Emissions From Animal Feeding Operations

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Table of Contents

Table of Contents (Cont.)

Table of Contents (Cont.)

Table of Contents (Cont.)

Table of Contents (Cont.)

List of Tables

List of Tables (Continued)

List of Tables (Continued)

Executive Summary

In 1997, the U.S. Department of Agriculture reported 450,000 animal feeding operations in beef, dairy, swine, and poultry sectors. While most of these operations are small, the majority of meat and dairy production occurs at large animal feeding operations. Over the past two decades, market forces and technological changes have promoted closure of many small operations and a significant expansion of large, confined operations. Individual operations can confine as many as 10's or 100's of thousands of animals each year. Currently, the trend in most animal sectors is for continued consolidation of production at even larger operations. These large operations must store large amounts of manure because the amount of manure generated exceeds the agronomic demands of local crop land. The microbial breakdown of the organic carbon and nitrogen compounds in manure can result in odors and other emissions to the air.

This report presents the results of a preliminary investigation into air pollution from large animal feeding operations (AFOs) for the beef, dairy, swine, and poultry (broilers, layers, and turkeys) animal sectors. An AFO defined by the U.S. Environmental Protection Agency is a lot or facility where: 1) livestock or poultry have been, are, or will be confined and fed for a total of 45 days or more in any 12-month period, and 2) crops, vegetative forage cover, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility (40 CFR 122.23). The stipulation of the absence of vegetative cover intentionally excludes operations where animals are maintained on pasture or rangeland.

Substances Emitted

Animal feeding operations can emit ammonia (NH_3), nitrous oxide (N_2O), hydrogen sulfide (H_2S), carbon dioxide, methane (CH_4), total reduced sulfur (TRS) compounds, volatile organic compounds (VOC), hazardous air pollutants (HAP), and particulate matter (including PM 10 and PM 2.5). The substances emitted and the quantity of emissions can vary substantially depending on the design and operation of each facility. Factors that influence emissions include feeding regiment, the type of confinement facility, type of manure management system (storage, handling, and stabilization), and the method of land application. The substances emitted will vary depending on whether the microbial breakdown of manure occurs in an aerobic or anaerobic (i.e., absence of free oxygen) environment.

These emissions have a variety of effects. The compounds primarily responsible for the odors associated with AFOs are VOC, hydrogen sulfide, and other reduced sulfur compounds. VOC also contributes to the formation of atmospheric ozone, which is a respiratory irritant. Some VOC are designated in the Clean Air Act as hazardous air pollutants. Ammonia also is a source of odor from AFOs but to a lesser degree because ammonia rapidly disperses in the air. Once released to the atmosphere, ammonia is readily deposited back to the earth in one of two forms. Ammonia rapidly adheres to particles in the air due to its cohesive properties. Ammonia also can be converted to ammonium sulfate or ammonium nitrate, which contribute to fine particulate concentrations (PM 2.5). When deposited back to the earth, these aerosols contribute to nutrient over-enrichment in aquatic systems and acidification of the environment. Carbon dioxide, methane, and nitrous oxide are odorless and nontoxic, but are considered to be greenhouse gases.

Study Methodology

The fundamental goal of this study was to develop a method for estimating emissions at the individual farm level that reflects the different animal production methods that are commonly used at commercial scale operations. The approach to this study was to: (1) identify the manure management systems typically used by large animal feeding operations for each animal sector, (2) develop model farms based on individual elements of the those systems (i.e. confinement, manure collection system, storage sites, land application), (3) search the literature for emission factors that could be associated with each element of the model farm, and (4) apply the emission factors to the model farms to estimate annual mass emissions. The report also summarizes information on emission control techniques that was found in the literature.

A set of 23 model farms was developed (Table 1). Each model farm included three variable elements: a confinement area, manure management system (which may include solids separation, manure storage, and stabilization), and a land application method. The models do not

Table 1.

Summary of Model Farms

Animal	Model Farm ID	Elements of Model Farms			
		Confinement and Manure Collection System	**Solids Separation Activities**	**Manure Storage and/or Stabilization**	**Land Application**
Beef	B1A	Drylot (scraped)	Solids separation for run-off (using a settling basin)	Storage pond (wet manure) and stockpile (dry manure)	Liquid manure application; and solid manure application
	B1B		No solids separation		
Veal	V1	Enclosed house (flush)	None	Anaerobic lagoon	Liquid manure application
	V2	Enclosed house w/pit storage	None	None	Liquid manure application
Dairy	D1A	Freestall barn (flush); milking center (flush); drylot (scraped)	Solids separation	Anaerobic lagoon (wet manure) and stockpile (dry manure)	Liquid manure application; and solid manure application
	D1B		No solids separation		
	D2A	Freestall barn (scrape); milking center (flush); drylot (scraped)	Solids separation	Anaerobic lagoon (wet manure) and stockpile (dry manure)	Liquid manure application; and solid manure application
	D2B		No solids separation		
	D3A	Milking center (flush); drylot (scraped)	Solids separation	Storage pond (wet manure) and stockpile (dry manure)	Liquid manure application; and solid manure application
	D3B		No solids separation		
	D4A	Drylot feed alley (flush); milking center (flush); drylot (scraped)	Solids separation	Anaerobic lagoon (wet manure) and stockpile (dry manure)	Liquid manure application; and solid manure application
	D4B		No solids separation		
Swine	S1	Enclosed house (flush)	None	Anaerobic lagoon	Liquid manure application
	S2	Enclosed house (pit recharge)	None	Anaerobic lagoon	Liquid manure application
	S3A	Enclosed house (pull plug pit)	None	Anaerobic lagoon	Liquid manure application
	S3B			External storage tank or pond	Liquid manure application
	S4	Enclosed house (w/pit storage)	None	None	Liquid manure application
Poultry-broilers	C1A	Broiler house w/bedding	None	Covered storage of cake; and open litter storage	Solid manure application

Table 1.

Summary of Model Farms (Continued)

Animal	Model Farm ID	Elements of Model Farms			
		Confinement and Manure Collection System	Solids Separation Activities	Manure Storage and/or Stabilization	Land Application
Poultry-broilers (Continued)	C1B	Broiler house w/bedding	None	Covered storage of cake	Solid manure application
Poultry-layers	C2	Caged layer high rise house	None	None	Solid manure application
	C3	Cage layer house (flush)	None	Anaerobic lagoon	Liquid manure application
Poultry-turkeys	T1A	Turkey house w/bedding	None	Covered storage of cake; and open litter storage	Solid manure application
	T1B			Covered storage of cake	

precisely describe every AFO in the U.S. due to the variety of designs that are characteristic of this industry. However, the models are intended to represent the great majority of commercial scale AFOs (500 animal unit capacity or larger) for purposes of representing the principal factors that influence emissions and the feasibility of emissions control.

The literature search returned nearly 500 potential emission data sources. While a large number of studies exist, there were a limited number that contained data on which emission factors could be developed. Where emission factors were not found, attempts were made to estimate emissions based on the responsible microbial and chemical mechanisms.

