requirement of 17.7 pounds per chicken (Havenstein 2007; Havenstein et al. 2003). With improved genetics and feed, the same market weight was achieved in 2001 in 32 days with 5.9 pounds of feed. In the case of pigs, market weight in 2000 was 15 percent greater than in 1950, but with much less fat in the 2000 animal and a requirement of 20 percent less feed per pound of meat produced (Allee 2007).

These amazing increases in productive efficiency have had significant impacts on animal waste production. For example, in 2007 dairy cattle waste solids production is estimated to be less than half of the amount produced in 1950 (123 million pounds/day in 2000 vs. 250 million pounds/day in 1950). Total waste solids production by pigs in 2000 was estimated to have been approximately the same as it was in 1950 when there were 12 percent fewer pigs marketed. Only broiler waste production increased during the time period in question, due to the very great increase in numbers of birds, but that increase (1.8 million pounds/day in 1957 vs. 4.3 million pounds/day in 2001) is more than offset by the sharp declines posted for dairy cattle and the lack of increases for beef cattle and pigs. The calculations made in the above paragraphs were based on data from various National Academy of Sciences publications on the Nutrient Requirements of Animals (NRC 1994; NRC, 1998; NRC, 2001).

The result of these developments is that animal waste production in the United States has actually declined during the past half-century, thanks to improvements in the genetic capability of the birds and animals as well as improved production practices that enhance the animals' genetic capacity for production. These increases in efficiency have directly contributed to a reduction in the fraction of disposable income spent for food in the United States to less than 50 percent of what it was in 1950!

On the other hand, the pressure to produce food from all sources in the United States has resulted in a steady change to fewer, more specialized, and significantly larger production units. Only with such a trend is the steady reduction in relative food prices possible for the general population. Animal production, like crop production, has seen a concentration of production (usually of a single species), greater mechanization and application of technology, and in many cases only a portion of the production cycle in one location. For example, the feed required for this concentrated production is increasingly produced elsewhere, where conditions are favorable

for that feed production. The result is that the animal waste produced as an inevitable consequence of production can no longer be recycled locally in support of the necessary feed production. The challenges of managing the animal waste in ways that are both environmentally and economically sustainable, within the framework of the pressure for ever decreasing food costs, are significant, and they are exacerbated by the fact that the general population has little understanding of the complexities of agriculture in general and animal production in particular.

This report addresses animal waste management issues associated with the concentration of animals in large production systems, and considers ways to reduce adverse environmental and economic impacts of those practices while ensuring that foods of animal origin remain readily and cheaply available to the total population of the United States.

Background

The increases in the US production of foods of animal origin correspond primarily to increases in both US population and global per capita income, as per capita consumption of meat in this country has remained relatively constant. Numerous studies indicate that food animal production is based directly on consumers' demand for animal protein in their diet, and that this demand is in turn directly related to increased disposable income, a connection that holds true the world over (Bradford 1999). On a global basis animal protein now accounts for more than 30 percent of all protein consumed, and in developed countries the amount is 50–65 percent, driven by disposable income (Farm Foundation, 2006). This trend will likely continue and by the middle of this century the global average is expected to approach 50 percent (Farm Foundation 2006).

But although food animal production has increased in the United States and other developed countries, concentration and specialization mean that fewer people and facilities are needed for production. Thus only about 1 percent of the US population is now involved in agricultural production, which has changed from an "art" to a high-technology science. This trend parallels that of all agricultural commodities as increased output per farming operation generates economies of scale and less risk per unit input.

Additionally, significant gains in technology that aid production efficiency, fueled by a national policy that calls for new applications of science and technology, and pressure to reduce the cost of food have all combined to reduce the percentage of disposable income used in the United States for the purchase of food to *less than half* of what it was 75 years ago (23 percent in 1929, 10 percent in 2007; USDA 2007)! At the same time, however, consumers' expectations of continued savings, and environmental compliance mandates that require new technological and waste management performance enhancements, may put unprecedented pressure on producers of animal products to further increase output in order to offset reduced income per unit (because of increased production costs) if they are to remain economically viable.

A further consequence of the dramatic changes in output enabled by greater reliance on technology and automation is the rise of larger, but fewer, agricultural facilities (production units). For example, in 1920 there were over 6.1 million farms in the United States, whereas in 2002 that number had fallen to just over 2.1 million (Farm Foundation 2006). Production efficiency and cost control have required a high degree of specialization, replacing the diversified and often self-contained one-family farms of a generation ago. The result is individual crop production units of thousands of acres, and animal production units with thousands of animals, concentrated in specialized facilities that are increasingly distant from the

source of feed and operated by individuals with highly specialized expertise and training in the efficient production of the particular food animals.

In addition to these production unit changes, genetic improvements in the selection of production traits have resulted in substantial increases in unit productivity per animal. This development is important for some species not only because fewer animals are needed, as each is capable of greater output, but also because fewer animals produce less waste both per unit and in total, as noted above.

Table 1 provides the number and percentage of US farms in each animal feeding operation (AFO) category (i.e., very small, small, medium, and large, based on the number of animal units [AUs], where 1 AU approximates 1,000 pounds of steady-state live animal weight).

Table 1. Number and percentage of US farms in each animal feeding operation (AFO) category, and average acres per animal unit for each AFO category (Gollehon et al. 2006)

Animal type	Very small <50 AUs*	Small§ 50-299 AUs	Medium§ 300-999 AUs	Large CAFOs† >1000 AUs	Total
Feedlot beef	487 (5%)	734 (8%)	635 (7%)	7,463 (80%)	9,318
Dairy	583 (6%)	5,344 (54%)	1,836 (19%)	2,135 (22%)	9,899
Swine	612 (7%)	2,656 (32%)	2,113 (26%)	2,852 (35%)	8,233
Poultry	202 (3%)	2,433 (40%)	1,651 (27%)	1,833 (30%)	6,118
Total	1,612 (5%)	11,105 (33%)	6,387 (19%)	14,463 (43%)	33,568
Average acres per animal unit	14.91	3.50	1.20	0.18	0.35

*1 animal unit (AU) is approximately 1,000 pounds of animal live weight.
† CAFOs – concentrated animal feeding operations. A CAFO has approximately 1,000 AUs, equivalent to: 1,000 beef cattle, 700 dairy cattle, 2,500 hogs, or 125,000 broiler chickens.
§ Some small and medium-sized AFOs may fall into the CAFO category based on specific criteria defining CAFOs.

Table 2 below provides data on the quantities of the critical nutrients, nitrogen and phosphorus produced annually in animal waste, according to the same size criteria shown in Table 1 (Gollehon et al., 2001). The nutrients noted in this table are contained in approximately 80,000,000 tons of dry solids, which includes the total excretion of organic and inorganic matter.

Table 2. Manure nutrients produced by animal type and farm size, 1997 data. (Taken from Gollehon et al. 2006)

Animal type	Very small <50 AUs	Small 50-299 AUs	Medium 300-999 AUs	Large CAFOs 1,000 AUs	Total
	----------------------------(tons)………………………………..				
Feedlot beef:					
Nitrogen	10,180	15,356	13,268	156,120	194,941
Phosphorus	6,632	10,004	8,655	101,709	127,000
Dairy:					
Nitrogen	18,721	171,615	58,950	68,563	317,849
Phosphorus	7,184	65,852	22,620	26,309	121,965
Swine:					
Nitrogen	10,136	44,648	35,928	46,327	137,038
Phosphorus	10,242	45,043	36,202	46,913	138,400
Poultry:					
Nitrogen	21,402	264,540	138,414	152,080	576,436
Phosphorus	9,463	114,927	72,026	80,515	276,932

Impact of Larger Production Facilities on Animal Waste Management

An inevitable consequence of food animal production is the corresponding production of animal waste that must be managed. When animal feed crops are grown on the same farm or near a food animal production facility, the animal waste generated by the latter can be used to some extent to fertilize the cropland of the former. But increasingly, if the animal waste is recycled locally, the amounts and balances of nitrogen, phosphorus, and other nutrients in the waste restrict the application of organic materials because they contain higher than allowed concentrations of certain nutrients and thus may require the addition of synthetic fertilizers to meet the needs of growing plants. This is an especially critical issue for those who produce "organic foods," in addition to concerns about the transmission of pathogens in organic fertilizers.

As a result, land application of animal waste was often governed by convenience or proximity of the field to which the waste was to be applied to the animal housing (especially in adverse weather), rather than nutrient requirements of growing crops, resulting in over-application, runoff on frozen ground, transfer of nutrients in excess of the capacity of the cropping system to use to ground water, etc. These factors resulted in localized pollution of waterbodies with animal waste nutrients, especially phosphorus and nitrogen, causing water quality deterioration, and make a strong case for nutrient management plans with monitoring and reporting.

Alternatives for waste management are necessary when animal production facilities import feed and may or may not either export some animal waste or be unable to use all remaining manure

nutrients on cropland. Nutrient excesses occur when imported nutrients (feed and animals) exceed exported nutrients (animal products and manure). An improved understanding of the environmental implications of the availability and movement of organic and synthetic fertilizer nutrients across or through soil to surface or groundwaters, and of nutrient losses both atmospherically and in groundwater, has resulted in the development of nutrient management plans (NMPs) for animal waste management, which usually apply to animal production facilities at or above a certain size. These plans typically support the protection of ground- and surface waters by addressing application methods and the impacts and remediation of specific nutrients.[1] The plans support the joint goals of appropriate use of animal waste nutrients for crop production and reduced generation of such nutrients through energy-intensive synthesis or mining from underground deposits.

Modifications to the Clean Water Act have identified the minimum national requirements for NMP use in an animal regulatory process, but actual regulation of animal waste management differs from state to state, by regions, or by county as each jurisdiction has the authority to be more stringent than federal law. Jurisdictions may mandate increased regulatory requirements for facilities based on size, proximity to waterways, water table depth, frequency and intensity of rainfall, or other environmental factors.

Animal Waste Production, Management, and Utilization

Amount of Waste Produced by Food Animals

The American Society of Agricultural and Biological Engineers estimates that roughly 540 million metric tons of excreta are produced annually by food animals in the United States (USDA 2005). Until the late 1950s manures were typically processed in solid form and either deposited directly by the animals onto pastures or collected along with the bedding (usually uneaten hay or straw, or wood-processing byproducts such as sawdust or shavings) from the animal housing facility and applied to the land as a crop nutrient. There were no regulated rates of application, seasonal restrictions, or requirements for reporting, analysis, or monitoring of applied manures

As the number and concentration of animals on individual farms have increased, more attention and a better understanding of the environmental impact of excessive nutrient application have focused on the need for more efficient and regulated methods of manure management. As a result, animal feeding operations (AFOs) in the United States now use a number of manure management strategies, depending on the type of operation, labor requirements, animal health and well-being, and state and federal regulations.

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[1] Nutrient management plans include the following components: proper storage of manure and maintenance of the storage structure; proper land application of the manure; appropriate site management that looks at the risks on a particular field, such as sinkholes, streams running through the field, shallow groundwater, or erosion that needs to be controlled; and record keeping that documents land practices, so that if questions arise there is proof of what is being done and why (http://www.wvu.edu/~agexten/forglvst/why.htm).

Animal waste components of concern include the specific nutrients, such as nitrogen in its various forms, phosphorus, and other minerals such as copper and zinc (specifically for swine and poultry), fine particulates, bacteria (with emphasais on pathogens), viruses and a wide range of chemical compounds that contribute to odors.

The type of housing unit, waste handling and treatment system, and local weather conditions (particularly average rainfall) all affect the volume and concentration of waste that must be managed by the production facility.

Recent Changes in Animal Waste Management

Large AFOs that are not pasture-based feeding operations provide supplemental feed to animals for more than 45 days during the year. In the 15 years from 1982 to 1997 the number of farms with animals on feed fell by more than half, from 435,000 to 213,000, while at the same time the number of animals per farm increased (Gollehon et al. 2001).

This shift toward animal intensification has required improvements to the methods used for the management and control of animal manure, much of it governed by permitting and nutrient management planning, implementation and reporting requirements by individual states. Containment systems of a variety of types (earthern vessel, etc) have been developed and a variety of processing technologies such as anaerobic digestion have been introduced to reduce unintended release of nutrients from animal waste and often, to effectively reduce odor emissions. Depending on the type of animal production system, separation of part of the liquid and fine solids from the coarser solid waste material has been the subject of technology development, to enable cost-effective ways for transporting animal waste nutrients greater distances. Transportation of high volume liquid animal waste materials to sites distant to the production site has often been proposed, but transportation costs have made that option unattractive in most cases. A greater discussion of introduction of newer, specific types of waste handling systems is found in the sections immediately following this one.
Large operations (see Table 1 for definitions of AFO sizes) that depend on importation of feed are often unable to rely solely on land application as a means of utilization as regulatory requirements have changed. Since they may not have the capacity to recycle animal waste nutrients to provide crop nutrients needed to produce the feed used by the animals, alternative utilization practices have been developed, including value-added product development. In 1997 roughly half of the nutrients excreted in animal waste (in excess of the requirements to support crop production on land owned by the producers) were produced by the largest operations (with more than 1,000AU's). This excess production was generated by only 2 percent of farms (Gollehon et al. 2001).

Underlying this discussion is the fact that concentration of animals into large units with reduced land per animal unit (Table 1) now requires that animal waste management be managed in ways that are environmentally sound, agronomically based where land application is concerned, and subject to the best management practices available. The emphasis on the environmental concerns associated with animal production in CAFO's has resulted in a significant increase in the development of new technologies to accomplish those needs. With few exceptions (most notably the North Carolina State University program, discussed below), there has not been an adequate

and coordinated process for objective evaluation of these technologies according to appropriate performance parameters. That deficiency continues.

Responsibility for Animal Waste Management

In the vast majority of cases, the responsibility for animal waste management rests with the owner/operator of the animal production facility, whether the animals are owned by the operator or managed by another party as part of a production contract with the facility. In integrated facilities technical support, including compliance with environmental reporting requirements, may be provided by the integrator. (**NOTE: The Integrator owns the animals and feed and provides services to the facility owner who is the operator**. **The actual waste management functions are the responsibility of the facility owner/operator.)**

Facility owners/operators generally do not treat waste beyond the level required to comply with state regulations (Paudel et al. 2004): there is no economic incentive for additional treatment. In addition, because of the cost to comply with many environmental regulations requiring a variety of technical improvements and facility changes, small farmers and producers could be significantly and adversely affected by regulations requiring further processing of animal waste. This could exacerbate the loss of farms and further concentrate the industry (Hutchison et al. 2005a..

Animal Production Facilities and Waste Management Methods

Animal feeding operations typically house animals either in open lots or inside buildings to prevent rainwater from coming in contact with animal waste in the production area. However there are variations of each and combinations involving both. For example, in open lot systems (beef cattle feedlots, for example), animals are maintained in pens with no roof.