Results

Emissions were estimated for ammonia, nitrous oxide, methane, hydrogen sulfide, PM, and VOC. All PM emission estimates are for total suspended particulates except for beef feedlots, which are PM 10. Information was not available to estimate emissions of total or speciated HAP, total reduced sulfur compounds (other than hydrogen sulfide), PM 10 (other than for beef cattle), and PM 2.5. Emissions were not estimated for carbon dioxide. Carbon dioxide emissions from manure are releases of carbon that were sequestered via photosynthesis in the past one to three years. The carbon emitted is part of a cycling of carbon from the atmosphere to crops to animals and back into the atmosphere over a relatively short period of time. Therefore, emissions of carbon dioxide from manure decomposition were judged not to contribute to a net increase in greenhouse gases in the long term.

Methane emissions tend to vary regionally depending on seasonal temperature profiles. As a result, methane emissions were not estimated for the model farms, but were estimated in Chapter 8.0 for an anaerobic lagoon in a cold climate and warm climate.

Table 2 summarizes the annual emission estimates for the model farms. The model farms were sized for a confinement capacity of 500 animal units. An animal unit as defined by EPA equates the number of animals to the equivalent water pollution potential of a 1,000 pound beef cow (see the glossary for the definition of animal unit). In general, there were significant data deficiencies for all the animal sectors. The study was unable to provide emission estimates for every substance emitted at every emission point at the model farms. Therefore, the emission estimates in Table 2 are partial estimates that represent the minimum level expected at typical operations.

A summary of the major emission data gaps for each animal sector is presented in Table 3. The table lists the model farm components for which emission factors could not be developed, but for which it was concluded that emissions would be expected based on principles of microbial decomposition and chemistry.

Data Limitations

Data deficiencies prevented the development of emission factors for all elements of the model farms. To develop emission factors, the ability to characterize emissions on an annual basis and in terms of a unit of production capacity was essential. For most of the references

Table 2.

Summary of Emissions from Model Farms (tons/yr-500 animal units)

Animal Sector	Model Farm ID	NH_3	N_2O	H_2S	VOC	PM
Beef	B1A	11.2	1.4	a	a	3.2[b]
	B1B	11.2	1.4	a	a	3.2
Veal	V1	a	0.005	a	0.02	Neg.[c]
	V2	a	a	a	a	Neg.[c]
Dairy	D1A	26	2.3	3.9	1.1	0.6
	D1B	26	2.3	3.9	1.1	0.6
	D2A	23	2.3	1.0	1.1	0.6
	D2B	23	2.3	1.0	1.1	0.6
	D3A	8.7	2.3	a	a	0.6
	D3B	8.7	2.3	a	a	0.6
	D4A	19	2.3	3.9	1.1	0.6
	D4B	19	2.3	3.9	1.1	0.6
Swine	S1	15	0.02	2.6	0.6	2.0
	S2	15	0.02	0.9	0.6	2.0
	S3A	15	0.02	0.9	0.6	2.0
	S3B	11	0.02	a	a	2.0
	S4	12	0.02	0.3	a	2.0
Poultry-broilers	C1A	13	1.8	a	a	2.1
	C1B	13	1.2	a	a	2.1
Poultry-layers	C2	13	0.9	Neg.[c]	Neg.[c]	a
	C3	22	0.09	1.2	0.98	a
Poultry-turkey	T1A	27	2.7	a	a	4.7
	T1B	26	1.8	a	a	4.7

[a] Emissions are expected but information is not available to estimate emissions.
[b] All PM estimates are for total suspended particulates except for beef, which is PM 10.
[c] No emissions or negligible emissions are expected.

Note: In most cases, the table reflects partial estimates of emissions because of data gaps for certain manure processing steps within the model farms.

Table 3.

Data Gaps for Emission Factors

Sector	Model Farm Component	Pollutants
Beef	Storage ponds	H_2S, VOC
	Solid manure application	N_2O
	Liquid Manure application	NH_3, N_2O, H_2S, VOC
Dairy	Solid manure land application	NH_3 N2O
	Liquid manure land application	N_2O, H_2S, VOC
	Storage ponds	NH_3, H_2S, VOC
	Drylot feed alley (flush)	NH_3
Veal	Confinement with pit storage	NH_3, H_2S, VOC
	Anaerobic lagoon	NH_3, N_2O, H_2S, VOC
	Liquid manure land application	NH_3, N_2O, H_2S, VOC
Swine	House with pit recharge	H_2S, VOC
	House with pull plug pit	H_2S, VOC
	House with pit storage	VOC
	Liquid manure land application	N_2O, VOC
	External storage	NH_3, H_2S, VOC
Broilers	Solid manure land application	N_2O
Layers	Caged layer flush house	H_2S, VOC, PM
	Caged layer high rise house	PM
	Solid manure land application	N_2O, PM
	Liquid manure land application	H_2S, VOC
Turkeys	Solid manure land application	N_2O

reviewed, this was not possible. Typically, the information was limited to point estimates of concentrations derived from air sampling over a limited period of time without the necessary background information to translate the concentration information into emission factors. For example, information for animal confinement facilities about building size, housing capacity, or ventilation rate at the time of air sampling often was lacking. In addition, some articles lacked information about the type of manure management system and the characteristics of manure present. Studies that lacked such information were not used.

In many cases, the accuracy of the emission factors that were developed based on the available data in the literature is a concern. In some instances, factors were based on a single study or only a few studies. Where it was possible to develop emission factors based on more than one independently conducted study, the range of emissions in some cases was substantial. On the basis of this observed variability, the validity or representativeness of factors derived from a single reference is questionable. This result is not unanticipated given the complexity of the mechanisms responsible for these emissions and the inability of limited monitoring efforts to capture all the effects of critical variables (e.g., seasonal temperature variations).

One of the more significant findings that emerged from this study was the absence of standardized methodologies for quantifying emissions from AFOs. Although generally accepted sample collection techniques typically have been used, test conditions that will provide representative emission estimates and provide a standard basis for comparisons have not been established. In addition, a standard basis for reporting emissions is lacking. For example, in some cases measured emissions could not be linked to a unit of confinement capacity or to the mass of an animal product produced.

Emission Control Techniques

The literature search identified a number of control practices that in theory are possible options for reducing the emissions from confinement facilities, manure management systems, and land application. Chapter 9.0 identifies more than 20 technologies that have been used to some extent at full-scale operations in the industry. However, for many of the technologies there is limited information about the potential effectiveness and cost that is derived from long-term operating experience under field conditions. For most of these practices, information that is available is the product of pilot studies, or relatively short-term research on commercial scale systems. Many of the studies did not use standard analytical methodologies for measuring emissions, and cost estimates often were based on empirical information rather than principles of engineering economics. Thus, more study is needed to establish the types and sizes of operations to which these technologies are technically and economically feasible.

1.0 INTRODUCTION

Animal agriculture in the U.S. is a $100 billion per year business (GAO, 1999). Most of this production occurs in agricultural enterprises where animals are raised in confinement, rather than on pastures, fields, or rangeland. There are about 1.2 million livestock and poultry farms in the United States. About one-third of these farms raise animals in confinement, qualifying them as an animal feeding operation (USDA, 1999).

This report is part of a preliminary investigation into air emissions from large animal feeding operations. This report addresses the beef, dairy, swine, and poultry (broiler, laying hens, and turkey) sectors. These animal sectors comprise the majority of animals raised in confinement in the U.S. There are more than 500,000 operations that raise sheep, horses, goats, mules, rabbits, ducks, and geese (USDA, 1999). But these operations are mostly small and do not generate emissions of the same magnitude as other animal sectors. These species, therefore, are not covered by this report. The objectives of this investigation were to characterize the magnitude of emissions from different livestock operations, assess the value of currently available information to support future air pollution policy decisions regarding AFOs, and identify areas where targeted research is necessary.

As defined by the U.S. Environmental Protection Agency (40 CFR 122.23), an AFO is a facility where: 1) livestock or poultry are confined and fed for a total of 45 days or more in any 12-month period, and 2) vegetative cover of any significance (crops, vegetative forage growth, or post-harvest residues) is lacking. To be considered an AFO, it is not necessary that the same animals are confined for 45 days. The 45 days do not have to be consecutive, and the 12-month period does not have to correspond to a calendar year. The stipulation of the absence of vegetative cover of any significance intentionally excludes operations where animals are maintained on pasture or rangeland. An AFO includes the confinement facility, manure management systems, and the manure application site.

The fundamental goal of this study was to develop a method for estimating emissions at the individual farm level that reflects the different animal production methods that are commonly used at commercial scale operations. The approach to this study was to: (1) identify the manure management systems typically used by large animal feeding operations for each animal sector, (2) develop model farms based on individual elements of the those systems (i.e. confinement, manure collection system, storage sites, land application), (3) search the literature for emission factors that could be associated with each element of the model farm, and (4) apply the emission factors to the model farms to estimate annual mass emissions. The report also summarizes information on emission control techniques that are being used in the industry, as reported in the literature. At the outset, it was recognized that there were insufficient data and scientific research to develop a complete set of emission estimates for the model farms. The study results, however, provide a framework for assessing emissions, identifying important data gaps, and focusing future study.

Chapter 2.0 of this report describes the substances emitted from AFOs and explains the factors that influence the emissions of different substances from manure management systems. Chapters 3.0, 4.0, 5.0 and 6.0 are profiles of the beef, dairy, swine, and poultry industries. Information is presented on the location, size, design, and mode of operation of typical operations in the industry. Information on the location, number, and size of animal feeding operations are based on analyses of the USDA's National Agricultural Statistics Service (NASS) statistical bulletins and Census of Agriculture for 1997. Chapters 3.0 through 6.0 incorporate analyses and discussions from the development document written by the EPA Office of Water in support of the revised effluent guidelines, and the National Pollutant Discharge Elimination System regulations for concentrated animal feeding operations (USEPA, 2001).

Chapters 3.0 through 6.0 also present a series of model farms for each animal sector. The model farms are hypothetical farms that were designed to represent the significant design and operating parameters that affect air emissions. The elements of model farms are a confinement facility, a manure management system, and a land application site. The design and operation of farms can vary substantially in different regions of the country. While the model farms may not mirror the precise configuration and operation of all AFOs, they are intended to represent the emission characteristics of about 80% of the commercial scale livestock operations in the U.S. Chapter 7.0 discusses emissions from the application of manure to crop land.

Chapter 8.0 presents estimates of air emissions from the model farms and explains the methodology used to estimate emissions. Emissions were estimated for the following substances:

- Ammonia
- Nitrous Oxide
- Methane
- Particulate Matter
- Volatile Organic Compounds
- Hydrogen Sulfide

Information to estimate emissions of hazardous air pollutants, total reduced sulfur compounds, and PM 2.5 generally was not available. Information for PM 10 was found for beef cattle only. Although emissions of speciated VOC and HAP have not been measured, some studies have monitored substances in the air within and outside of confinement facilities. A list of VOC and HAP identified from these studies is presented in Appendix A.

The mechanisms for emitting carbon dioxide are explained in Chapter 2, but carbon dioxide emissions were not estimated in this study. Carbon dioxide emissions from manure are releases of carbon that were sequestered via photosynthesis in the previous one to three years. The carbon emitted is part of a cycling of carbon from the atmosphere to crops to animals and back into the atmosphere over a relatively short period of time. Therefore, emissions from manure were judged not to contribute to a net increase in greenhouse gases in the long term.

Chapter 9.0 summarizes the methods for reducing emissions from AFOs. The chapter summarizes control technology performance and cost data that were available in the literature and identifies the technologies that have been used at commercial scale. Chapter 10.0 is a glossary of terms used in this report.

1.1 References

GAO. 1999. Animal Agriculture: Waste Management Practices, Report to the Honorable Tom Harkin. GAO/RCED-99-205. U.S. General Accounting Office, Washington, D.C., July 1999.

USDA. 1999. Cattle: Final Estimates 1994-1998. Statistical Bulletin 953. U.S. Department of Agriculture (USDA), National Agricultural Statistics Service, Washington, D.C.

USEPA. 2001. Development Document for the Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations. EPA-821-R-01-003. U.S. Environmental Protection Agency (USEPA), Office of Water. Washington D.C.

2.0 AIR EMISSIONS FROM FEEDLOT OPERATIONS

Animal feeding operations emit particulate and gaseous substances. The primary mechanism for releases of particulate matter is the entrainment of feeds, dry manure, soil, and other material caused by movement of animals in both indoor and outdoor confinement. The gaseous emissions are the products of the microbial decomposition of manures. For this report, manure is defined as any combination of fecal matter, urine and other materials that are mixed with manure (e.g., bedding material, waste feeds, wash water). Manure can be in a solid, slurry, or liquid state (e.g., surface liquids from storage facilities). Decomposition and the formation of these gaseous compounds begin immediately at excretion and will continue until the manure is incorporated into the soil. Therefore, the substances generated and the subsequent rates of emission depend on a number of variables, including the species of animal being produced, feeding practices, type of confinement facility, type of manure management system, and land application practices.

In addition, animals directly emit some of the gaseous substances listed above as a result of normal metabolic processes such as respiration. However, these emissions were not included in this assessment given that they are uncontrollable. Emissions associated with the use internal combustion engines and boilers also were not included because of the lack of the information to characterize typical use. This section describes the general characteristics of AFOs and the substances emitted (Brock and Madigan, 1998; Alexander, 1977; Tate, 1995).

2.1 General Characteristics of Animal Feeding Operations

An AFO has a confinement facility, a system for manure management (storage and in some cases stabilization), and a land application site. Due to the different methods of confinement and associated manure management, there is no typical AFO. The design and operation of an AFO varies depending on animal type, regional climatic conditions, business practices, and preferences of the operator. However, the combinations of confinement and waste management systems that are most commonly used in each sector of animal agriculture are identified in this study. A general overview of AFOs is presented below and more detailed, species-specific discussions are presented in Chapters 3.0 through 6.0.

Confinement. A confinement facility may be a totally enclosed structure with full-time mechanical ventilation, a partially enclosed structure with or without mechanical ventilation, an open paved lot, or an open unpaved lot. Method of confinement, which varies among and within the animal species, probably is the most significant factor affecting emissions, because it influences ventilation and method of manure handling and disposal. Whether manure is handled as a solid, liquid, or slurry will influence if the microbial degradation occurs aerobically or anaerobically, and thus the substances generated.

Manure Management System. A manure storage facility may be an integral part of the confinement facility or located adjacent to the confinement facility. When manure is handled as a solid, storage may be within the confinement facility or in stockpiles that may or may not be covered. For liquid or slurry manure handling systems, manure may be stored in an integral tank, such as a storage tank under the floor of a confinement building, or flushed to an external facility such as a pond or an anaerobic lagoon. Emissions from storage tanks and ponds will differ from anaerobic lagoons, which are designed for manure stabilization. Stabilization is the treatment of manure to reduce volatile solids and control odor prior to application to agricultural land. The use of the term "stabilization" rather than "treatment" is intended to avoid the implication that stabilized animal manure can be discharged to surface or ground waters.