Standard manure collection procedures for animals in closed facilities include scraping (slurry) or flushing (liquid) to transport the waste to storage or treatment facilities (Hutchison et al. 2005a).[2] These flush systems require large volumes of flushwater—dairies that practice flush cleaning may use more than 150 gallons a day per cow (AWMF 1999), and a 5,000-swine AFO may use an estimated 340 million gallons of flushwater each year (AWMF 1999). For the vast majority of animal operations the flushwater is recycled from either the surface of an anaerobic waste treatment lagoon or, at dairies, wastewater from the milking parlor.[3]

Housing Type

The choice of a particular waste management system determines the characteristics of the resulting waste, and that choice is informed in part by the climate, species, feed availability, and

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[2] Litter-based poultry operations and open-corral housing (feed lots and some dairies) manage manure as solids.
[3] The flush volumes used in swine operations, which use recycled lagoon or holding tank water, result in liquids with a solids content of less than 1 percent. For dairies, the numbers vary between 0.5 and 3 percent solids. In both cases, the water is not "net new" (formed by the use of fresh groundwater) but recycled wastewater (and/or water from milking parlor use), along with whatever rainwater has accumulated on the surface. The total static volume of water is also subject to the region's evaporation rate.

tradition at each AFO. But the most important factor is often the type of animal housing. Housing types at animal production facilities vary by species, region, and animal numbers. For the purposes of this discussion the important distinction is between open lot systems and partially or completely enclosed housing, and the ramifications of these housing types on waste collection, storage, treatment, and utilization choices.

Open Lots
Open lot systems house animals in corrals with either an earthen or concrete floor. Bedding material—such as sawdust, straw, sand, wood shavings, recycled newspaper, or dried manure solids—may be used seasonally (e.g., during periods of high rainfall). These materials mix with the animals' excreta, and the soiled bedding blend (manure, bedding, and soil or sand) is removed periodically and either applied immediately to cropland or stockpiled for later land application. Cropping patterns and local regulatory requirements determine the frequency of solid manure removal from open lots (ranging from 1 to 4 times per year). The collected liquid runoff from open lots may pass through a settling basin to remove some solids before being stored in either above-ground concrete or steel tanks or in-ground earthen retention ponds or concrete tanks. After storage, the liquid waste is applied to cropland as a nutrient source. The USDA Natural Resources Conservation Service (NRCS) Practice Standards set minimum guidelines for waste management practices. The NRCS also has resource materials to assist producers and system designers in determining the appropriate size for storage systems (NRCS 2007).

Partially or Completely Enclosed Housing Systems
Swine, poultry, and some dairy cattle are housed in partially (e.g., with three walls) or completely enclosed housing structures. For dairy cattle and swine, these systems typically rely on either slurry (scraping, vacuuming, or other nondilution methods) or liquid flushing systems to collect and transport manure to storage or treatment facilities. Storage is usually in either a containment/holding facility or an anaerobic treatment unit (a lagoon or tank). Poultry systems generate either loose litter when animals are housed on an earthen or concrete pad with bedding or stacked manure (excreta and sloughed-off feathers) that accumulates below the animals and is removed when the animal production stage and manure transport conditions are conducive.

Storage, Treatment, and Disposition

It is difficult to generalize the performance of the waste management systems in use throughout the United States because of the variety of systems that operate in different climates and treat different types of wastes from different types of animal production facilities of vastly different sizes. Standard components of manure management systems include collection, storage, treatment, transportation, and utilization of the manure. Storage systems serve as receptacles and temporary holding compartments for solid and liquid waste. Treatment systems may serve as storage structures but their primary design criteria include chemical and biological alterations to fractions in the manure streams. Engineering criteria are developed specifically to store and/or treat manure streams. Transportation of waste materials varies depending on the physical form: liquefied materials may be transported through irrigation systems and may not lend themselves to vehicular transportation; solid systems cannot be transported through irrigation systems and are best suited for hauling in manure spreaders or trucks.

Two major considerations in animal waste management that affect manure treatment options include the consistency of the manure (fecal matter and urine) waste stream and the method of removal from animal housing facilities. Swine, beef cattle, and some dairy cattle manures are generally handled as liquids or slurries, and other dairy cattle manures as well as poultry manures are handled as semisolids or solids. Many techniques have emerged for dewatering and concentrating the solids in liquid manures to concentrate nutrient and solids fractions and minimize both handling efforts and costs after removal of the manure from the animal housing. Among the most commonly used systems are biological treatments with anaerobic waste treatment lagoons, digestion and composting..

The two most commonly used storage and treatment methods are liquid holding or retention systems and anaerobic waste treatment lagoon systems. As the name suggests, a liquid holding or retention system is designed to hold liquid materials (e.g., washwater, manure, rain runoff) with no biological treatment. Anaerobic waste treatment systems, on the other hand, are designed based on a specific retention time (physical treatment time) to enhance anaerobic conditions and harness methanogenic bacteria to degrade carbonaceous materials to methane and CO_2 . After the upfront costs associated with engineer design specifications and installation needs (moving soil, grading sides, permitting the impoundment), these methods typically have relatively low operation and maintenance costs annually.

While generally not cost effective for on-farm use, thermochemical oxidation of waste may be an alternative for disposition of animal dry waste in areas where it is allowed and farm density make a centralized facility feasiable. Several processes can be classified as thermochemical oxidation processes, including pyrolysis, gasification, and combustion. The primary differences in these processes involve the temperature and the amount of oxygen that is introduced into the combustion chamber (Burnette et al. 2005). Pyrolysis involves temperatures between 200–600°C and is carried out in the absence of oxygen. The gasification process is carried out in the 600–1,000°C range with limited amounts of oxygen supplied to the process. Combustion involves temperatures in the range of 2,000°C with ample oxygen available to fully oxidize the material. If not properly designed and operated any of these systems may impair air quality through emission of primary pollutants (particulate matter and select gaseous compounds).

Slurry Holding or Retention Systems

Slurry containment structures (in-ground or under-floor pits, above-ground tanks, and retention ponds) are used in many parts of the country to store collected manure and conserve its fertilizer value until it can be applied to cropland. Indoor pits are located below animal housing (under slatted or perforated floors); outdoor pits, basins, or retention ponds may be lined earthen basins or containers of concrete or steel, and may be partially or completely above or in the ground (the surface of the structure may be even with the ground surface). In addition to storing the manure, indoor structures (which tend to be smaller than liquid treatment lagoons) are climate-controlled and, because of their proximity to animals and workers, may include chemical treatment of the waste to maintain air quality. The aim of the treatment is to maintain adequate indoor air quality, but it also achieves N conservation by minimizing N losses as NH3. No extra ("net new") water is used for flushing the houses (Lorimor et al. 2006).

Anaerobic Waste Treatment Lagoon Systems

Anaerobic waste treatment lagoons store and treat animal waste collected in a liquid form. Their use is generally restricted to the southern and western United States, where average annual

temperatures are high enough to allow the microbial activity to operate effectively throughout much of the year and where freezing of the surface is not common, but there are examples of their use in northern states as well.

Well-functioning anaerobic lagoons stabilize and reduce the organic-matter content of the manure, resulting in the production and emission of carbon dioxide (CO2) and methane (CH4), as well as volatile losses of ammonia, dinitrogen gas, and volatile organic compounds. (Jones el al. 2000, Harper et al. 2004, Ro et al. 2006). The mass of nutrients may be further partitioned as denser particles settle into the sludge at the bottom of the lagoon (part of the engineering design criteria of these systems). For example, particulate-incorporated and/or insoluble phosphorus and other inorganic nutrients along with metals such as copper and zinc partially settle to the bottom of the lagoon and can be sequestered for a number of years before being land applied.

Even though properly functioning anaerobic systems are designed, in theory, to decompose organic matter to CH_4 and CO_2; incomplete decomposition generally occurs and intermediate compounds are emitted—there are over 100 such compounds—often result in locally detected odors. The volatilization of some fraction of the intermediate compounds and other noncarbonaceous compounds can be a source of complaints from people who live near the animal production facility.

Land Application

The final process in the management and use of animal waste has long been its application on land in support of nutrient requirements for crop production. This practice, if done in accordance with established and recommended agronomic rates, is the approved and preferred use of production-generated waste (USDA-EPA 1999). However, high rates of application on sprayfields has bee associated with increase groundwater nitrate levels and elevated levels of nitrate in nearby streams (REF.) Application methods include spray or sprinkler systems, direct surface application from drop hoses and center-pivot irrigation systems, or direct soil application and incorporation (e.g., by injection). In recent years, direct soil application and incorporation have been recommended as the preferred practices.

Animal manures are an excellent source of plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K) as well as many secondary organic and inorganic nutrients not normally found in chemical fertilizers (Risse et al. 2006). In addition, the application of manure to cropland maintains soil pH, increases soil organic matter, improves soil physical properties, and sequesters carbon.

Land application does, however, have some limitations. Long-term manure applications conducted without a nutrient management plan can result in high levels of conservative elements such as phosphorus in soils (Chang et al. 1991). Furthermore, agronomic applications have historically been based solely on the N requirements of the receiving crop, which has sometimes led unintentionally to an overabundance of P or of metals such as copper and zinc (which are used as mineral nutrition supplements or antibacterial agents in the animal feed for some species) (Zhang et al. 2006). Recent knowledge of the soil and crop impacts of these practices is resulting in the modification of application rates and/or practices for treatment in many areas.

Research has led to an improved understanding of crop nutrient requirements, the appropriate timing of their use, their availability in animal waste, and the unintended negative environmental impacts of excessive application to cropland of nutrients from any source (including chemical fertilizers). Recent changes in regulatory requirements and technical assistance guidelines call for land application of animal waste according to a nutrient management plan, with regular data

gathering, frequent analysis of nutrient sources, and quantification of the application of nutrients.[4] The regulations also typically limit the timing of the application to the period when the crop is actively growing (which means storage is necessary when crop growth is not taking place) and take into account factors such as expected rainfall in order to limit possible environmental impacts. The vast majority of commercial production facilities that use this practice adhere to regulations governing nutrient requirements.

The primary nutrient of concern from an agronomic perspective in many areas is nitrogen; insufficient nitrogen, either in quantity or in an available form, results in reduced crop yield or even crop failure. From an environmental perspective, nitrogen and phosphorus impairment of surface waters has been identified as a concern in many places, especially the eastern United States. Heavy metals such as copper and zinc (Cu and Zn) have also received attention in certain applications when there is a crop sensitivity to those elements.

Several tools have been developed and implemented to assist livestock producers in managing the application of manure to cropland. Comprehensive nutrient management plans (CNMPs) incorporate practices to utilize animal manure and organic byproducts as beneficial resources while also addressing environmental concerns about soil erosion, manure, and organic byproducts and their potential impacts on water quality (USDA 2007). To help gauge appropriate land application (and resulting increases in P), producers and resource managers can use a P index, an assessment of a field's potential phosphorus loss, to assess and rank the risk of P loss from individual fields based on factors such as field slope, soil P levels, and distance to surface water (Daniel et al. 2006). All states are required to develop and implement P loss assessment tools as part of the NRCS Nutrient Management (590) guidelines (Geohring et al. 2002); and EPA's Consentrated Animal Feeding Operation (CAFO) rules require a CNMP and possibly a P index for facilities of any size that require a CAFO permit (EPA 2006b).

Species-Specific Waste Management

Beef Cattle

Beef cattle manure is predominantly left on pastures by the animals. In the case of confinement systems it is generally handled as a solid or semisolid (only a small number of production systems use slurry collection and handling, with slatted floors or unbedded production systems). Bedding material (e.g., straw, sand/soil, or wood shavings in loafing sheds or open lots) combines with the animals' excreta and the resulting mixture forms a manure pack that is generally removed once or twice a year and used as fertilizer for crop or pasture land. Approximately 83 percent of beef feedlot operators apply manure to land owned or managed by the operation (USDA 2000a).

Manure scraped from open lots may be immediately land applied or, for later land application, stacked in an uncovered pile or structure (in dry climates) or placed in a covered storage structure (in wet climates). The storage structure is usually walled on at least three sides so that the manure can be stacked. In all cases some type of liquid containment system is required to prevent runoff or drainage from reaching nearby bodies of water. Runoff control systems include settling basins in conjunction with detention ponds or lagoons. On small feedlots

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[4] An example of the requirements for and development of an NMP is available at the USDA Natural Resources Conservation Service (NRCS) site (http://www.nrcs.usda.gov/).The PDF for the Nutrient Management section (Code 590) of the NRCS Conservation Practice Standard is posted at: ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/590.pdf.

a settling basin may be used in conjunction with a grass infiltration area as a means of controlling off-site runoff.

Dairy Cattle

Dairy production facilities use a variety of manure handling systems: manure left on pasture by cattle, gutter cleaner (tie-stall barns), alley scraper, alley flush, slotted floor, manure pack, and dry lot scraper. A 2002 national survey conducted by the USDA (2002a) found that the majority (56 percent) of small operations (those with fewer than 100 cows) use gutter cleaners, while nearly 64 percent of medium-sized operations (with 100–499 cows) use alley scrapers as their primary manure handling method. Large farms (with 500 or more cows) were fairly evenly split in their primary manure handling systems: 31.9 percent reported using alley scrapers, 27.4 percent alley flush, and 31.2 percent dry lot systems (USDA 2002a). Among operations of all sizes only 8.6 percent left manure on pasture as their primary form of manure management.

The choice of primary manure handling method by facility also varies by geographic region and is generally based on weather-related factors. In the southeast manure left on pasture (41.0 percent) and alley scrapers (52.9 percent) are the primary handling methods. In the northeast, gutter cleaner (59.9 percent) and alley scraper (30.4 percent) are the primary methods, along with manure left on pasture. The Midwest region also prefers gutter cleaner (46.9 percent) and alley scraper (34.1 percent) but also includes manure left on pasture (7.4 percent) as well as scraped dry lots (7 percent) as significant management methods. In the west, alley scraper (33.5 percent) and scraped dry lot (30.8 percent) are the most prevalent methods of manure handling, although alley flush (17.6 percent) and manure left on pasture (12.1 percent) are also widespread. These values represent the percentage of facilities reporting each manure management method and not the percentage of manure collected by each method.

Regardless of the handling method, the manure that is not left on pastures is eventually moved to a waste storage or treatment system. In the northeast and Midwest, where small farms are prevalent, nearly half of the farms reported storing manure as a solid in a manure spreader for a short time (less than one day, typically, if the receiving ground is not frozen) until it is land applied (USDA 2002a). Approximately 58 percent of medium-sized operations store manure as either a slurry or liquid with no treatment before land application. About half (53 percent) of large operations use slurry or liquid storage systems, and approximately half of those use a treatment lagoon before land application. About one-third of large operations reported storing manure outside as a solid either in the dry lot or in a separate storage facility (USDA 2002a). The eventual method used determines the duration of storage, which varies with the length of the growing season and other factors that are typically defined in state-specific requirements for manure management.

The manure generated by dairies is typically used as a plant nutrient source on land owned or managed by the operation. As herd size increases the operation is more likely to transport manure off the farm (either selling it or giving it away) and to transport feed onto the farm from varying distances. Among large operations 27 percent used composted manure as a bedding material, thereby recycling manure fiber through the dairy. Numerous studies on the health aspects of the use of recycled, composted, or digested manure solids for bedding have determined that, when well managed, this material is a safe alternative, although in recent years sand has increasingly replaced this and other materials for safe, inexpensive bedding. Recent advances in the ability to effectively separate sand from scraped or flushed manure, with the

possibility of reusing the recovered sand, have enhanced the attractiveness of that option, with significant cost benefits to producers {Hogan, 2003 #316}{Hogan, 2003 #317}{Hogan, #318}.