Land application. Currently, almost all livestock and poultry manure is applied to cropland or pastures for ultimate disposal. The method of applying manure can affect emissions. Emissions from manure applied to the soil surface and not immediately incorporated will be higher than with immediate incorporation by disking or plowing. Injection, which is possible with manures handled as liquids or slurries, also will reduce emissions. Conversely, the use of irrigation for the land application of liquid manure will increase emissions of gaseous pollutants due to the increased opportunity for volatilization.

Table 2-1 presents an overview of the most common methods of confinement and manure management for large operations. As discussed below, these different combinations affect the relative magnitudes of emissions from each operation.

Table 2-1.

Common Types of Animal Confinement and Manure Management Systems

Species	Animal Confinement	Typical Type of Manure Management System
Broilers	Enclosed building	Integral with confinement[1], or open or covered stockpiles
Turkeys	Enclosed building	Integral with confinement, or open or covered stockpiles
Layers (dry manure)	Enclosed building	Integral with confinement
Layers (flush systems)	Enclosed building	Ponds and anaerobic lagoons
Swine	Enclosed building	Integral with confinement, or tanks, ponds, anaerobic lagoons
Dairy	Enclosed building and open lots	Anaerobic lagoons, tanks and ponds, and uncovered stockpiles
Veal	Enclosed building	Integral with confinement, or tanks, ponds, anaerobic lagoons
Beef	Open lots	Uncovered stockpiles

[1] Manure is stored in the confinement building until it is applied to land.

2.2 Substances Emitted

A number of factors affect the emission of gases and particulate matter from AFOs. Most of the substances emitted are the products of microbial processes that decompose the complex organic constituents in manure. The microbial environment determines which substances are generated and at what rate. This section describes the chemical and biological mechanisms that affect the formation and release of emissions.

Table 2-2 summarizes the substances that can be emitted from different operations within an AFO. Although all AFOs share the same three common elements (confinement facilities,

Table 2-2.

Substances Potentially Emitted from Animal Feeding Operations

Animal Sector	Operations	PM[1]	Hydrogen Sulfide	Ammonia	Nitrous Oxide	Methane	VOC[1]	CO_2[1]
Boilers, Turkeys, Layers (dry)	Confinement	✔		✔				✔
	Manure Storage and Treatment	✔		✔				✔
	Land Disposal	✔		✔	✔			✔
Layers (Liquid)	Confinement	✔	✔	✔		✔	✔	✔
	Manure Storage and Treatment		✔	✔		✔	✔	✔
	Land Disposal		✔	✔	✔		✔	✔
Swine (Flush)	Confinement	✔	✔	✔			✔	✔
	Manure Storage and Treatment		✔	✔		✔	✔	✔
	Land Disposal		✔	✔	✔		✔	✔
Swine (Other[2])	Confinement	✔	✔	✔			✔	✔
	Manure Storage and Treatment		✔	✔		✔	✔	✔
	Land Disposal		✔	✔	✔		✔	✔
Dairy (Flush)	Confinement	✔	✔	✔			✔	✔
	Manure Storage and Treatment		✔	✔		✔	✔	✔
	Land Disposal		✔	✔	✔		✔	✔

Table 2-2.

Substances Potentially Emitted from Animal Feeding Operations (Continued)

Animal Sector	Operations	PM[1]	Hydrogen Sulfide	Ammonia	Nitrous Oxide	Methane	VOC[1]	CO_2[1]
Dairy (Scrape)	Confinement	✔	✔	✔			✔	✔
	Manure Storage and Treatment		✔	✔		✔	✔	✔
	Land Disposal		✔	✔	✔		✔	✔
Dairy (Drylot)	Confinement	✔	✔	✔	✔	✔	✔	✔
	Manure Storage and Treatment	✔	✔	✔	✔	✔	✔	✔
	Land Disposal	✔	✔	✔	✔		✔	✔
Veal	Confinement	✔	✔	✔			✔	✔
	Manure Storage and Treatment		✔	✔		✔	✔	✔
	Land Disposal	✔	✔	✔	✔		✔	✔
Beef	Confinement	✔	✔	✔	✔	✔	✔	✔
	Manure Storage and Treatment	✔	✔	✔	✔	✔	✔	✔
	Land Disposal	✔	✔	✔	✔		✔	✔

[1]PM = particulate matter, as total suspended particulate ,VOC = volatile organic compounds, CO_2 = carbon dioxide.
[2] Other includes pit storage, pull plug pits, and pit recharge systems.

manure management system, and land application site), the differences in production and manure management practices both among and within the different animal sectors result in different microbial environments and therefore different emission potentials. Factors that affect emissions of ammonia, nitrous oxide, methane, carbon dioxide, volatile organic compounds, hydrogen sulfide, particulate matter, and odors are discussed below.

2.2.1 Ammonia

Ammonia is produced as a by-product of the microbial decomposition of the organic nitrogen compounds in manure. Nitrogen occurs as both unabsorbed nutrients in manure and as either urea (mammals) or uric acid (poultry) in urine. Urea and uric acid will hydrolyze rapidly to form ammonia and will be emitted soon after excretion. The formation of ammonia will continue with the microbial breakdown of manure under both aerobic and anaerobic conditions. Because ammonia is highly soluble in water, ammonia will accumulate in manures handled as liquids and semi-solids or slurries, but will volatize rapidly with drying from manures handled as solids. Therefore, the potential for ammonia volatilization exists wherever manure is present, and ammonia will be emitted from confinement buildings, open lots, stockpiles, anaerobic lagoons, and land application from both wet and dry handling systems.

The volatilization of ammonia from any AFO operation can be highly variable depending on total ammonia concentration, temperature, pH, and storage time. Emissions will depend on how much of the ammonia-nitrogen in solution reacts to form ammonia versus ionized ammonium (NH_4^+), which is nonvolatile. In solution, the partitioning of ammonia between the ionized (NH_4^+) and un-ionized (NH_3) species is controlled by pH and temperature. Under acidic conditions (pH values of less than 7.0) ammonium is the predominate species, and ammonia volatilization occurs at a lower rate than at higher pH values. However, some ammonia volatilization occurs even under moderately acidic conditions. Under acidic conditions, ammonia that is volatized will be replenished due to the continual reestablishment of the equilibrium between the concentrations of the ionized and un-ionized species of ammonia in solution following volatilization. As pH increases above 7.0, the concentration of ammonia increases as does the rate of ammonia volatilization. The pH of manures handled as solids can be in the range of 7.5 to 8.5, which results in fairly rapid ammonia volatilization. Manure handled as liquids or semi-solids tend to have lower pH.

Because of its high solubility in water, the loss of ammonia to the atmosphere will be more rapid when drying of manure occurs. However, there may be little difference in total ammonia emissions between solid and liquid manure handling systems if liquid manure is stored over extended periods of time prior to land application.