Swine

Although there are significant regional differences in the manure handling methods used by swine producers, most swine manure is handled as a liquid or slurry. Slurry storage systems, in either above-ground storage tanks or in-ground storage (using indoor or outdoor pits), are the choice of over 62 percent of swine farms (USDA 2002b). In these systems, the manure falls through a slotted floor into a concrete pit or gutter, removing it from physical contact with the animals. Either it is stored in the under-floor pits (which are 4–10 feet deep to allow for 3–12 months of manure storage), or the under-floor pits (or gutters) are drained or flushed to an outside storage unit (an earthen basin or a container of concrete or steel) (EPA 2006a). When under-pen pits are used for extended storage, building ventilation is typically designed to draw air from the animal space down into the pit and then exhaust it from the building in order to enhance in-house air quality for the animals.

In warmer regions, such as the southeast, flush systems and anaerobic waste treatment lagoons are more prevalent. In these systems the under-floor pits are shallow (usually less than 4 feet deep) and are flushed or drained periodically to an outside lagoon for storage and anaerobic treatment. Nationwide, such lagoons account for the primary manure management and treatment system on just 23 percent of the swine farms, but they represent a significantly higher percentage of the animals because of the prevalence of this type of system at larger production units. In cooler regions such as the upper Midwest, however, in-barn manure storage systems are the primary form of manure handling and storage.

Approximately 21 percent of operations, most of them too small to be considered a large AFO or to require an NMP, reported using "other waste storage systems." These methods include scraper systems that produce manure solids, which are either collected and spread or hauled to other locations for land application (USDA 2002b). In the case of operations where animals are raised in open lots, land application is by indiscriminate deposit by the animals. These are typically small operations, as noted above.

Almost 95 percent of US swine operations apply manure (either treated or untreated) to land owned or rented by the operation. The method of land application varies with herd size and region. In the south, especially, and in many large operations in general (those with 10,000 head or more) where liquid systems predominate, irrigation is the primary application method, and the application rate is based on a nutrient management plan. On a national basis, medium-sized operations (2,000–9,999 head) typically apply slurry via surface application or subsurface injection, and small operations (with fewer than 2,000 head) tend to use broadcast spreaders (USDA 2002b).

Poultry. Given an average production rate of 1.5–3.0 kg litter bird[-1] year^{-1}, it is estimated that 13–26 million metric ton (mT) of poultry litter (i.e., the combination of excreta, feathers, spilled feed, bedding material, soil, and dead birds) is produced annually in the United States, of which more than 90 percent is applied to land (Moore et al. 1995; Paudel et al. 2004; EPA 2004). The most common handling method for poultry litter is to store it for an undetermined period of time before land application (Moore et al. 1995). Storage, usually in roofed structures called "dry-stack barns," allows for flexibility in the timing of land application (Moore et al. 1995). In many

states, poultry litter is also used as a protein supplement for beef cattle production (Martin and McCann 1998).

Layers. "Highrise houses," which have their own manure handling method, are the most common type of production housing for poultry operations in the Great Lakes and North Central regions, accounting for about 56 percent of the operations in this area (USDA 2000b). The highrise house consists of an upper level where the birds are housed in pens or cages with wire floors, and a lower level where the manure is collected. In the southeast 42 percent of the operations reported flushing the area under the cages to remove manure and convey it to a lagoon for treatment. Approximately 44 percent of the operations in the west use scraper systems to remove waste from the production area.

Broilers and Turkeys. For the majority of these operations the manure is handled as a solid and collected in bedding or in litter placed on solid floors to absorb moisture. The frequency of manure and litter cleanout varies based on a number of factors, including the type and age of the birds, litter source (e.g., wood or crop-residue based), and climate conditions.

The combination of manure and litter removed from the production houses is most often surface applied, although in some cases it is incorporated into the soil in tillage operations (EPA 2006a). Litter may be stockpiled for several months before land application; rules and regulations vary by region. In most cases it must be covered, and some locations require storage on an impervious surface such as concrete or compacted clay soil in order to limit leaching and unintended liquid runoff into adjacent areas.

Mortality Management

Animal deaths (mortalities) are an inevitable occurrence at all animal operations and must be managed in ways that protect both the environment and the health of the remaining animals on the farm. Daily loss factors vary by animal species and stage of production (USDA-NRCS 2003). Swine mortality for example can range from over 10% during the birth to farrowing phase to less than 2% during the grow-out phase of production (Harper et al. 2003). Approved methods of mortality disposal include burial, incineration, rendering, composting, gasification, anaerobic digestion, lactic acid fermentation, alkaline hydrolysis, and nontraditional and other techniques (NABSC 2004). The choice of method on individual farms depends on the type and number of animals, state and local rules, storage capacity, and proximity to and cost of available options.

Rendering and incineration are the predominant methods: an estimated 50 percent of all mortalities are rendered (heat processing with grinding and separation of byproducts for a variety of uses such as feed ingredients, cosmetics, and others) (Kaluzny 2007). An effective method for many poultry producers is the composting of mortality between layers of litter or straw (EPA 2000), although burial and incineration are still used in areas where they are allowed. Because of the size of cattle (both beef and dairy), carcasses are generally rendered or buried on site if burial is allowed; rendering accounts for 94 percent of cattle mortalities and onsite burial for 5 percent (landfills are also used for disposal in 0.5 percent of cases) (USDA 2000a). Swine producers bury, incinerate, render, or compost their mortalities (EPA 2000). Many areas with high water tables have seen a transition away from burial toward rendering, incineration, and gasification because of concerns about potential groundwater contamination.

The USDA-APHIS Carcass Disposal Workgroup was the first group to effectively document current methods. More importantly, this group articulated the need for identification of regulatory concern prior to a catastrophic event and for cooperation among numerous agencies; chapter 11 of their report cites the importance of strengthened cooperation among government agencies, industry, and organizations representing the public. The report recommends scenario analysis to help participants be better prepared during an emergency. Designated participants hold a roundtable discussion to identify the roles and responsibilities of particular groups or people during a hypothetical disaster. In many states there is sufficient history to apply lessons learned from previous disasters—hurricanes on the East coast or in Gulf Coast states, exotic Newcastle disease in poultry, accidental pesticide poisoning of part of a dairy herd, and elevated temperatures (heat waves or high temperatures due to electrical outage). The analysis of each scenario determines the proper fate and disposition of animals, animal products, manure, potentially contaminated soil, and related matters.

Catastrophic mortality (a mortality rate that exceeds rendering capacity) may require emergency alternative methods of carcass treatment and disposal. For example, three separate individual herd incidents at California dairies during the last 10 years caused mortalities that exceeded rendering capacity and were buried or burned. The summer heat wave of 2006 claimed 1 million broilers, layers, and turkeys that were buried. The 2002 exotic Newcastle disease outbreak in southern California required the euthanasia of millions of birds and their disposal (after double bagging) in landfills.

A recent development in North Carolina has resulted in the commercialization of an approved gasification system for on-farm disposal of poultry and swine mortalities, replacing the less environmentally sustainable and more energy-demanding use of incinerators. Research at North Carolina State University (NCSU) has shown that the inorganic residue (ash) that remains after gasification of animal mortalities or waste is an excellent, sterile source of minerals needed by animals, equal in bioavailability to that of more traditional chemical forms used in the feed industry.[5] Other advances are being made in the conversion of fat byproducts to biodiesel for transportation fuel.

Environmental Impacts of Waste Application

Drainage, runoff, leaching, and air emissions are all associated with animal production facilities and have varying environmental impacts on the water and air quality of surrounding areas. Facilities and manure application to land are therefore regulated to prevent or reduce specific impacts to natural resources. Federal, state, and local regulations govern aspects of the management, treatment, and utilization of animal waste through different regulatory processes; in some instances all identified negative impacts are identified and addressed through regulation; in other instances it may be impossible to predict and reduce or eliminate all such impacts. However, some federal regulations are mandated with an insufficient provision for funding to effectively implement a regulatory program.

Point and Nonpoint Sources

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[5] The system is described on the NCSU website, at www.cals.ncsu.edu/waste_mgt.

Discharges to surface waters are classified as either point or nonpoint sources of contamination. Point sources of contamination have a single origin and are generally legally permitted for discharge; municipal sewage treatment plants, certain industrial plants, and waste disposal sites are examples of point sources of contamination. Livestock and poultry CAFOs that met specific legal criteria were defined as point sources in the Clean Water Act. Facilities obligated to seek National Pollution Discharge Elimination System Permits were not allowed to discharge to surface waters. Specific obligations for CAFOsregarding NPDES permit requirements and the agricultural stormwater exemption remain uncertain (EPA 2006b, EPA 2008b)

Runoff from agricultural fields may represent a nonpoint source of pollution. Outside of the agricultural stormwater exemption, agricultural animal operations are required to refrain from any discharge. But these facilities, along with many other nonpoint sources, nonetheless contribute to the heavy burdens of sediment, chemical, and microbial contaminants that result in surface waters that do not meet the quality for their designated classification.

The Code of Federal Regulations (CFR) prohibits all point source discharges from CAFOs (40 CFR 122.23), and nonpoint source discharges are regulated both under Section 6712(g) of the Coastal Zone Act Reauthorization Amendments (CZARA) and under Section 319 of the Clean Water Act. (Federal regulations are described more fully below.) These prescribe specific discharge prohibitions or management practices. Total Maximum Daily Loading (TMDL) rates for some impaired surface waters began after the 1987 amendments to the Clean Water Act which required development of reduction in nonpoint source contaminant of surface waters. These establish measureable criteria and limits for a range of contaminats (physical, chemical, and microbial) based on the designated purpose of the water body (e.g., as a source of drinking water, for recreational use, or for shellfish cultivation) (Stow and Borsuk, 2003; Benham et al. 2005; Ning and Chang, 2006). .

Water Contamination

Animal waste can contribute to the contamination of both surface and groundwaters. Surface waters include rivers and streams, lakes and reservoirs, coastal resources (estuaries and coastal shorelines), and wetlands. Groundwater, on the other hand, is the water located beneath the ground surface in soil pore spaces and in fractures of underlying geologic formations.

Direct discharge or runoff of animal waste (including feces, urine, bedding or litter, unconsumed feed, or process water) can be deleterious to both flora and fauna in surface and groundwaters. Deleterious impacts from animal waste to habitat can be caused by oxygen-demanding substances, plant nutrients (e.g., N, P, other macro or micro nutrients), organic solids, salts, metals, sediments, bacteria, viruses, and other microorganisms. An increase in nutrient load of limiting nutrient(s), for example, that exceed(s) the threshold for particular aquatic species may cause impairment or death and/or excessive growth of aquatic plants and algae. Subsequent decomposition of aquatic plant production can decrease or deplete oxygen supply, causing anoxic or anaerobic conditions that result in fish kills.

The most recent *National Water Quality Inventory* report (EPA 2000) summarizes state and territory reports from 1999 and 2000. The state assessments consistently identify nonpoint source (NPS) pollution as the leading cause of surface water impairments. But because of diverse record-keeping practices and an inability to clearly identify causes of impairment, the reported results may be useful from a generalist's perspective but they are less useful to determine actual impairment as a result of point or nonpoint source contamination specifically from animal

feeding operations. This report is not the primary source of information about groundwater contamination, but we cite some of its findings as at least illustrative of the nature and extent of surface and groundwater contamination from animal waste.

Surface Water Contamination

Offsite discharges to surface water can result in impairments to the beneficial uses of that water. According to the *Water Quality Inventory*, 19 percent of the 3.7 million miles of US rivers and streams were assessed, and of those assessed about 38 percent (269,258 miles) were impaired. Agriculture was directly associated with the contamination of 128,859 miles, and animal feeding operations (AFOs) were specifically associated with 24,616 (9 percent) of the impaired miles (4 percent of total miles). These percentages indicate that the data suggest AFOs are a minority compared to other sources of river and stream contamination. The leading pollutants/stressors for streams and rivers included pathogens, siltation, habitat alterations, oxygen-depleting substances, nutrients, thermal modifications, metals, and flow alterations. Primary agricultural NPS pollutants include nutrients (N, P), sediment, animal wastes, salts, pesticides, and habitat impacts, according to EPA's *National Management Measures to Control Nonpoint Source Pollution from Agriculture* (EPA 2003).

Groundwater Contamination

Based on the required assessments received from the states and territories, EPA's *Water Quality Inventory* identified underground storage tanks, septic systems, and landfills as major sources of groundwater contamination. Not all states submitted data about groundwater contamination, but of those that did seventeen reported AFOs as a major source of groundwater impairment.

In addition to the inconsistent data provided by states, there has not been adequate research on the impacts of animal wastes on groundwater. Many studies document the nutrient value for crops of land-applied manure, but only recently has there been analysis to identify groundwater degradation that results from land-applied nutrients (Harter et al. 2002). Because overapplication of manure and liquid wastewater has been implicated in the nitrate contamination of shallow groundwater (Stone et al. 1995), an understanding of organic N mineralization rates and, especially, the ability to predict them are crucial.

Another potential pathway for groundwater contamination from AFOs is seepage from waste storage and treatment facilities.[6] Although most states have design and construction standards for earthen manure storage structures, in order to govern the allowable seepage rate or hydraulic conductivity, additional research is needed to determine how site-specific factors affect seepage rates (Parker et al. 1999).

Federal Regulations to Protect Surface and Groundwaters

Two federal acts, the Clean Water Act (CWA) and the Coastal Zone Act Reauthorization Amendments (CZARA), prohibit the discharge of manure or process wastewater to surface waters under normal operating conditions. The Clean Water Act of 1972 imposed effluent limitations on all industries identified as point source dischargers; animal facilities that meet the

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[6] Numerous studies have evaluated the capacity of liquid manure storage structures to "self-seal" (Ciravolo et al. 1979; Davis et al. 1973; Meyer et al. 1972; Korom and Jeppson 1994; Ritter and Chirnside 1990; Sewell 1978). Some suggest the use of additional material (e.g., liners) to minimize infiltration to groundwater (Hart and Turner 1965; Ham and DeSutter 1999), as storage structure design seldom sufficiently accounts for all soil characteristics and structural design options.

criteria and discharge manures to US waters are subject to permitting requirements and responsibilities (e.g., zero discharge to surface waters, with the exception of partial runoff from a storm that exceeds a 25-year, 24-hour record).

The Clean Water Act (Sections 305(b) and 303(d)) also requires states and territories to conduct regular surface water assessments that identify beneficial uses of the water, the numeric and narrative criteria used to assess its biological, chemical, and physical parameters, and antidegradation policies; numeric criteria establish thresholds and narrative criteria describe the conditions that must be maintained to support a designated use. Furthermore, revisions to the Clean Water Act (PL 100-4) and CZARA (PL 101-508) require states to conduct regular water quality assessments and to develop nonpoint source control plans. But although the Clean Water Act covers protection of ground- and surface water from animal waste contamination (whether from handling, storage, or land application), such contamination is an ongoing regulatory concern.