2.2.2 Nitrous Oxide

Nitrous oxide also can be produced from the microbial decomposition of organic nitrogen compounds in manure. Unlike ammonia, however, nitrous oxide will be emitted only under certain conditions. Nitrous oxide emissions will occur only if nitrification occurs and is followed by denitrification. Nitrification is the microbial oxidation of ammonia to nitrites and nitrates, and requires an aerobic environment. Denitrification most commonly is a microbially mediated process where nitrites and nitrates are reduced under anaerobic conditions. The principal end product of denitrification is dinitrogen gas (N_2). However, small amounts nitrous oxide as well as nitric oxide also can be generated under certain conditions. Therefore, for nitrous emissions to occur, the manure must first be handled aerobically (i.e., dry) and then anaerobically (i.e., wet).

Nitrous oxide emissions are most likely to occur from unpaved drylots for dairy and beef cattle and at land application sites. These are the sites most likely to have the necessary conditions for both nitrification and denitrification. At these sites, the ammonia nitrogen that is not lost by volatilization will be adsorbed on soil particles and subsequently oxidized to nitrite and nitrate nitrogen. Emissions of nitrous oxide from these sites will depend on two primary factors. The first is drainage. In poorly drained soils, the frequency of saturated conditions, and thus, anaerobic conditions necessary for denitrification, will be higher than for well-drained soils. Conversely, the opportunity for leaching of nitrite and nitrate nitrogen through the soil will be higher in well-drained soils, and the conversion to nitrous oxide will be less. Therefore, poorly drained soils will enhance nitrous oxide emissions. The second factor is plant uptake of ammonia and nitrate nitrogen. Manure that is applied to cropland outside of the growing season will have more available nitrogen for nitrous oxide emissions as will manure that is applied at higher than agronomic rates.

At most operation, the manure application site will be the principal source of nitrous oxide. However, if manure is applied correctly and at agronomic rates, there should be little if any increase in nitrous oxide emissions relative to emissions from application of inorganic commercial fertilizers.

2.2.3 Methane

Methane is a product of the microbial degradation of organic matter under anaerobic conditions. The microorganisms responsible, known collectively as methanogens, decompose the carbon (cellulose, sugars, proteins, fats) in manure and bedding materials into methane and carbon dioxide. Because anaerobic conditions are necessary, manures handled as a liquid or slurry will emit methane. Manures handled as solids generally have a low enough moisture content to allow adequate diffusion of atmospheric oxygen to preclude anaerobic activity or permit the subsequent oxidation of any methane generated.

Methane is insoluble in water. Thus, methane volatilizes from solution as rapidly as it is generated. Concurrent with the generation of methane is the microbially mediated production of carbon dioxide, which is only sparingly soluble in water. Therefore, methane emissions are accompanied by carbon dioxide emissions. The mixture of these two gases is commonly referred to as biogas. The relative fractions of methane and carbon dioxide in biogas vary depending on the population of methanogens present. Under conditions favorable for the growth of methanogens, biogas normally will be between 60 percent and 70 percent methane and 30 percent to 40 percent carbon dioxide. If, however, the growth of methanogens is inhibited, the methane fraction of biogas can be less than 30 percent.

The principal factors affecting methane emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The portion of the manure that decomposes anaerobically depends on the biodegradability of the organic fraction and how the manure is managed. When manure is stored or handled as a liquid (e.g., anaerobic lagoons, ponds, tanks, or pits), it will decompose anaerobically and produce a significant quantity of methane. Anaerobic lagoons are designed to balance methanogenic microbial activity with organic loading and, therefore, will produce more methane than ponds or tanks. The organic content of manure is measured as volatile solids. When manure is handled as a solid (e.g., in open feedlots or stockpiles), it tends to decompose aerobically and little or no methane is produced. Likewise, manure application sites are not likely sources of methane, because the necessary anaerobic conditions generally do not exist except when soils become saturated. In addition, because methane is insoluble in water, any methane generated during liquid storage or stabilization treatment will be released immediately and will not be present when manure is applied to cropland.

2.2.4 Carbon Dioxide

Carbon dioxide is a product of the microbial degradation of organic matter under both aerobic and anaerobic conditions. Under aerobic conditions, carbon dioxide and water are the end-products, with essentially all of the carbon emitted as carbon dioxide. Under anaerobic conditions, carbon dioxide is one of the products of the microbial decomposition of organic matter to methane. Under these conditions, carbon dioxide is formed as a by-product of the decomposition reactions involving complex organic compounds that contain oxygen. Thus, carbon dioxide will be emitted under both aerobic and anaerobic conditions and will occur wherever manure is present. Land application sites will emit carbon dioxide from the decomposition of manurial organic matter by soil microorganisms.

Although AFOs emit carbon dioxide, the emissions do not contribute to a net long-term increase in atmospheric carbon dioxide concentrations. The carbon dioxide from animal manures is a release of carbon sequestered by photosynthesis during the past one to three years at most. Thus, the carbon dioxide emitted is part of a cycling of carbon from the atmosphere to crops to animals and back into the atmosphere over a relatively short time period. For this reason, AFOs were judged not to contribute to a buildup of greenhouse gases, and emissions of carbon dioxide were not estimated in the study.

2.2.5 Volatile Organic Compounds

Volatile organic compounds are formed as intermediate metabolites in the degradation of organic matter in manure. Under aerobic conditions, any VOC formed are rapidly oxidized to carbon dioxide and water. Under anaerobic conditions, complex organic compounds are degraded microbially to volatile organic acids and other volatile organic compounds, which in turn are converted to methane and carbon dioxide by methanogenic bacteria. When the activity of the methanogenic bacteria is not inhibited, virtually all of the VOC are metabolized to simpler compounds, and the potential for VOC emissions is nominal. However, the inhibition of methane formation results in a buildup of VOC in the manure and ultimate volatilization to the air. Inhibition of methane formation typically is caused by low temperatures or excessive loading rates of volatile solids in a liquid storage facility. Both of these conditions create an imbalance between populations of the microorganisms responsible for the formation of VOC and methanogenic bacteria. Therefore, VOC emissions will be minimal from properly designed and operated stabilization processes (such as anaerobic lagoons) and the associated manure application site. In contrast, VOC emissions will be higher from storage tanks, ponds, overloaded anaerobic lagoons, and associated land application sites. The specific VOC emitted will vary depending on the solubility of individual compounds and other factors (including temperature) that affect solubility.

2.2.6 Hydrogen Sulfide and Other Reduced Sulfur Compounds

Hydrogen sulfide and other reduced sulfur compounds are produced as manure decomposes anaerobically. There are two primary sources of sulfur in animal manures. One is the sulfur amino acids contained in the feed. The other is inorganic sulfur compounds, such as copper sulfate and zinc sulfate, which are used as feed additives to supply trace minerals and serve as growth stimulants. Although sulfates are used as trace mineral carriers in all sectors of animal agriculture, their use is more extensive in the poultry and swine industries. A possible third source of sulfur in some locations is trace minerals in drinking water.

Hydrogen sulfide is the predominant reduced sulfur compound emitted from AFOs. Other compounds that are emitted are methyl mercaptan, dimethyl sulfide, dimethyl disulfide, and carbonyl sulfide. Small quantities of other reduced sulfur compounds are likely to be emitted as well.

Under anaerobic conditions, any excreted sulfur that is not in the form of hydrogen sulfide will be reduced microbially to hydrogen sulfide. Therefore, manures managed as liquids or slurries are potential sources of hydrogen sulfide emissions. The magnitude of hydrogen sulfide emissions is a function of liquid phase concentration, temperature, and pH. Temperature and pH affect the solubility of hydrogen sulfide in water. The solubility of hydrogen sulfide in water increases at pH values above 7. Therefore, as pH shifts from alkaline to acidic ($pH<7$), the potential for hydrogen sulfide emissions increases (Snoeyink, 1980). Under anaerobic conditions, livestock and poultry manures will be acidic, with pH values ranging from 5.5 to 6.5.