The CWA prohibits the discharge of animal waste from animal feeding operations to surface waters. Discharge of such wastes is only allowed when it occurs according to a relatively stringent federal permit (allowing a discharge under a 25 year, 24-hour storm condition) and the owner/operator is covered under the permit. This is a bit of a Catch-22, however, as permits for animal owners prohibit the discharge of animal manure under other circumstances. This can be confusing as it becomes difficult to understand why you would request "coverage" under a permit that forbids the discharge of manure to surface water in order to have a legal discharge approximately once in 25 years.

The Safe Drinking Water Act provides the federal authority to protect drinking water. There are minimum standards for drinking water but no specific section addresses potential impacts from animal feeding operations.

Air Emissions

Air emissions from animal production systems (animal housing facilities, waste storage, and land application practices) is a concern in many areas. AFO emissions of ammonia nitrogen (a precursor to fine particulate matter), volatile organic compounds (especially in California), hydrogen sulfide, particulate matter and contributions to greenhouse gases (carbon dioxide, methane, and nitrous oxide) are also a concern (NAS 2003). EPA is conducting a national study on the impact of animal production systems on air quality which might result in some revisions to the Clean Air Act.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; often referred to as the Superfund law, enacted by Congress on December 11, 1980) provides broad federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. A recent report for Congress (Copeland 2006a) highlights legal actions that cite this Act in proceedings that concern animal feeding operations. Amendments to CERCLA in 1986 added the Emergency Planning and Community Right-to-Know Act (EPCRA). The primary objectives of these amendments were (1) to support emergency planning by local governments to address chemical hazards and (2) to provide citizens and local governments with information about appropriate responses to potential community-based chemical hazards. Both CERCLA and EPCRA include reporting requirements that are triggered when certain substances (such as ammonia nitrogen or hydrogen sulfide) exceed threshold quantities that may impair the environment (Fletcher 2005). EPA is currently

considering exempting emissions resulting from treatment of animal waste from these reporting requirements [EPA, 2008]

In addition to these federal regulations, some states are enacting their own laws. For example, a few states now regulate emissions of hydrogen sulfide (Schliesser 2003). In California, a recent law (SB 700; Florez 2003) requires agricultural operations greater than 100 contiguous farmed acres or 500 dairy animals to develop conservation management practices plan to reduce emissions of particulate matter (Rule 4550). California law also requires large dairy facilities (those with a federal ozone nonattainment area and/or 1,000 milk-producing dairy cows) to obtain a permit to operate, and companion legislation required them to develop and submit a Volatile Organic Compounds (VOC) Emissions Mitigation plan (Rule 4570) by December 15, 2006. North Carolina also passed legislation in 2007 which requires "substantial reduction" in emissions of ammonia and odor as well as other soil, water and pathogen related requirements on any new or exnpasion permits issued for hog farms greater than 250 animals. (see http://www.ncga.state.nc.us/Sessions/2007/Bills/Senate/HTML/S1465v7.html)

Public Health Impacts of Animal Wastes

Animal waste can contain microbial pathogens that may lead to disease outbreaks, and therefore most public health interventions for controlling infectious agents in the environment focus on the control of such wastes. There are many pathogens that can be excreted in animal feces (manure), which, when not managed properly, can lead to both human diseases and environmental contamination. Human disease outbreaks can result from direct transmission (through contact with animal manure) or indirect transmission (through contact with contaminated environmental media such as water, air, and soils).

Waste management strategies generally rely on aerobic and anaerobic advanced biological treatment techniques. Agricultural waste management is governed by federal and state regulations that stipulate allowable methods and content levels for reducing nutrients and other potentially harmful elements in the fecal waste managed on farm properties. In addition, there are well-established methods to detect and quantify bacteria in the environment that originate from the gastrointestinal tracts of warm-blooded mammals (e.g., fecal coliform bacteria, *E. coli*, or enterococci) which tend to be indicative of fecal contamination in the environment and of the potential for adverse public health consequences. However, the use of these indicators is not always completely protective of public health as there have been documented zoonotic disease outbreaks associated with waters that meet indicator quidelines.

In addition to microbial pathogens associated with animal wastes, risks associated with farm emissions of airborne respiratory irritants, toxic chemicals, and particulates are of public health concern. Emerging issues related to endocrine disruptors, hormones, and antibiotics are also a concern for future considerations. It should be noted that another Pew Report will focus specifically on Public Health Issues Related to Animal Waste Management, therefore, the focus of this report will primarily be to address microbial pathogens associated with waste management systems on farms.

Microbial Pathogens Associated with Animal Waste

Microbial pathogens can infect and cause disease in a variety of susceptible hosts; their presence and associated infections may be asymptomatic or symptomatic, and they may cause severe symptoms and in some cases the death of the infected host. Diseases associated with microbial pathogens require a viable and infectious pathogen, a susceptible host, and a suitable environment (Figure 1). In the context of animal wastes, animal waste management, and public health, zoonotic pathogens that are capable of causing infections in both animals and humans are of greatest concern.

Figure 1. Interactions of Biological Agents (Pathogens), Susceptible Host, and Environment (Johnson 2001)
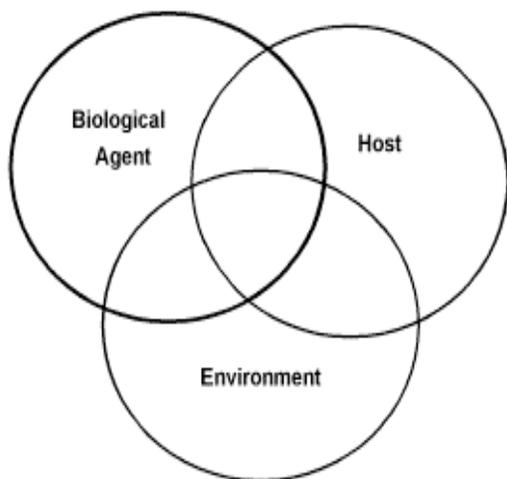
The primary sources of zoonotic disease agents are fecal matter, urine, and sloughed feathers, fur, or skin, but zoonotic pathogens are also associated with respiratory secretions and farm animal mortalities (Strauch and Ballarini 1994). Concentrations of some zoonotic pathogens in animal wastes can occur at levels of millions to billions per gram of wet-weight feces or millions per milliliter (ml) of urine. For some agricultural animals, such as cattle and swine, fecal production equals or far exceeds that of humans, and because industrial production facilities house thousands to tens of thousands of animals in confined areas, AFOs produce large quantities of concentrated fecal and other wastes that require effective management in order to minimize environmental and public health risks.

Zoonotic pathogens are associated with each of the major microbial classes—bacteria, viruses, parasites, and fungi. Many zoonotic pathogens of importance to public health are enteric agents (infecting the gastrointestinal tract of susceptible hosts) and are transmitted primarily through fecal-oral exposure. However, important zoonotic agents can be transmitted directly from fecal matter or indirectly through contaminated water, the air, soils, and other routes discussed below.

Bacteria

Bacteria (single-celled prokaryotic organisms) reproduce by simple division. They have a simple internal organization and range in size from 0.5 μm to as large as 2.0 μm in diameter. Toxins produced by bacteria can lead to rapid and severe symptoms in susceptible hosts. Zoonotic bacterial pathogens may cause symptomatic or asymptomatic infections in animals (which then become carriers), but can lead to severe clinical symptoms in infected humans. Exposed humans can also be carriers, with no clinical symptoms, depending on the responsible organism.

Bacteria are of particular importance because, given the right conditions (e.g., temperature, nutrients, and humidity), they can survive and proliferate in the environment, leading to extremely high concentrations in environmental media such as water, waste residuals, and soils. Several common zoonotic bacterial pathogens associated with animal agriculture are *Escherichia coli* O157:H7, *Salmonella*, *Campylobacter*, and *Yersinia* (Guan and Holley 2003; Smith et al. 2004; Hutchison et al. 2005a,b). In one Canadian study of three different cattle feedlots, the prevalence of *E. coli* O157 varied from 2.5 percent to 45 percent (Vidovic and Korber 2006).

In addition to the bacterial pathogens associated with animal waste management systems, the presence of airborne bacterial endotoxins has been associated with dusts from animal housing units (Chang et al., 2001; Golbabaei and Islami, 2000; Kirychuk et al., 2006; Reynolds et al., 2002). Endotoxins, present in certain bacteria, are contained within the cell walls and are released upon cell death. When inhaled, endotoxins can cause inflammatory reaction in humans, especially at high doses, which can lead to fever, flu-like symptoms, cough, headache and respiratory distress (Donham, 1990; Dosman et al., 2006; Heederik, et al., 2007; Schiffman et al., 2005).

Important zoonotic bacteria associated with industrial animal production are summarized in Table 1.

Table 1. Important Bacteria Potentially Present in Animals and Wastes (adopted from Sobsey et al. 2006)

Genus	Species	Animal Hosts	Disease in Animals	Human Infection/ Disease	Trans- mission Routes	Presence in Manure
Aeromonas	*hydrophila*	Many	Usually no	Yes, but only virulent strains	Water, wounds, food	Yes
Arcobacter	*butzleria*	Many	Yes, often	Yes	Direct contact, maybe food and water	Yes
Bacillus	*anthracis*	Goats; other animals	Yes	Yes	Air, wounds, ingestion	Yes
Brucella	*abortus*	bovine	Yes	Yes	Direct contact, food, air, water	Yes, rare
Campylo- bacter	*aejuni*	Poultry, other fowl	No	Yes	Food and water	Yes
Chlamydia	*psittaci*	Parrots, other fowl	Yes	Yes	Direct contact, air	Unlikely
Clostri- dium	*perfringens*	Many	Sometimes	Yes	Food, wounds	Yes
Clostri- dium	*botulinum*	Many	Sometimes	Yes	Food	Potentially
Escheri-	*coli*	All mammals	No	Yes,	Food and	Yes

chia				pathogenic strains	water	
Francisella	*tularensis*	Ovines, other animals, ticks, deerflies	No	Yes	Direct contact, fomites	Yes
Listeria	*monocytogenes*	Many animals	No	Yes	Food, water, fomites	
Mycobacterium	*tuberculosis*	Rare; some animals	No	Yes	Air	Yes
Mycobacterium	*para-tuberculosis*	Some animals	Yes	Yes	Air	Yes
Salmonella	Species	Many animals	No	Yes	Food, water, fomites	Yes
Yersinia	*Pestis*	Rats, squirrels, other animals	No	Yes	Flea bite, direct contact	Yes
Yersinia	*enterocolitica*	porcine, other animals	No	Yes	Direct contact, food, water	Yes

Viruses

Viruses are the smallest of the microbial pathogens[7], ranging in size from 0.02 μm to 0.3 μm in diameter. They have a simple structure, consisting of nucleic acid (either single- or double-stranded DNA or RNA) surrounded by a protein coat and in some cases a lipoprotein envelope. Viruses are obligate intracellular organisms, meaning they replicate only when infecting host cells; thus they do not replicate in the environment.

Generally, most viruses are species specific and human health implications from common animal viruses are unclear. However, there are several common zoonotic viruses that have been implicated in human disease outbreaks, which include influenza and novel emerging viruses, such as the caliciviruses and hepatitis E (Kimura et al. 1998; van Der Poel et al. 2000; Smith et al. 2002; Takahashi et al. 2003; Dauphin et al. 2004; Goens and Perdue 2004; Kobasa and Kawaoka 2005; Nakai et al. 2006; Ning et al. 2006).

Important zoonotic viruses associated with industrial animal production are summarized in Table 2.

Table 2. Important Viruses Potentially Present in Animals and Wastes (adopted from Sobsey et al. 2006)

Virus or Virus Group	Taxonomic Group	Animal Hosts	Disease in Animals	Human Infection/ Disease	Trans-mission Routes	Presence in Manure
Entero-viruses	Picorna-viridae	Bovine, porcine, avian	Yes in some	Needs further study	Fecal-oral and air	Yes
Caliciviruses	Caliciviridae	Bovine, porcine, avian	Yes in some	Needs further study	Fecal oral and air	Yes
Reoviruses	Reoviridae	Wide host range for some	Yes in some	Needs further study	Fecal-oral and air	Yes
Rotaviruses	Reoviridae	In many animals	Yes in some	Needs further	Fecal-oral and air	Yes

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[7] Discounting prions of which little is known.

				study		
Adeno-viruses	Adenoviridae	In many animals	Yes in some	Needs further study	Fecal-oral and air	Yes
Herpes-viruses	Herpesviridae	In many animals	Yes in some	Needs further study	Air	Yes
Myxoviruses	Myxoviridae	In many animals	Yes in some	Yes, some; No, others	Air	Yes
Pestiviruses	Pestiviridae	In many animals	Yes in some	No	Fecal-oral and air	Yes, some
Corona-viruses	Coronaviridae	In many animals	Yes in some	Yes	Air	Yes
Hepatitis E virus	Uncertain	Swine, rats, chickens, maybe others	Yes, but mild effects	Needs further study	Fecal-oral and air	Yes
Vesicular stomatitis virus	Rhabdovirus	Cattle, horses, swine, others	Yes	Yes, occupa-tionally	Contact with infected animals	Potentially

Parasites

Parasites are a diverse group of pathogens categorized as either single-cell organisms (protozoans) or multicell organisms (worms, or helminths). Helminths are very important for public health in the developing world, but are generally less so in the United States. Some zoonotic protozoans, however, have been responsible for notable human disease outbreaks in the United States. For example, the protozoan parasite *Cryptosporidium* caused a waterborne disease outbreak in Milwaukee in 1993, with over 400,000 cases and 160 deaths (MacKenzie et al. 1994, 1995; Addiss et al. 1996; Cicirello et al. 1997; Cordell et al. 1997). While inconclusive molecular evidence has linked this massive waterborne outbreak to the *Cryptosporidium* human genotype, there have been numerous other smaller outbreaks clearly and specifically linked with the bovine serotype thus demonstrating the zoonotic nature of this parasite (Mathieo et al., 2004; Goh et al., 2004; Xiao et al., 2004; El-Osta et al., 2003; Patel et al., 1998). Another protozoan, *Giardia*, which has a wide host range and can infect many animal species, is the leading cause of human parasitic infections in the United States (Lewis and Freedman 1992; Hoar et al. 2001; Guan and Holley 2003; Smith et al. 2004).

Important zoonotic parasites associated with industrial animal production are summarized in Table 3.

Table 3. Important Parasites Potentially Present in Animals and their Wastes (adopted from Sobsey et al. 2006)

Parasite	Taxonomic Group	Animal Hosts	Disease in Animals	Human Infection/ Disease	Trans-mission Routes	Presence in Manure
Ascaris suum	Helminth, nematode	Swine	Yes	Yes	Ingestion of water, food, soil	Yes
Balantidium coli	Protozoan,	Swine,	No	Yes	Contact,	Yes

					ingestion of water and soil	
Cryptosporidium parvum	Protozoan, coccidian	Many animals	Yes	Yes	Ingestion of water	Yes
Giardia lamblia	Protozoan, flagellate	Many animals	Yes	Yes	Ingestion of water	Yes
Toxoplasma gondii	Protozoan, coccidian	Felines	Yes	Yes	Ingestion of feces, food, water	Yes, if an infected host

Note: "ciliate | other animals" appears as the top partial row.