Under aerobic conditions, any reduced sulfur compounds in manure will be oxidized microbially to nonvolatile sulfate, and emissions of hydrogen sulfide will be minimal. Therefore, emissions from confinement facilities with dry manure handling systems and dry manure stockpiles should be negligible, if there is adequate exposure to atmospheric oxygen to maintain aerobic conditions. Any hydrogen sulfide that is generated in dry manure generally will be oxidized as diffusion through aerobic areas occurs.

In summary, manure storage tanks, ponds, anaerobic lagoons, and land application sites are primary sources of hydrogen sulfide emissions whenever sulfur is present in manure. Confinement facilities with manure flushing systems that use supernatant from anaerobic lagoons also are sources of hydrogen sulfide emissions.

2.2.7 Particulate Matter

Sources of particulate matter emissions include feed, bedding materials, dry manure, unpaved soil surfaces, animal dander, and poultry feathers. Therefore, confinement facilities, dry manure storage sites, and land application sites are potential PM emission sources. The relative significance of each source depends on three interrelated factors: 1) the type of animal being raised, 2) the design of the confinement facility being utilized, and 3) the method of manure handling.

The National Ambient Air Quality Standards currently regulate concentrations of particulate matter with a mass median diameter of 10 micrometers or less (PM 10). Studies have shown that particles in the smaller size fractions contribute most to human health effects. The current PM 10 standard may be replaced by a standard for PM 2.5. A PM 2.5 standard was published in 1997, but has not been implemented pending the results of ongoing litigation.

The particle size distribution of particulate matter emitted from AFOs has not been well characterized. Virtually all of the emission studies to date have measured total suspended particulate or did not report the test method used. Particle size distribution data was found only for beef feedlots. In one study, ambient measurements of PM 10 and PM 2.5 (using five hour sample collection periods) were taken downwind (15 to 61 meters) of three cattle feedlots in the Southern Great Plains (Sweeten, et al., 1998). In this study, PM 10 was measured as 20 percent to 40 percent of TSP (depending on the measurement method used), and PM 2.5 was 5 percent of TSP. No studies were found of particle size distribution from confinement buildings. Based on the emission mechanisms at AFOs, one would expect to find that: (1) PM from AFOs would have varying particle size distributions depending on the animal sector, method of confinement, and type of building ventilation used, and (2) the PM emitted would include PM 10 and a lesser fraction of PM 2.5. In addition to direct emission, PM 2.5 can be secondarily formed in the atmosphere from emissions of ammonia. If sulfur oxides or nitrogen oxides are present in the air, ammonia will be converted to ammonium sulfate or ammonium nitrate, respectively. No information is available at this time to quantify the emissions of secondarily formed PM 2.5. For this report, PM means total suspended particulate, except where noted specifically as PM 10.

All confinement facilities are sources of particulate matter emissions. However, the composition of these emissions will vary. The only constant constituent is animal dander and feather particles from poultry. For poultry and swine, feed particles will constitute a significant fraction of particulate matter emissions because the dry, ground feed grains and other ingredients used to formulate these feeds are inherently dusty. Pelleting of feeds reduces, but does not eliminate, dust and PM emissions. Dried forages also generate particulate matter, but most likely to a lesser degree. Silages, which have relatively high moisture contents tend to generate less PM than for other types of feed. Because veal calves are fed a liquid diet, feed does not contribute to particle emissions from veal operations.

The mass of particulate matter emitted from totally or partially enclosed confinement facilities, as well as the particle size distribution, depend on type of ventilation and ventilation rate. Particulate matter emissions from naturally ventilated buildings will be lower than those from mechanically ventilated buildings. Mechanically ventilated buildings will emit more PM at higher ventilation rates. Therefore, confinement facilities located in warmer climates will tend to emit more PM because of the higher ventilation rates needed for cooling.

While confinement facilities for dairy and beef cattle typically are all naturally ventilated, facilities for poultry, swine, and veal are mechanically ventilated for all or at least part of the year. When mechanical ventilation is used for only part of the year, it is used during the coldest and hottest months with natural ventilation used during the remainder of the year.

Open feedlots and storage facilities for dry manure from broilers, turkeys, laying hens in high rise houses, dairy drylots, and beef cattle drylots also are potential sources of particulate matter emissions. The rate of emission depends on whether or not the manure is covered. Open sites are intermittent sources of particulate matter emissions, because of the variable nature of wind direction and speed and precipitation. Thus, the moisture content of the manure and the resulting emissions will be highly variable. The PM emissions from covered manure storage facilities depend on the degree of exposure to wind.

2.2.8 Odors

Odor generated from an AFO is not the result of a distinct compound, but is caused by the presence of several constituents of manure degradation. The principal compounds responsible for noxious odors are hydrogen sulfide, ammonia, and VOC. The VOC that contribute to odors are volatile acids (acetic, propionic, formic, butyric, and valeric), indole, phenols, volatile amines, methyl mercaptan, and skatole.

Most the odorous compounds are products of anaerobic digestion of organic compounds. Therefore, the potential for odors is greater at operations with liquid manure management systems. In liquid systems, odors can be produced from storage pits, ponds, and land application. Properly designed and operated anaerobic lagoons should have relatively low odors, but odors can be produced under two conditions: (1) in the spring and fall when sudden temperature changes can upset the microbial balance, or (2) if the lagoon is overloaded with volatile solids. Drylots can produce odors whenever warm, wet conditions produce transient anaerobic conditions. Odors also can be caused by decaying animals, if the carcasses are stored too long prior to disposal.

2.3 Summary of Factors Affecting Emissions

To summarize Section 2.2, emissions from AFOs depend on manure characteristics and how the manure is managed. Manure excreted by each type of animal will have specific characteristics (e.g., nitrogen content, moisture content). The characteristics, however, can be altered depending on how the manure is collected, stored, and land applied. Chapters 3.0 through 6.0 of this report discuss the different types of confinement and manure management systems used for the beef, dairy, swine, and poultry sectors. The potential for generating emissions at any point in the process depends on several factors. The potential for PM emissions depends on whether the manure is handled in a wet or dry state. The potential for gaseous emissions generally depends on several factors: (1) the presence of an aerobic or anaerobic microbial environment, (2) the precursors present in the manure (e.g., sulfur), (3) pH of the manure, and (4) time and temperature in storage, which primarily affects mass emitted. The effect of each these factors on emission is summarized in Table 2-3 and described below.

Wet/dry manure management systems. To form hydrogen sulfide (and other reduced sulfur compounds), methane, and VOC requires an anaerobic environment. Therefore, the potential to emit these substances is greatest when manure is handled as a liquid or slurry. Ammonia will be generated in both wet and dry manure. Nitrous oxide will be

Table 2-3.

Factors That Increase Emissions

Substance Emitted	Wet Manure Handling	Dry Manure Handling	pH	High Temperature	Manure Residence Time	Precursors
Ammonia			>7.0	✔	✔	Nitrogen
Nitrous Oxide		✔				Nitrogen
Hydrogen Sulfide	✔		<7.0	✔	✔	Sulfur
Methane	✔			✔	✔	Carbon
VOC	✔			✔	✔	Carbon
Particulate Matter[1]		✔				

[1] Total suspended particulate. Fine particles (PM2.5) in the form of ammonium sulfate and ammonium nitrate can be secondarily formed in the atmosphere from ammonia emissions; if sulfur oxides or nitrogen oxides are present in the air.

formed only when manure that is handled in a dry state becomes saturated (thus forming transient anaerobic conditions).

<u>pH</u>. Emissions of ammonia and hydrogen sulfide are influenced by pH. The manure pH affects the partitioning between these compounds and their ionized forms (NH_4^+ and HS^-), which are nonvolatile.

<u>Temperature</u>. Temperature has two effects: (1) Temperature affects gas phase vapor pressure, and therefore, the volatility. For substances that are soluble in water (ammonia, some VOC, hydrogen sulfide and other reduced sulfur compounds), emissions will be greater at higher temperatures. Emission rates of these substances will be greater in warmer climates and in the summer rather than winter. Methane is insoluble in water, and at any temperature will be emitted very quickly after formation. (2) Higher temperature favors the microbial processes that generate methane and other substances.

<u>Time in storage</u>. Long periods of manure residence time in either confinement, storage, or stabilization facilities provide greater opportunities for anaerobic breakdown and volatilization to the air. Also, masses emitted will increase with time.

<u>Precursors</u>. The amount of sulfur ingested by an animal will affect the potential for hydrogen sulfide production in manure. Sulfur can be present in feed additives and, in some cases, from water supplies. The amount of nitrogen in feed (proteins and amino acids) affects ammonia and nitrous oxide emission potential. The amount of carbon affects methane and carbon dioxide potential. Ensuring that the composition of feedstuffs does not exceed the nutritional needs of the animal will reduce emissions.

2.4 References

Alexander, M. 1977. Introduction to Soil Microbiology, 2nd Ed. John Wiley and Sons, New York, New York.

Brock, T.D. and M.T. Madigan. 1988. Biology or Microorganisms, 5th Ed. Prentice Hall, Englewood Cliffs, New Jersey.

Snoeyink, V.L. and D. Jenkins. 1980. Water Chemistry. John Wiley and Sons, New York, New York

Sweeten, J.M., C.B. Parnell, B.W. Shaw, and B.W. Auvermann. 1998. Particle Size Distribution of Cattle Feedlot Dust Emissions. Transactions of the American Society of Agricultural Engineers 41 (5): 477-1481.

Tate, R.L., III. 1995. Soil Microbiology. John Wiley and Sons, New York, New York.

5.0 SWINE FEEDING OPERATIONS

The U.S. swine industry has undergone major consolidation over the past several decades. The number of hog operations, which approached 3 million in the 1950s, had declined to about 110,000 by 1997 (USDA, 1999a). The rate of consolidation has increased dramatically in the last decade, during which the number of swine operations decreased by more than 50% (USDA, 1999b). This trend toward consolidation appears to be continuing today.

While the number of operations has decreased, annual hog production has risen. The domestic hog industry is increasingly dominated by large totally enclosed confinement operations capable of handling 5,000 hogs or more at a time (USDA,1999a; USDA, 1999c). These operations typically produce no other livestock or crop commodities.

Another trend in the industry is an increasing degree of vertical integration that has accompanied consolidation. Hogs are raised by independent producers under contract with integrators who slaughter and market the hogs produced. The integrator provides the animals, feed, required vaccines and other drugs, and management guidance. The grower provides the labor and facilities, and is responsible for manure and carcass disposal. In return, each grower receives a fixed payment, adjusted for production efficiency.

These changes at both the industry and farm levels represent a significant departure from earlier eras, when hogs were produced primarily on relatively small but integrated farms where crop production and other livestock production activities occurred and where animals spent their complete life cycle at one location.

5.1 Size and Location of Swine Industry

In 1997, there were 109,754 swine operations in the U.S. These operations produced 142.6 million pigs (USDA, 1999b). Farms vary in size from operations with a few hundred pigs to some newer operations that house hundreds of thousands of animals at one time. Table 5-1 shows the distribution of farms by size (based on 1997 inventory) and state. Table 5-2 shows the

Table 5-1.

Number of Swine Operations by Size in 1997

STATE	INVENTORY			
	<2000 Head	2,000 to 4,999 Head	>5,000 Head	
ALABAMA	909	15	8	
ALASKA	53	0	0	
ARIZONA	201	4	1	
ARKANSAS	1115	89	43	
CALIFORNIA	1579	4	10	
COLORADO	1202	9	14	
CONNECTICUT	210	0	0	
DELAWARE	127	4	1	
FLORIDA	1429	2	0	
GEORGIA	1706	39	19	
HAWAII	247	1	0	
IDAHO	711	3	0	
ILLINOIS	6673	381	114	
INDIANA	6003	326	113	
IOWA	15711	1224	308	
KANSAS	2719	76	36	
KENTUCKY	1826	38	17	
LOUISIANA	631	1	1	
MAINE	341	0	0	
MARYLAND	574	10	0	
MASSACHUSETTS	382	1	0	
MICHIGAN	2729	91	33	
MINNESOTA	6873	463	176	
MISSISSIPPI	627	23	12	
MISSOURI	5192	165	62	
MONTANA	597	23	7	
NEBRASKA	5753	189	75	
NEVADA	112	0	1	
NEW HAMPSHIRE	249	0	0	
NEW JERSEY	428	2	1	
NEW MEXICO	346	0	0	
NEW YORK	1498	9	1	
NORTH CAROLINA	1756	648	582	
NORTH DAKOTA	782	10	5	
OHIO	5801	125	26	
OKLAHOMA	2936	36	30	
OREGON	1382	1	0	
PENNSYLVANIA	3305	115	36	
RHODE ISLAND	60	0	0	
SOUTH CAROLINA	1184	27	15	
SOUTH DAKOTA	2775	68	56	
TENNESSEE	2019	18	6	
TEXAS	5410	5	13	
UTAH	499	3	9	
VERMONT	238	0	0	
VIRGINIA	1140	20	10	
WASHINGTON	974	4	0	
WEST VIRGINIA	645	0	0	
WISCONSIN	3629	51	6	
WYOMING	292	0	4	
UNITED STATES	**103580**	**4323**	**1851**	**109,754**

USDA, 1999a

Table 5-2.

U.S. Swine Operations and Inventory by Farm Size in 1997

Farm Size[a]	Percent of Operations	Percent of National Inventory
<1,999 Head	94.4	39.3
2,000 - 4,999 Head	3.9	20.8
>5,000 Head	1.7	40.2

[a] Based on Inventory
USEPA, 2001

1997 animal population by farm size. These data show the increasing dominance by large operations. In 1997, 94% of the farms had a capacity of 2,000 pigs or less. These smaller operations confined 40% of the total inventory of pigs. In contrast, larger operations, which represent 6% of the number of farms, confined 60% of the inventory. The largest 2% of farms (>5000 head) confined 40% of the inventory (USEPA, 2001). Table 5-3 shows the total inventory by state of breeding sows and hogs raised for market.