Fungi

Fungi (mycotic agents) are eukaryotic organisms that acquire nutrients from their environment through external digestion and adsorption. Although fungal infections or mycoses from exposure to animal waste are generally underreported and therefore usually not considered a major public health concern, disease-causing mycotic agents in livestock fecal matter can be transmitted to humans through airborne contamination from industrial animal facilities (Gibbs et al. 2004; Jo and Kang 2005; Fulleringer et al. 2006). Most people do not show clinical symptoms from mycotic infections but susceptible populations, such as those with compromised immune systems, the young, and the elderly, are at greater risk from exposure.

One study documented concentrations of culturable airborne fungi at approximately 1,000 colony-forming units (CFU) per cubic meter of air in an open-air swine house (Chang et al. 2001). Another study measured fungal concentrations at six semienclosed swine and poultry facilities and found *Aspergillus*, *Cladosporium*, and *Penicillium* as the most prevalent genera in air samples from the farms. This is of particular importance because many of these outdoor, open-air measured concentrations exceeded bioaerosol guidelines established to protect public health for indoor environments (Jo and Kang, 2005).

Although originally classified as a protozoan parasite, the microsporidia, an extremely diverse group with more than 1,200 species, are now recognized as fungi. Genetic analyses have confirmed the zoonotic potential of several microsporidial species, including *Encephalitozoon cuniculi*, *E. intestinalis*, and *E. hellem* (Mathis et al., 2005; Dengjel et al., 2001). Zoonotic infections have been associated with dairy cattle and swine (Santin et al., 2005; Sulaiman et al., 2004; Breitenmoser et al., 1999). Microsporidia remain primarily opportunistic pathogens for humans and epidemiological data is lacking to determine the extent to which this poses public health risks associated with commercial farm operations.

Environmental Transmission Routes for Microbial Pathogens

A variety of microbial pathogen transmission routes are linked with animal wastes and farm mortalities (Figure 2). Exposure to microbial pathogens can be through direct contact with contaminated manure or other animal excreta or through environmental matrices such as water, soils, foods, and air (not depicted in Figure 2). Additional considerations are wild or feral animals that serve as reservoirs (carriers) for disease agents and may spread microbial pathogens to susceptible farm animals or humans.

Figure 2. Sources and Routes of Exposure to Pathogens from Animal Agriculture (Sobsey et al. 2006)
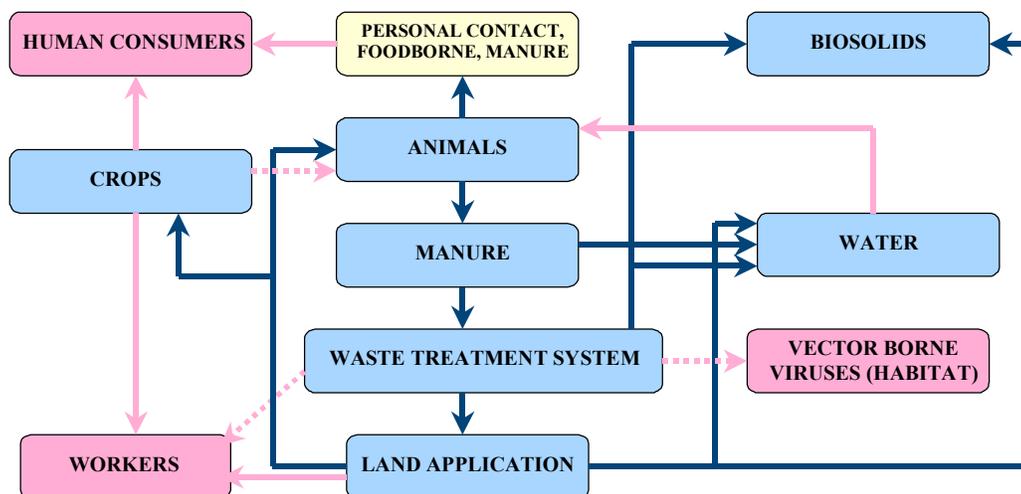
Direct Contact

The most direct route of pathogen exposure is contact with pathogens in manures, urine, respiratory secretions, or other infectious materials (e.g., bedding, saliva, blood, fur, feathers). Public health concerns generally focus on animal-to-human transmission, but human-to-animal transmission routes do exist and are extremely important for the biosecurity of animal feeding operations. Many animal facilities take precautionary measures such as the use of a disinfectant chemical on vehicles that enter the farm property, the use of booties and masks for farm workers, and in some cases a requirement to "shower in/shower out" for workers that enter the barns and have direct contact with the animals. These precautions are necessary biosecurity measures to ensure the health of the farm animals and to prevent the incidental spread of microbial pathogens from farm to farm. Because large numbers of animals are housed in confined areas, infectious disease agents can spread easily and rapidly from animal to animal, with detrimental and drastic effects on the health of all animals on a farm.

Feral animals (discussed below) and other vectors such as rodents, amphibians, and insects also play a role in the secondary (indirect) spread of disease both between animal facilities and between animals and humans.

Water

As discussed above, nonpoint source microbial contamination is a leading cause of impairment of many watersheds throughout the United States (EPA 2002), and industrial animal production facilities are one of many sources of such contamination. Animal facilities have also been implicated for microbial contamination of groundwaters that has resulted in human exposures and disease outbreaks. For example, a waterborne outbreak of *E. coli* O157:H7 and *Campylobacter jejuni* in Walkerton, Ontario, Canada in 2000 (CCDR 2000; Clark et al. 2003; Auld et al. 2004; Schuster et al. 2005) resulted from heavy rainfall that led to local flooding, which in turn caused cattle manure to enter the groundwater supply. This weather incident, in combination with local geological features (fractured limestone), resulted in cattle manure directly contaminating the groundwater supply. The outbreak caused 2,300 cases of illness, 65 hospitalizations, and 7 deaths. Retrospective epidemiological studies used DNA fingerprinting techniques to directly link the groundwater outbreak to surface runoff, and confirmed that the bacteria infecting humans were similar to those from cattle on a nearby farm.

In addition to waterborne outbreaks associated with drinking water, zoonotic microbial disease outbreaks have also been associated with recreational use of surface waters. In 1998 an

outbreak of leptospirosis occurred in Springfield, Illinois, when 876 triathlon swimmers were exposed to contaminated surface water, resulting in 98 illnesses, 3 hospitalizations, and 1 case of acute kidney failure (CDC 1998a,b; Morgan et al. 2002). The contamination was linked to pathogen-carrying horses, sheep, and cattle in the watershed; heavy rains with surface runoff had preceded the event and led to microbial contamination of the lake where the event took place.

Air

Industrial animal production facilities can have adverse effects on ambient air quality both on and near farm properties. A number of studies have measured bacteria concentrations on and downwind of animal facilities (Venter et al. 2004; Jo and Kang 2005; Paez-Rubio et al. 2005; Green et al. 2006). One study documented the following average microbial concentrations associated with animal agriculture: 9,900 to 39,000 spores per cubic meter for total fungal spores, 300 to 6,000 colony-forming units (CFU) per cubic meter for culturable fungal spores, and 300 to 3,000 CFU per cubic meter for culturable bacteria (Lee et al. 2006). These levels are extremely high when compared with upwind or control sites, where levels are often much lower or even below levels of detection (LOD) for the detection system. High levels of airborne bacteria have been documented up to 150 meters from facilities, leading to recommendations that residential neighborhoods have setback distances of 200 meters or more from industrial animal facilities (Green et al. 2006).

Airborne bacterial endotoxins are another major microbial concern associated with animal facilities. Endotoxins are naturally occurring structural components in certain bacteria that are released following bacterial cell dissolution, destruction, or death. They are generally present in dust from animal housing facilities and have been shown to have adverse health effects for exposed farm workers (Von Essen and Auvermann 2005). Medical complaints primarily involve respiratory health effects, including symptoms of pulmonary disease and reduced lung function, but headaches, eye irritation, and nausea have also been reported (Schiffman et al. 2005).

Soils

Land application, widely used among industrial animal production facilities, is advantageous for farmers as it enables the recovery of nutrients from treated waste residuals for use on crops. But although many agricultural waste management systems moderately reduce microbial concentrations in fecal wastes, high residual concentrations often remain when the waste is land applied because of the high initial concentrations in the raw manure (Guan and Holley 2003). As a result, rain events soon after land application can transport microbial contaminants to surface and groundwater (Krapac et al. 2002; Ritter et al. 2002; Kinzelman et al. 2004; Hill et al. 2005; Orosz-Coghlan et al. 2006).

For perspective, land application of municipal waste residuals (biosolids)[8] is regulated by state and federal standards for sludge quality, with loading rates based on metals, organic content, and pathogens (40 CFR Part 503). Federal regulations have established microbial quality standards for both the unrestricted[9] and restricted use[10] of municipal sludge, as well as operational criteria for treatment technologies to meet these standards. Given these

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[8] Municipal biosolids are residual material from the aerobic and anaerobic biological treatment of human sewage. Treated and stabilized biosolids can be land applied at agronomic rates on crops.

[9] Class A standards per gram dry weight: < 1,000 fecal coliforms/g, < 3 salmonellae/4g, < 1 enteric virus/4g, and < 1 helminth ovum/4g.

[10] Class B standards per gram dry weight: < 2,000,000 fecal coliforms/g.

classifications and regulations for municipal systems, limits of no more than 1,000 to 100,000 fecal coliforms/100 milliliters or 0.1 to 1 intestinal nematodes (e.g., *Ascaris*) have been proposed for the microbiological quality of land-applied agricultural wastewater (Blumenthal et al. 2000). These recommended microbial concentrations are lower than those found in standard lagoon treatment systems used by many animal waste management facilities (Hill and Sobsey 1998). Current farm operational practices allow land application of treated agricultural wastewaters with microbial levels that exceed those recommended for agricultural use as well as the levels regulated for land application of domestic or municipal biosolids.

To ensure the protection of public health, attention should be given to establishing regulations (similar to those for municipal wastes) to address levels of metals, organic content, and pathogens in treated agricultural wastewaters that are land applied.

Food
Foodborne disease outbreaks are caused by both pre- and postharvest contamination from microbial pathogens. Most consumers are aware of the potential health risks associated with animal products such as undercooked meats, eggs, milk, cheese, and other foods (CDC 1997a; Vogt and Dippold 2005; McLaughlin et al. 2006; Strachan et al. 2006; Uyttendaele et al. 2006). However, with changing dietary patterns, more people are becoming aware of foodborne risks associated with fruits and vegetables as well. These foods are of particular importance because they are often consumed raw and they have uneven surfaces that make it difficult to remove or inactivate microbial pathogens on their surface. The September 2006 *E. coli* O157:H7 outbreak linked to contaminated spinach showed that preharvest contamination from fecal matter can have severe consequences for the crop, for farmers, and for consumers (CDC 2006). Retrospective epidemiological studies of that outbreak directly linked the agent of disease to spinach crops grown in northern California and, more specifically, to infected cattle and feral swine in the area (Brackett 2006).

Microbial disease outbreaks have also been associated with dairy foods, such as milk (Tacket et al. 1985; Ryan et al. 1987; Donnelly 1990; Reed and Grivetti 2000; Agodi et al. 2006), cheese (Bone et al. 1989; Cody et al. 1999), and yogurt (Govaris et al. 2002), all of which were contaminated as a result of mishandled animal manure on industrial animal farm facilities. Additional human disease outbreaks have been associated with apples and apple cider that were fecally contaminated by cows either directly or through washing with fecally contaminated water on the originating farm (Millard et al. 1994; JAMA 1997; CCDR 1997; Blackburn et al. 2006; Garcia et al. 2006).

Wild/Feral Animal Reservoirs
As demonstrated in the case of the spinach contaminated by infected animals, wild or feral animals can serve as reservoirs (carriers) of zoonotic pathogens and aid in their spread. Feral animals associated with the spread of zoonotic microbial pathogens include swine (Gibbs 1997), pigeons (Tanaka et al. 2005), wildfowl (Lillehaug et al. 2005), and rodents (Glazebrook et al. 1977). Canada geese, although not technically a reservoir for *Cryptosporidium*, have been shown to transport the parasite in their intestines (Graczyk et al. 1998; Dieter et al. 2001; Kassa et al. 2004; Zhou et al. 2004; Chvala et al. 2006). The geese do not become infected with the organism, but become carriers when they feed on undigested corn in cow paddies. Further evidence that this may be a transmission route of public health importance is that the *Cryptosporidium* oocysts remain infectious while passing through the gut of the geese (Graczyk

et al. 1997). The ubiquitous presence of geese in both agricultural and urban settings raises questions about their role in the transmission of *Cryptosporidium* in these areas.

In addition to the potential spread of parasites by wildfowl, other wild birds (e.g., songbirds) may play a role in the spread of viruses, namely avian influenza (AI). This route of transmission was first documented 30 years ago (Webster et al. 1976; Hinshaw et al. 1978) in a cross-species transmission to poultry and swine, from which these and other domesticated animals can become infected (Webster et al. 1977; Yasuda et al. 1991). Attention has recently focused on the H5N1 strain of avian flu that has proven highly infective for humans and is a significant public health concern (Ellis et al. 2004; Alexander 2006). This particular strain of AI has so far occurred only in Europe and Asia, not in the United States, but aggressive ongoing surveillance programs are in place to monitor for US occurrences.

Microbial Survival in Environmental Matrices
In order to fully understand microbial contamination associated with the transmission routes discussed above, microbial survival and inactivation in the environment must be considered. Microbial survival (or stability) in the environment is subject to a number of environmental conditions, such as temperature, humidity, particle association, state of aggregation (clumping of microorganisms), matrix type (environmental suspension media including air, water, and soil), and other environmental matrix effects (such as concentration of organisms, ultraviolet irradiation, predation by other microbes). There are generally seasonal variations for each class of microbial pathogen, but most survive better in cooler temperatures (and the corresponding decrease in ultraviolet irradiation [UV] during the winter months also promotes higher rates of environmental survival).

Bacteria are a unique class of pathogen because they can reproduce and multiply in the environment, as opposed to viruses and parasites, which can replicate only in susceptible hosts. The non-spore-forming bacteria are generally the least environmentally stable, followed by viruses, with parasites generally being the most environmentally stable. Exceptions to this are acid-fast bacteria and bacteria that form environmentally stable spores, both of which are extremely environmentally stable. Although they are the least hardy, bacterial pathogens may be stable and remain infectious in the environment for days or weeks (Guan and Holley 2003), and some of the more stable parasites, such as *Cryptosporidium,* can remain infectious for months to more than a year (Robertson et al. 1992; Kato et al. 2004; Collick et al. 2006).

Information about survival rates for microbial pathogens in animal wastes that are land applied and in environmental soil following land application is incomplete. More research is needed in order to fully assess the public health implications of land application of animal wastes.

Assessing Environmental Impacts and Public Health Risks Associated with Animal Waste Management

The foregoing discussions of microbial disease outbreaks and transmission routes demonstrate the potential risks of environmental and public health impacts associated with animal feeding operations. While regulatory measures exist to contain these risks, it is also essential to establish the capacity to recognize and address potential or emerging risks to public health and the environment. The World Health Organization (WHO) and US Environmental Protection Agency (EPA) have suggested the use of a quantitative microbial risk assessment to determine health

risks from microbial pathogens in food and water (Figure 3), and the method can be readily adapted for use in assessing risks from animal waste management practices on animal feeding operatons. Quantitative assessments of the risks from industrial animal production facilities can support the development of risk management plans to more effectively protect public health.

Quantitative Microbial Risk Assessments for Assessing Public Health Risks

The quantitative microbial risk assessment, illustrated in Figure 3, is a logical, systematic approach for identifying and assessing human risks from exposure to microbial pathogens (Hoglund et al. 2002; Carr et al. 2004), and then determining methods to manage and minimize the risks for human disease.

Figure 3. Basic Quantitative Microbial Risk Assessment (FAO/WHO 2003)
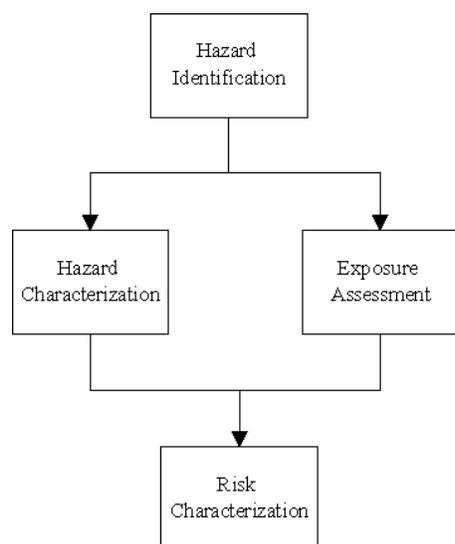
The first step for a quantitative microbial risk assessment is *hazard identification*, which entails the description of both the potential infectious agents and the hazardous practice that may lead to human exposure through a known pathogen transmission pathway. The second step has two components: *hazard characterization* involves assembling information on the dose response for the pathogens of interest as well as any available epidemiological data; *exposure assessment* involves the determination of sources, occurrence, and transmission routes for the pathogen. The final step calls for a synthesis of the information to produce a *risk characterization*, which identifies the human health risks given the particular set of conditions. This systematic approach has proven useful for assessing public health risks from drinking water and foods (Vose 1998; Ashbolt and Bruno 2003; Sobsey and Bartram 2003; Chen et al. 2006; Howard et al. 2006; Masago et al. 2006).

The quantitative microbial risk assessment described above has a simple structure while more current frameworks include a variety of measurements allowing the models to be more accurate and predictable of health risks from specific locations or practices (Eisenburg et al., 2004; Soller, 2006; Soller et al., 2003). Such specific measurements include a prediction of the concentration of microbial pathogens in the background environmental matrix, natural multiplication or decay of the microbial pathogens of interest, other sources of pathogenic organisms, distribution of the pathogens prior to and following treatment, and specifics of the exposed population (Soller,

2006). These newer frameworks also allow for dynamic modeling as some of the parameters will change temporally.

Among the specific criteria considered in a quantitative assessment for microbial risks from animal production facilities are susceptible populations, microbial reduction methods for commonly used on-farm waste management systems, and changes in environmental conditions or pathogen characteristics that may affect the interactions and result in a greater impact on public health. Such changes may be catastrophic weather events, the emergence of newly recognized zoonotic pathogens and reservoirs, and adaptations of microbial pathogens (such as increased antibiotic resistance) that may render them more virulent or environmentally resistant.

Susceptible Populations

In order to have public health consequences, microbial pathogens must come in contact with and infect susceptible hosts, whether humans or animals. Many factors influence this interaction between pathogen and host. Host variables include age, health, pregnancy status, the presence of medications or other chemicals, and the amount of pathogen to which the potential host is exposed. (Certain populations—pregnant women, and people with compromised or less developed immune systems, such as children, the elderly, organ transplant patients, and those with AIDS—are inherently at higher risk of infection by microbial pathogens.) Pathogen factors include virulence (a function of genetic variability in the microorganism), environmental stresses (e.g., adverse temperatures, desiccation, exposure to ultraviolet radiation), pH levels, the matrix in which the organism is suspended, and immunological uniqueness. The infectivity of microbial pathogens is quantified by the infectious dose (ID_{50}), which is the minimum number of organisms necessary to infect half of the healthy hosts to which the pathogen is exposed. This measure accounts for variability in the pathogen and host.

The number of exposures over a given period also influences the likelihood of microbial disease: individuals who are exposed more frequently have a higher probability of becoming infected. Thus populations at higher risk of zoonotic illness from animal feeding operations are the workers on the farm and individuals that live nearby, and indeed studies have confirmed higher rates of health effects associated with bacterial endotoxins in both these groups (Kirkhorn 2002; Von Essen and Auvermann 2005).

Microbial Reductions by Common Waste Management Systems

The types and concentrations of zoonotic microbial pathogens in animal wastes vary depending on the types of pathogens circulating in the herd. Nonetheless, some generalizations can be made about the efficacy of certain types of waste management systems in reducing microbial pathogens.

One of the more common and inexpensive options is a biological treatment that uses anaerobic, aerobic, or facultative waste ponds (holding structures that allow for degradation of microbes through natural processes) typically called lagoons. These systems generally rely on a clay lined earthen structure into which the manure is flushed to be held for a certain period (the retention time). These waste management systems can be operated under aerobic conditions (where oxygen is pumped into the waste slurry), anaerobic conditions (where no oxygen is added), or as facultative systems (where both aerobic and anaerobic conditions exist based on the design characteristics of the holding structure, such as depth, surface area, and mixing). The majority of these lagoons are anaerobic. The systems utilize aerobic and/or anaerobic microorganisms to convert organic manure constituents into inorganic nutrients such as

phosphorus and nitrogen, and carbon dioxide and methane. The systems also reduce pathogens over specified retention times based on temperature, season, and rainfall. Microbial reductions in these systems are variable and depend on the previously mentioned factors, but reductions of 90–99 percent (1 to 2 $\log_{10}$) are standard (Hill and Sobsey 1998).

Studies have demonstrated greater efficiency and higher microbial pathogen reductions with the use of multistage treatment structures, which use multiple holding/treatment structures through which the treated wastes flow over time. Many of these systems use a gravity flow to minimize the necessary power requirements and result in greater microbial removal/degradation by the system due to increased retention times and unique microbial populations in each of the holding and treatment structures. The study of one three-structure multistage system reported microbial reductions of nearly 100 percent (99–99.99 percent; 2 to 4 $\log_{10}$) depending on the pathogen type (Sandhya and Parhad 1998).

For dewatered manures, separated solids, and animal mortalities, digestion and composting are viable, albeit more expensive, management options. Digestion treatments are anaerobicsystems which are operated at one of three tempertures: ambient, mesophilic ($\sim 35^{o}$C), or thermophilic ($> 50^{o}$C) temperatures. Generally, higher temperatures result in more efficient reduction of microbial pathogens. Expected reduction of microbial pathogens by mesophilic anaerobic digestion is moderate, up to 90 percent (1 $\log_{10}$), whereas thermophilic processes can achieve greater than 99.99 percent (4 $\log_{10}$) reductions at temperatures of 55°C, given sufficient retention times (Lund et al. 1996). Anaerobic digestion produces "stabilized" solids (which are nutrient-rich and have very low pathogen levels), methane, and carbon dioxide. All nitrogen in the digester effluent will be in the ammoninical form and hence easily lost to the atmosphere through volatilization unless carefully managed.

Composting, a form of aerobic digestion, relies on proper aeration and microbial activity to effectively stabilize mortalities and waste residuals from animal production facilities. Proper composting (i.e., pH, air flow, temperature [$>55^{o}$C], retention time) can result in pathogen reductions of 99.99 percent (4 $\log_{10}$) and more (Lung et al. 2001; Gong et al. 2005; Vinneras 2006).

Incineration and gasification, which require very high temperatures, are additional effective methods for the complete reduction of microbial pathogens in waste residuals.

Catastrophic Events

The proximity of animal feeding operations to bodies of surface water raises public health concerns associated with catastrophic events such as flooding, earthquakes, tornadoes, or other severe disturbances that compromise the integrity of a waste containment system. For example, North Carolina is subject to Atlantic hurricanes, which can cause heavy downpours and flooding in low-lying areas, and in the eastern part of the state many swine and poultry facilities are sited near surface water bodies. In 1999, a series of three hurricanes led to major flooding in areas with animal feeding operations. Many of the affected farms suffered significant animal mortalities as well as flooded waste-holding structures that caused the widespread fecal contamination of watersheds from the flow of partially treated waste materials. The presence of high levels of nutrients also had detrimental effects on the watershed (e.g., algal blooms, depletion of oxygen, and fish kills). Compounding the devastation of these events, the affected area's low per capita income levels increased the severity of the public health impacts (Wing et al. 2002). In response to these floods, state legislators are devising plans to relocate some facilities from areas most susceptible to flooding (Schmidt 2000).

Emerging Zoonotic Pathogens

Emerging zoonotic disease agents associated with industrial animal production farms include hepatitis E virus (HEV), avian influenza, and coronaviruses. It has long been known that HEV affects swine and that the type that affects swine shares a similar genetic sequence with human HEV; however, recent evidence indicates that swine HEV is capable of cross-species transmission (Stoszek et al. 2006; Blacksell et al. 2007).

Avian influenza can also be considered an emerging agent because of its high mutation rate, which gives rise to different strains of the virus and thus to the threat of a large-scale outbreak of a highly virulent strain (Alexander 2006). Studies have shown that industrial animal production may lead to the amplification and increased mutation of the virus responsible for avian flu, which can spread to local human populations through exposed workers (Saenz et al. 2006).

Another emerging zoonotic pathogen associated with animal feeding operations is the coronavirus, which was responsible for the massive outbreaks of Severe Acute Respiratory Syndrome (SARS) (Wu 2003; Lau and Peiris 2005; Ooi et al. 2006). Because this is an emerging pathogen, the transmission routes and animal reservoirs are not fully understood. However, investigators have found that bats and civets are animal reservoirs for the zoonotic virus capable of causing human disease outbreaks (Hampton 2005; Wang et al. 2005, 2006; Shi and Hu 2007). Furthermore, studies have shown that the virus can quickly undergo genetic mutations (resulting in changes to its genetic structure) in the natural environment, raising concerns about the potential for SARS to infect farm animals (Jackwood 2006). Researchers have suggested the use of avian influenza as a model for deducing more information about the epidemiology and transmission routes for SARS (Bush 2004).

In addition to these viral pathogens, *Salmonella* and *Campylobacter* are two bacterial pathogens that are considered emerging or reemerging infectious agents associated with farm animal production. *Salmonella* is of particular importance as it caused the largest percentage of foodborne bacterial outbreaks in the United States from 1998 to 2002 (Lynch et al. 2006; Swaminathan et al. 2006). *Salmonella* contamination has been associated with a wide variety of foods from large-scale animal facilities, including chickens, eggs, milk, cheese, and food plants (Roberts et al. 1982; Tacket et al. 1985; Ryan et al. 1987; Donnelly 1990; Carraminana et al. 1997; Cody et al. 1999; Olsen et al. 2004; Lynch et al. 2006). *Campylobacter* has a wide host range and has been associated with industrial animal production, including cattle, swine, and poultry facilities (Hoar et al. 2001; Guan and Holley 2003; Smith et al. 2004; Hutchison et al. 2005). *Campylobacter,* like many of the other disease agents, is cosmopolitan, causing zoonotic illnesses worldwide. In New Zealand, for example, *Campylobacter* infections reached a new peak in 2006 with more than 100,000 cases and more than 800 estimated hospitalizations, resulting in an annual cost of $75 million to the New Zealand economy (Baker et al. 2006).

An emerging issue associated with antibiotic resistant organsims that should be mentioned is the increasing prevalence of zoonotic methicillin-resistant *Staphylococcus aureus*, or MRSA, associated with food animals. The occurrence of MRSA is well recognized in clinical settings for both humans and animals. First identified from mastitic cattle in 1972, there currently appears to be increasing occurrence of this organsim in raw meat from commercially produced food animals, including cattle and poultry (Devriese et al., 1972; Kwon et al., 2006; Lee, 2006). This is of particular public health importance because methicillin is a principle drug used in the treatment of human disease. One report suggests the presence of MRSA in raw meat products may constitute a health risk to some consumers (Kitai et al., 2005). However, there is little

epidemiological data to support this claim and further studies are needed to better assess whether this truly constitutes a public health risk to consumers.

Antibiotic-Resistant Bacteria

Increasing levels of antibiotic-resistant (AR) bacteria in the environment are another serious emerging public health issue associated with animal feeding operations (which is only one of a number of sources that contribute to this trend). Many industrial animal production facilities use antibiotics both therapeutically, for disease treatment and prevention, and subtherapeutically, for growth promotion (Anthony et al. 2001; Zdziarski et al. 2003; Jindal et al. 2006). But many of the ingested antibiotics are only partially metabolized and the unmetabolized portion is excreted in the manure, where naturally occurring bacteria adapt to the presence of the antibiotics by developing resistance to them.

Of further concern, the animals' steady exposure to antibiotics causes their naturally occurring gut flora to become resistant to antibiotics in the feed and, often, to multiple antibiotics (MAR), thus impairing the effectiveness of the antibiotics and enabling bacteria to flourish in the animals' system (Hayes et al. 2004; Burgos et al. 2005; Casanova et al. 2005; Chapin et al. 2005; Sullivan et al. 2005; Peak et al. 2007). In addition to to the development of antibiotic resistance in the gut flora of the animal, there can be various methods of genetic transfer in the environment that allows for perpetuation of these MAR characteristics to both pathogenic as well as other non-pathogenic bacteria. This is of particular importance in waste management systems that rely primarily on biological treatement, where another bacterial species present may serve as an environmental reservior for the genes responsible for antibiotic resistance and allow for their transfer to potnantially pathogenic species of importance in causing human infections.

Salmonella DT104 is a well-known example of an MAR bacteria. This zoonotic pathogen infects both animals and humans and is resistant to ampicillin, chloramphenicol, streptomycin, sulfonamides, and tetracycline. The increased incidence of human DT104 infection during the 1980s and 1990s corresponded to an increased incidence in cattle in the United States and in multiple livestock species in Great Britain (Hogue et al. 1998; Akkina et al. 1999; Davies and Morrow 1999). Studies in both countries found that contact with sick cattle or their meat and dairy products is the primary risk factor for human disease (Glynn and Bradley 1992; Hogue et al. 1997); the US study reported that as many as 10 percent of human cases may result from direct contact with infected animals (Hogue et al. 1997). There is also evidence that gene coding for specific resistance patterns is molecularly indistinguishable between bacteria isolated from humans and those from animals, which indicates both the zoonotic transmission of this pathogen and the exchange of resistance genes between animal and human populations (Davies and Morrow 1999; Angulo and Griffin 2000).

The factors described above result in the presence of both unmetabolized antibiotics and AR bacteria in waste management systems and then in soils and other environmental media after land application. The impacts and risks of AR bacteria are fairly well understood, but further research is needed on the environmental fate and consequences of metabolites excreted in animal wastes.

Technological Advances and Alternatives: Historical and Recent Developments

Animal waste management methods have continually evolved over the years with advances in technology and knowledge. Early improvements (i.e., a century ago) focused on replacing manual labor with mechanical devices such as self-unloading manure spreaders and tractor-mounted hydraulic loaders for solid animal manures; slurry and liquid spreaders involving mechanical pumps for loading from reception pits and containment facilities; a ceiling-mounted conveyor track and bucket-moving system for cattle and poultry barns; mechanical "barn cleaners" with a chain or cable connected to scraper paddles; and mechanical or pneumatic piston-pump transfer systems coupled with scrapers and contained storage for slurries and semisolid manure. Common to most of these devices was a return to covered storage (primarily to conserve nutrients for land application), which had been substantially abandoned earlier in favor of uncovered stacking or daily spreading. The application of these technologies was dependent on both the climate in which they were used (winter temperatures were the most significant determining factor) and the species of animals raised.

Increases in the size and density of animal production facilities and in the use of covered animal housing, especially for swine and cattle, led to the adoption of slurry or liquid-flush systems in under-pen storage pits along with slatted floors to allow waste to collect in an area removed from the animal housing space, eliminating or reducing the use of bedding material.

As environmental considerations associated with animal production increased, and especially related to CAFO/AFO operations which generate larger amounts of waste in confined areas, technology development shifted to reflect the need to contain and manage the residuals associated with animal production. The evolution of this process in the United States followed a similar trend that started in Europe (Ogink et.al, 2000). While odor emissions often received significant attention at a local level (Schiffman and Studwell, 2005), nitrogen species emissions in air and groundwater as well as phosphorus contribution to water quality deterioration represent wide-ranging impacts (Ogink et al., 2000). The goal of the recent advances in technology development has been to identify those technologies and processes that reduce the environmental impact of animal production through the development of targeted performance standards associated with air, water and soil quality protection, as well as control of emissions of potential disease vectors associated with human and animal health (www.cals.ncsu.edu/waste_mgt/).

North Carolina's Technological Innovation Program

The most scientifically comprehensive, objective, documented effort to assess alternatives to traditional waste handling systems was led by the Animal and Poultry Waste Management Center (APWMC) at North Carolina State University (NCSU). The Center managed a 6-year (2000–2006), swine-industry-funded, $17.4-million program to seek technically effective, operationally and economically feasible alternatives to the anaerobic waste treatment lagoon and spray-field land application systems that predominate swine production in North Carolina and other southeastern states.[11] The study received approximately 100 applications from technology

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[11] A complete description of the study, including all of the performance data, measurements, and economic analysis, is available at www.cals.ncsu.edu/waste_mgt/.

providers, 18 of which were selected for peer review to evaluate their ability to address criteria in the following areas:

- containment of waste without discharge to ground- or surface waters;
- significant reduction in emissions of ammonia, odors, and pathogenic organisms;
- containment and recovery of nitrogen, phosphorus, and heavy metals; and
- operational and economic feasibility.

Although many of the systems evaluated met one or more of the performance criteria, only 5 system components met all of the technical criteria (4 treating separated solids and 1 treating the liquid), and none met the economic feasibility requirements. As of this writing, none have been commercially implemented, although two are being refined in an attempt to meet the economic feasibility expectations, and it is possible that a combination of systems might effectively address many of the requirements (especially if the most critical of these were prioritized) and do so in an economically feasible way.

In addition to the NCSU initiative, the North Carolina legislature enacted a partnership between the swine industry and a major public utility to install covers on existing lagoons, collect the produced biogas, and convert it to electricity at a purchase price of up to $0.18 per kWh. A North Carolina moratorium on construction of new swine facilities and lagoons ended in September 2007. and new requirements for waste management in future construction call for alternatives to lagoon systems (existing lagoons will be allowed to continue to operate). A Lagoon Conversion Program was also established as part of the Agricultural Cost Share program, covering 90% of the costs of installing alternative waste mangement systems which meet innovative treatment standards (which are the same as those described above for the APWMC evaluation.)

Other Technological Innovations

Beyond the efforts of North Carolina's APWMC program, new or modified systems are being installed and evaluated throughout the United States. Most of these systems target odor emission control, nitrogen and phosphorus containment, and dust (particulate) control as primary considerations along with economic and operational feasibility. Particulate emissions from animal production facilities represent an increasing concern for the respiratory health of both the animals and the people who work or live around them, and several emerging technologies seek to address the problem, especially particulate emissions of very small size and those in arid areas. Many proposed systems also incorporate methods for the recovery of energy and other valuable byproducts.

Two abiding concerns in the management and application of animal wastes are the separation of liquid from solids and the stabilization of nitrogen, and many proposed innovations include methods to address these. Proposals and recent developments in these areas are briefly described here, along with performance observations.

Separation of Liquid from Solids
Cost-effective and efficient technology for the separation of liquid and solid waste has long been a high-need area. Separation is most critical in low-solids liquid systems, but application to slurries is also a consideration. The goal is to concentrate nutrients in the solid component of the waste for ease and economy of transport, further processing, and especially the containment of organic matter and phosphorus. Additional aims include the separation of inert bedding such as

sand from slurries before further processing or for recycling. Recent developments in centrifuge applications show significant promise, and innovations in sand separation appear to make it possible to overcome earlier limitations. The use of chemical flocculants has improved separation efficiency but at increased cost. Even with newer solid-liquid separation methods, nitrogen remains substantially in the liquid fraction. The APWMC program demonstrated the effective use of moving belt systems for the separation of urine and feces from swine production systems that use slatted floors.[12] Commercial installations of belt systems are also used in Europe (Ogink et al. 2000). After numerous efforts to evaluate new technology, gravity settling using temporary containment areas still appears to be the most economically viable of the methods available for flushed liquid swine waste. EPA has posted assessments of several types of liquid-solid separators.[13]

Stabilization of Nitrogen

Stabilization of nitrogen in nonvolatile forms such as nitrate is a primary goal of any waste treatment technology.[14] Ammonia, the primary form of nitrogen in livestock waste, is volatile and as such contributes to air quality concerns. Depending on the waste handling method, post-treatment nitrogen is typically more than 60 percent ammonia, with negligible amounts of nitrate. But when urine and feces are held in combination for as long as 24 hours, the fraction of ammonia may exceed 85 percent of the total nitrogen in the sample. An example of the effective conversion of ammonia to oxidized and more stable forms is found in one of the technologies evaluated in the APWMC program.[15]

Energy Capture from Animal Waste

The recovery of energy from animal waste, primarily by anaerobic digestion, has been practiced for hundreds of years. Recent technological advances have led to several novel commercial designs for anaerobic digestion that are now available to producers, unlike the situation a decade ago when each system was basically built from on-site components. EPA recently released a protocol for evaluating the efficiency of anaerobic digestion systems for animal waste (www.epa.gov/agstar/resources/protocol.html), a resource that will likely provide significant assistance in the evaluation and comparison of those systems.

Most anaerobic systems are designed to convert recovered biogas to electricity through an engine-generator or microturbine system.[16] Heat recovered from either the direct combustion of the biogas or the generation of electricity is used to heat the digester and/or hot water. In US commercial animal production systems, the primary application has been in the dairy industry, with more than 150 on-farm anaerobic digestion systems in use or under construction. The need

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[12] Examples of two such systems are available at the APWMC website: http://www.cals.ncsu.edu/ waste_mgt/ smithfield_projects/phase1report04/A.5Belt%20cb.pdf and http://www.cals.ncsu.edu/waste_mgt/ smithfield_projects/phase1 report04/A.4Belt%20tvk.pdf.

[13] See the EPA Environmental Technology Verification Reports at http://www.epa.gov/etv/verifications/vcenter9-4.html.

[14] For more on this topic, see the report on *Development of Environmentally Superior Technologies*, available at http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase1report04/front.pdf.

[15] A description of this technology is available at http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/phase1report04/A.9Super%20Soil%20final.pdf.

[16] All energy-generating technologies require the use of additional methods for the management of residuals such as minerals from anaerobic digestion.

for hot water in dairy operations makes that application an added asset of the energy conversion process. In one well-known and successful case in Minnesota, the recovered heat is also used to prevent manure from freezing on the dairy barn floor. A smaller number of systems are in use for swine or poultry waste, albeit with less success than those on dairy facilities because of less favorable wastestream composition (especially ammonia-N level compared to energy sources) and a lower demand for the resulting heat (a byproduct of the conversion of biogas from anaerobic digestion to electricity) in the production facilities.

Most animal production facilities that generate electricity from the processing of animal waste use it for their own purposes, for several reasons. Those that seek to market electricity to the local power grid encounter challenges such as the very low purchase price that utilities are allowed to offer, the costly process needed to connect to the power grid, high standby fees for small power producers that may need power if their system fails, and a variety of other, noncooperative pressures applied by utilities. In some states, such as New York, net metering laws have substantially improved the climate for small producers and this trend is expanding to other states as the move toward renewable energy sources increases in momentum.[17] In areas where utility purchase price is unfavorable, some producers use their own power at peak times.

Numerous animal production facilities practice direct combustion of animal waste, with poultry litter most often used because of its lower moisture content. Emissions from such incinerators continue to be a concern. An increasingly popular process similar to incineration is gasification, in which the solid is converted to a synthetic gas ("syngas"), scrubbed to remove undesirable pollutants, and burned to produce electricity (often involving steam production for turbine operation). Syngas can also be converted to liquid fuels and may represent a superior use relative to electric generation. A related emerging option is the "co-firing" of animal waste with pulverized coal in slurry form using high-efficiency gasification equipment and existing power plant locations.

There is increasing interest in the recovery of carbon credit income as a value-added product from renewable energy production. This is not yet adequately developed in the United States because of the failure to sign the Kyoto agreements, but a climate credit exchange in Chicago (www.chicagoclimatex.com), as well as others, should assist in that process. The current and significant effort throughout the United States to develop sources of renewable energy, especially from agricultural and forestry sources, should help identify new processes and technologies for this use of animal waste.[18]

Animal Waste Treatment Facilities

Relatively few facilities exist specifically for animal waste treatment beyond those for on-farm management, largely because of the cost of transportation of animal waste to a consolidated treatment facility relative to the value of the material. The cost-value ratio is especially critical in the case of swine waste, which is diluted with water for flushing and often ends up with a solids content of less than 1 percent. However, there are some notable exceptions.

A centralized processing facility in the DelMarVa area of concentrated poultry production transforms poultry litter into pellets that can be transported efficiently by rail to other locations

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[17] For a discussion of the issues, see "Net energy metering for residential solar or farm waste electric generating systems" on the New York Public Service Law website, at www.dsireusa.org/documents/Incentives/NY05R.htm.
[18] The nonprofit group 25x25: America's Energy Future (www.25x25.org) is an example of a broad-based coalition active in promoting sustainable energy from renewable sources such as agriculture and forestry.

for use as fertilizer. That facility has been in operation for more than 5 years and is reducing the local retention of nutrients, notably nitrogen and phosphorus. This is an important development as long-term land application in the area has resulted in excessive accumulations of those nutrients (especially phosphorus) in the soil.

In Utah, 28 swine production facilities with a combined total of over 200,000 animals are connected to a central processing facility that receives pumped, low-solids waste material. The solids are gravitationally concentrated and anaerobically digested to produce biogas (methane and carbon dioxide) that is subsequently converted to methanol for use in the production of biodiesel fuel. This facility (www.bestbiofuels.com) is in the early stages of operation, having faced several technical difficulties, and the feasibility and economic sustainability of the process as designed are as yet unproven.

In Missouri, as part of a state initiative, swine waste is pumped to a central facility (www.crystalpeakenvironmental.com) that separates solids and liquids. The liquid is then concentrated by freezing (during freezing weather only) and combined with the solids to form a high-analysis (N-P-K) organic fertilizer for marketing.

In Vermont, a dairy farm with an anaerobic digestion system has developed a central processing facility that produces compost from the solids exiting the digester along with animal waste from surrounding dairy and poultry facilities (www.moodoo.com). This enterprise successfully markets its products throughout the northeast. Other facilities produce compost either entirely from animal waste or using animal waste as an important ingredient in the process.

The Future

This report has documented the enduring and worldwide increase in demand for foods of animal origin, an increase that is directly linked both to population growth and to the demonstrated connection between rising standards of living and higher consumer demand for animal food products. The likelihood that the average percentage of global protein supply from animal sources will approach or exceed 50–60 percent in this century is further indication of the importance of the animal production sector.

Current Factors and Concerns

Competing factors and trends affect the animal production industry and will define its future. First, agricultural production costs are rising even as consumers allocate less and less of their income to the purchase of food products. As the demand for animal protein continues to rise, the need for large-scale animal production facilities will continue to grow as well. These larger facilities require more and increasingly expensive technologies and inputs (such as energy and fertilizers), all of which contribute to higher production costs. Yet the percentage of global disposable income used to purchase food has steadily decreased; in the United States it has fallen from about 18 percent in 1955 to less than 10 percent today {Farm Foundation, 2006 #314}. There is no indication that consumers will reverse this trend on a scale that would enable small food producers to maintain economic viability, which depends on the ability to cover the higher cost per unit of production with higher retail prices. While there are some niche markets that can command a higher price, they are a relatively small fraction of the total. And the issues

associated with food safety and inspection that continue to emerge will make compliance by small producers more difficult economically.

Second, even as both demand and production increase, the percentage of the population that is directly engaged in food production is declining. In developed countries such as the United States, the percentage hovers at only 1–2 percent. In order for fewer producers to meet the growing demand, production units must expand in both physical and organizational size. Larger production facilities are in turn associated with more serious environmental challenges, based on the concentration of waste nutrients and their utilization and on public health impacts that may result from large-scale contamination of products from large processing facilities (which may not always be associated only with large production systems).

In a book titled *Livestock's Long Shadow: Environmental Issues and Options* (Steinfeld et al. 2006) the authors summed up the current state and future outlook for animal production in the United States:

> "[T]here is a need to accept that the intensification and perhaps industrialization of livestock production is the inevitable long-term outcome of the structural change process that is ongoing for most of the sector. The key to making this process environmentally acceptable is facilitating the right location to enable waste recycling on cropland, and applying the right technology, especially in feeding and waste management…." (p. 283)

This statement captures the complex intersection of needs, changes, and concerns associated with the trend toward large-scale animal production facilities.

One means of allaying concerns about environmental impacts of industrial animal production will be an increase in the contributions by agriculture of all types to the global supply of renewable energy. The need for greater efficiencies and new methods of energy capture will also require innovations to create both new technologies and new applications of existing technologies. These technological developments will both improve agricultural methods and reduce environmental impacts.

Future Trends and Developments

Based on these and other recent and anticipated trends in the management of animal production facilities, specific developments likely to characterize US animal agriculture in the future might be predicted. These, of course, assume no major change in current trajectories of dietary preferences and ability to economically transport animal feed and finished products.

- Water availability issues will drive the use of safe water recycling in all sectors, and animal production will reduce the net use of water on a productivity unit basis.
- Technologies developed and refined in the animal sector will be adapted for applications in other sectors for the benefit of all of society, as has already been the case with many biological discoveries. Examples include: mechanisms of nutrient absorption, artificial insemination, in vitro fertilization, much of the progress in cardiovascular surgery, ultrasound application to human medicine and health, quantification of inheritance and quantitative trait loci, and many others.
- A nationally coordinated system, with comprehensive and equitable criteria for measuring performance, will be established to evaluate technologies for managing animal waste and other animal production residuals.
- Animal feed will increasingly depend on the use of human-inedible byproducts (e.g., distillers grains, wheat middlings, wheat bran, reprocessed animal fat), as it has for

centuries, and modifications in genetics of feedstuffs as well as post-harvest treatment will improve efficiency of utilization of nutrients, such as has been accomplished with phosphorus in swine and nitrogen in ruminant animals.. CURRENTLY MUCH OF THE CORN AND SY HARVEST GOES TO LIVEESTOCK PRODUCTION – THIS STATEMENT SEEMS TO SUGGEST OTHERWISE.

- Animal production will be based on optimal productivity standards that include environmental considerations, which will dictate dietary formulations that minimize the excretion of nutrients consumed in excess of requirements.
- Environmental regulatory requirements and food production needs will result in animal production remaining concentrated in large, socially acceptable systems that both meet animal needs and can afford the cost of compliance, especially for air and water quality.
- Waste management will become a service industry, like recycling, operated on a for-profit basis by third-party vendors, based on value-added products.
- Waste treatment will include on-farm preprocessing of waste products that are then transported to a central processing facility, strategically located based on transportation cost and volume requirements.
- Municipal waste materials will be commingled with animal waste in appropriate processing technologies for efficiency in the production of value-added products and community assistance.
- Animal waste will contribute substantially to the supply of renewable energy in the United States and to the reduced use of mineral fertilizers, using both existing and yet-to-be-discovered technologies.

The actual development of these predictions for the future will depend on a great many factors working together. What is visualized here is not a radical approach to animal production but rather the systematic, incremental adoption of developments that are both economically and environmentally sustainable, with the decision on which options to be adopted first based on individual production unit priorities and needs.

An analogy can be drawn between these suggestions and the evolution of today's more environmentally friendly automobile. Slightly over half a century ago automobiles in the United States were fueled by gasoline to which lead was added to improve ignition and performance. When it was later found that the lead emitted by those automobiles was a serious environmental pollutant, the car was not simply "parked and forgotten": there was an effort to develop fuels and engines that did not require lead to enhance their performance. Further concerns about emissions resulted in the development and adoption of the catalytic converter. And most recently, the products substituted for lead in automobile fuel are being replaced by the more environmentally friendly ethanol. Each of these incremental steps has brought continuous improvement while maintaining the role of the automobile in society.

Recommendations for Sustainable Animal Production

Based on the environmental and economic concerns and trends described in this report, the committee offers the following recommendations to support and promote sustainable animal production in the United States:

- Encourage the use of animal waste treatment systems that can process wastewater to meet industrial discharge standards and permit the discharge of this treated water according to the same oversight regulations as industrial wastewater.   THIS IS AN INCREDIBLE BAD IDEA – SEE MY COMMENTS WITHIN THE TEXT.
- Set higher standards for waste treatment such that ammonia, odor and pathogen losses from the farm are minimized and phosphorus and heavy metal build up in the soil is reduced.
- Encourage utilities and state utility commissions/legislatures to develop net metering programs of sufficient production quantity to encourage the recovery of energy from animal waste using treatment systems that reduce nitrogen, odor and pathogen pollutant losses from the farm.
- Promote recycling of wastewater treated to varying levels appropriate for intended reuse within production systems.
- Require nutrient management plans for all AFOs, consistent with priority nutrients of concern in the area (e.g., based on soil type, crop need, climate) and in downstream ecosystems.
- Form a nationally coordinated animal waste technology verification program similar in concept to that developed by EPA (Environmental Technology Verification).
- Study better ways to reduce pathogen dispersal from animals during transport especially to processing facilities. Improve and standardize the guidelines for biosecurity during interstate and intrastate transport. In many areas there are no industry standards for the cleaning of trucks that transport animals. (This should also be addressed in a national coordinated effort, such as that initiated by the APWMC and addressed in other recommendations.)
- Design a standard operating procedure for the measurement of microbial loads in liquid and dry manure to facilitate the evaluation of manure handling systems. A set of performance metrics for assessing all systems is important to ensure that producers get the right systems. Very little work is currently being done on airborne microbial pathogens, and most of the focus is on PM 10 and PM 2.5. (Again, national coordination and standards are needed that will be applicable to a wide range of facilities in geographically diverse locations with variable climate conditions.)
- As with land application of municipal wastes (liquid or sludge), establish minimum guidelines for microbial, chemical, and heavy metal loads (concentration × quantity) in agricultural wastes that can be land applied. This would be a regulatory responsibility that would require established protocols for measuring each of the constituents or designated surrogates.
- Encourage the use of biofilters to prevent pathogen dispersal beyond farm boundaries. Where there is land application of treated agricultural waste residuals, encourage the use of riparian buffers to minimize environmental watershed contamination. Utilize dehydration systems and broadleaf evergreen filters for air filtration. It may be useful to have setback requirements for new systems from surface waters; for example, in coastal areas, prohibit the construction of new systems in a 100-year flood plain.
- Increase the use and study of feed practices that reduce the pathogen load of manure.
- Support studies of human exposures at AFO property boundaries and for neighbors, because insufficient information is currently available about the human health impacts from AFOs,. See attached literature survey

- Conduct risk assessments of animal waste management technologies as well as the production facilities, especially with regard to pathogens and other agents with impacts on human health.
- Animal production barns are a source of airborne and liquid/solid microbial contaminants. These have not received the attention that is warranted. For example, promote control strategies, such as air scrubbers, to reduce airborne contaminants (chemical and microbial) and improve the health both of the farm animals and of the humans that work on or live near the farms. (One of the "lessons learned" from the APWMC evaluation in North Carolina was that barns were overlooked in efforts to address "new, alternate, environmentally superior" systems.)
- Develop federal and local guidelines for the disposal of mortalities, whether they result from natural causes (e.g., normal losses, catastrophic events) or from intentional contamination (e.g., a bioterrorist event). Such guidelines should address different-sized farms and different types of animal operations, and local plans should also take into account geography, climate, and other considerations specific to the area.
- Eliminate use of antibiotics in the livestock production from families of antibiotics important to human medicine except in the treatment of individual animals with diseases, as was done in Europe.
- Improve animal husbandry practices, such as was done in Europe, ot provide more room for sows.

Abbreviations

AFO	animal feeding operation
APHIS	USDA Animal and Plant Health Inspection Service
APWMC	Animal and Poultry Waste Management Center at North Carolina State University
AR	antibiotic-resistant
AU	animal unit
BOD	biological oxygen demand
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CFU	colony-forming unit
CNMP	comprehensive nutrient management plans
COD	chemical oxygen demand
CZARA	Coastal Zone Act Reauthorization Amendments
CWA	Clean Water Act
EPCRA	Emergency Planning and Community Right-to-Know Act
HEV	hepatitis E virus
LOD	levels of detection
MAR	resistant to multiple antibiotics
NMP	nutrient management plan
NPS	nonpoint source
NRCS	USDA Natural Resources Conservation Service
PM	
SARS	Severe Acute Respiratory Syndrome
TMDLs	total maximum daily loads

Glossary

1. Metabolic activity: Metabolism is comprised by diverse biological activities which either create macromolecules (anabolism) or break down macromolecules (catabolism). Catabolism usually involves the production of energy, often with the production of carbon dioxide or the consumption of oxygen but also with the transfer of electrons. Methods exist to either measure production of carbon dioxide or consumption of oxygen[19], or to measure the transfer rate of electrons[20]. These methods are effectively measuring the **metabolic activity** of the organisms being evaluated.

2. Maintenance (diet): The minimum caloric and nutrient requirements for livestock to maintain weight and health[21].

3. Efficiency: Livestock characteristics which determine the amount of calories consumed that are converted into bodyweight by the animal[22].

4. Integrator: In general, an integrator provides animals and feed to a grower, who contractually matures the animals in their grower-owned facility[23]. Traditionally, growers have been responsible for waste management but this relationship may be changing, resting more the liability and risk on the integrator[24].

5. Volatilized: Compounds which have become airborne and escaped from animal waste; of particular concern are nitrogenous compounds such as ammonia[25].

6. Conservative elements: Compounds found in animal waste which do not become volatilized and thus to do not decrease in total amount over time. These compounds, such as zinc and copper, can be used in mass-balance calculations to assess changes over time in the concentration of other compounds such as ammonia and carbon dioxide[26].

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7. Tie stall barn: A barn design used for cows which involves placing each cow in an individual stall, and tying them such that their head is at the back wall. The stall is designed such that a cow will urinate and defecate into a gutter at the opening of the stall. Changes in the size of the stall and the tying apparatus can cause the animal to urinate or defecate into the bedding, increasing "dirtiness" and possible disease transmission[27].

8. Rendering: A process that converts waste animal tissue into a usable product; most commonly a fat product (lard, suet, grease), and a protein product (supplement for animal feeds). Raw materials for the rendering process include carcasses, feathers, bones, and blood[28].

9. Gasification: The conversion of a carbon-rich material (such as animal manure) into carbon monoxide and hydrogen by controlled heating in the presence of carefully limited oxygen. The product is an ash material which must be disposed of, and a gas (syngas) which can be combusted for the generation of electricity[29].

10. Microbial contamination: Both animal manure and human biosolids may be contaminated with small pathogens (bacteria, parasites, viruses) and this contamination may persist following inadequate composting or treatment of the waste material. If the manure or biosolids are then subjected to land application there may be a significant risk to public health[30].

11. Nutrient load: The nutrient load is a measure of the concentration and total amount of the nutrients in a material. Nutrients present in animal feed that are not completely utilized by the animal are excreted in the waste and form the "nutrient load" of the manure. These nutrients primarily include nitrogen and phosphorus but can also include metals such as zinc and copper. The nutrient load in the manure can be reduced through composting and treatment of waste and manipulation of livestock diet, but cannot generally be eliminated[31]. Nitrogen and phosphorus, when they enter the surface water, can lead to algae blooms and oxygen depletion while metals can be toxic to plants and animals.

12. Pathogens: Organisms that are capable of eliciting disease, including bacteria, viruses, parasites, fungi, etc. Over 100 human pathogens have been identified in animal manure

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but some of the most important include *Salmonella, Campylobacter, E. coli, Listeria, Cryptosporidium*, and influenza viruses[32].

13. Zoonotic: A pathogen which normally infects animals, perhaps commensally, but which is capable of infecting and causing illness in humans. Several have been identified in animal manure, including *E. coli*, *Salmonella*, *Listeria*, *Campylobacter*, and *Cryptosporidium*[33].

14. Asymptomatic: A state in which an individual does not have symptoms of disease. This may be because they are not infected with a pathogen, because they are infected but are not exhibiting symptoms, because they are infected but have recovered from the symptomatic phase, or because the infection does not produce symptoms[34].

15. Lipoprotein envelope: Some types of viruses have an envelope as their outer layer, surrounding a protein capsid and genetic material. The envelope contains **proteins** coded for by viral genetics and **lipids** gained from the host cell, and is therefore a "lipoprotein" envelope. By utilizing some of the host material in their own physical form, enveloped viruses adopt some of the characteristics of the host within which they replicate[35].

16. Eukaryotic organisms: Eukaryotes possess sub-cellular components, particularly a nucleus. This is in contrast to prokaryotes, which do not have sub-cellular components. All prokaryotes are unicellular, while eukaryotes can be unicellular or multicellular[36].

17. Mycotic agents: Mycotic agents cause fungal infections and include *Sporothrix schenckii, Histoplasma capsulatum, Blastomyces dermatitidis, Paracoccidioides brasiliensis, Coccidioides immitis*, and *Penicillium marneffei*. Most fungal infections in humans are dermatological. In immunocomprimised individuals or in cases where the body barriers have been broken (as in injury or surgery), fungi can cause more systemic disease – mycosis. Among the fungi which can enter the body without extenuating circumstances, primary colonization of the respiratory system due to aerosolized fungi is most common[37].

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18. Bio aerosol: A collection of aerosolized biological particles. Concentrations inside confined spaces, such as poultry houses or processing facilities, may be very high and a significant source of exposure for individuals[38].

19. Epidemiological study: An investigation of cases and patterns of disease to determine causes and risk factors for individuals[39].

20. Fecal coliform count: A count of the number of indicator organisms typically found in feces, such as *E. coli*, in a substance. The count is only accurate for those indicator organisms, however, and is not always indicative of the total pathogen load[40]. Often used to assess the safety of foods and fertilizers.

21. Nematodes: The most common animal on the planet, nematodes are commonly known as roundworms. Some nematodes can act as carriers of other pathogens, ingesting them in one location and depositing them in other locations[41]. Other nematodes are human parasites, usually infecting humans who have consumed their eggs. These include *Ascaris*[42] and *Trichnella*[43].

22. Inactive microbial pathogens: Pathogens that cannot cause disease[44]. The process which leads to the inactive pathogen can potentially be reversible. Irreversible inactivation of all pathogens is called "decontamination"[45].

23. Oocyst: A resilient cellular form in the life-cycle of certain organisms which allows survival in extreme conditions such as high or low temperature or desiccation. *Cryptosporidium* is one of the organisms that forms an oocyst; in this case the oocyst is the infectious stage, maturing in the gut of the host[46].

24. Environmental matrices: The various substances in which something can be found; principally soil and water.

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25. Aerobic organisms: Organisms which can survive in the presence of oxygen. Facultative aerobic organisms can survive with or without oxygen while obligate aerobic organisms must have oxygen to survive[47].

26. Anaerobic organisms: Organisms which cannot survive in the presence of oxygen[47].

27. Mesophilic: Moderate temperature. Can refer to bacteria (as in the optimal growing temperature), composting phases (a moderate-temperature phase), etc[48].

28. Homology: Similarity between different organisms in the structure and/or sequence of organs, proteins, and genetic material. When coupled with genetic (sequence) homology it is strong evidence of shared ancestry[49].

29. Metabolized: A compound which has been subjected to the suite of biological and cellular activities to which it CAN be subjected, it is said to have been metabolized[50].

30. Chemical flocculants: Chemical compounds which cause suspended solids to group together and fall out of solution for removal by filtration. In cow manure this can result in a decrease in methane production[51].

31. Substrate: The raw material which is added to a digester for the production of biogas and energy. The choice of substrate should be matched to the ideal bacterial organism for the digestion process[52].

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