Swine production historically has been centered in the Midwest, with Iowa being the largest hog producing state in the country. Although the Midwest continues to be the nation's leading hog producer (five of the top seven producing states are still in the Midwest), significant growth has taken place in other areas. Perhaps the most dramatic growth has occurred in the Mid-Atlantic Region, in North Carolina. From 1987 to 1997, North Carolina advanced from being the 12th largest pork producer in the nation to second behind only Iowa. The idea of locating production phases at different sites was developed in North Carolina. The state also has a much higher per farm average inventory than any of the states in the Midwest. Whereas Iowa had an average of fewer than 850 head per farm, North Carolina had an average of more than 3,200 head per farm in 1997 (USEPA, 2001).

Growth has occurred elsewhere as well. There has been significant growth in recent years in the panhandle area of Texas and Oklahoma, Colorado, Utah, and Wyoming. Some of the very large new operations have been constructed in these States. Since this growth has taken place in

Table 5-3.

Swine Inventory by State in 1997

STATE	INVENTORY (1,000 Head)	
	Breeding	Market
ALABAMA	20	170
ALASKA	1	2
ARIZONA	15	130
ARKANSAS	113	768
CALIFORNIA	27	183
COLORADO	160	630
CONNECTICUT	1	4
DELAWARE	4	26
FLORIDA	10	45
GEORGIA	70	498
HAWAII	5	24
IDAHO	4	26
ILLINOIS	545	3,993
INDIANA	448	3,265
IOWA	1,295	11,980
KANSAS	196	1,296
KENTUCKY	71	499
LOUISIANA	5	27
MAINE	1	5
MARYLAND	11	74
MASSACHUSETTS	3	16
MICHIGAN	130	895
MINNESOTA	625	4,800
MISSISSIPPI	28	192
MISSOURI	445	3,018
MONTANA	20	160
NEBRASKA	440	3,085
NEVADA	1	7
NEW HAMPSHIRE	1	4
NEW JERSEY	3	20
NEW MEXICO	1	5
NEW YORK	11	68
NORTH CAROLINA	1,000	8,675
NORTH DAKOTA	24	176
OHIO	203	1,335
OKLAHOMA	211	1,319
OREGON	5	30
PENNSYLVANIA	119	941
RHODE ISLAND	1	2
SOUTH CAROLINA	35	270
SOUTH DAKOTA	161	1,069
TENNESSEE	45	295
TEXAS	75	505
UTAH	55	240
VERMONT	1	2
VIRGINIA	43	357
WASHINGTON	6	33
WEST VIRGINIA	3	13
WISCONSIN	126	639
WYOMING	19	76
UNITED STATES	**6,810**	**51,697**

USDA, 1999b

the past three years, these operations are not reflected in the 1997 statistics presented in this report (USEPA, 2001).

5.2 Swine Production Cycles

The production cycle for hogs has three phases: farrowing, nursing, and finishing. Some farms specialize in a single phase of the growth cycle, while other farms may handle two or all three phases.

The first phase begins with breeding and gestation over a 114 day period followed by farrowing (giving birth). After farrowing, the newly born pigs or piglets normally are nursed for a period of three to four weeks until they reach a weight of 10 to 15 pounds. Typically, there are from 9 to 11 pigs per litter, with a practical range of 6 to 13. The average number of pigs weaned per litter in 1997 was 8.7. Sows can be bred again within a week after a litter is weaned. Sows normally produce five to six litters before they are sold for slaughter at a weight of 400 to 460 pounds. After weaning, pigs are relocated to a nursery.

Nursery operations receive weaned pigs and grow them to a weight of 40 to 60 pounds (feeder pigs). Weaned pigs are fed a starter ration until they reach a weight of 50 to 60 pounds. At this point, they are eight to ten weeks of age. The third phase of swine production is the growing-finishing phase where the gilts (young females) and young castrated boars (males) not retained for breeding are fed until they reach a market weight, typically between 240 and 280 pounds. In this phase of swine production, a growing ration is fed to a weight of 120 pounds and is then followed by a finishing ration. Growing-finishing usually takes between 15 and 18 weeks. Hogs normally are slaughtered at about 26 weeks of age. After weaning, swine typically are fed a corn-soybean meal based diet that may include small grains such as wheat and barley and other ingredients until slaughtered.

Swine operations can be of several types. The most common is the farrow-to-finish operation that encompasses all three phases of swine production. Another common production mode is the combination of the farrowing and nursing phases, which provide feeder pigs for stand-alone grow-finish operations. Although not as common, some newer farms may operate only the farrowing phase or only the nursery phase.

The annual production capacity of a farrowing operation is determined by the number of sows that can be confined and the number of litters of pigs produced per sow each year. Because the gestation period for the pig is 114 days, more than one litter of pigs can be produced per sow each year.

The annual production capacity of a farrow-to-finish or a grow-finish operation is determined by capacity of the confinement facility, the duration of the growing period, and the time required to clean out and disinfect the confinement facility between herds. The latter two factors determine the number of groups of pigs (i.e., or turnovers) per year. The grow-finish production phase usually takes between 15 and 18 weeks. The length of the grow-finish cycle depends on the finished weight specified by the processor. Extremely hot or cold weather can reduce rate of weight gain and also lengthen the grow-finish period. The duration of the clean-out period between groups of feeder pigs may be only a few days or several weeks depending on market conditions. A typical range for a grow-finish operation is 2.4 to 3.4 turnovers per year.

Turnovers affect the amount of manure generation. A grow-finish operation with a confinement capacity of 1,000 pigs and 2.4 turnovers per year will produce approximately 2,400 pigs for slaughter per year whereas the same operation with 3.4 turnovers per year will produce 3,400 pigs per year. Assuming the same initial and final weights and the same rate of weight gain, this difference translates into one third more manure production per year.

Production practices tend to vary regionally depending on climate conditions, historical patterns, and local marketing and business practices. Table 5-4 presents the frequency of farrowing, nursing, and finishing operations in the three major hog production regions. Based on survey results in 1995, 61.9% respondents were farrow-to-finish operations and 24.3% were grow-finish operations (USDA, 1995). Although many large operations are farrow-to-finish operations, this no longer is the norm. New operations commonly specialize in either feeder pig

Table 5-4.

Frequency of Production Phase in 1995 (Percent of Farms)[a]

Production Phase	Size	USDA APHIS Region[b]		
		Midwest	North	Southeast
Farrowing	<5000 hogs marketed	76.6	68.6	69.3
Nursery		20.1	51	57.8
Finishing		78.8	79.7	93.4
Farrowing	>5000 hogs marketed	44.8	80.4	89
Nursery		75	67.1	97.4
Finishing		45.8	69.7	62.8

[a] Totals do not add to 100 percent because many operations combine production phases.
[b] Midwest=SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast=MO, KY, TN, NC, GA
USDA, 1995

production, nursery, or grow-finish phases of the production cycle. These operations may be linked by common ownership or separately owned, but all under contract with a single integrator. Thus, pigs may begin their life-cycle in a sow herd on one site, move to a nursery on another, and then move again to a finishing facility. Specialized operations can take advantage of skilled labor, expertise, advanced technology, streamlined management, and disease control.

5.3 Swine Confinement Practices

Table 5-5 summarizes the five major housing configurations used by domestic swine producers. Although there are still many operations where pigs are raised outdoors, the trend in the swine industry is toward larger operations where pigs are raised in totally or partially enclosed confinement facilities. Typically, the gestation and farrowing, nursery, and grow-finish phases of the production cycle occur in separate, specially designed facilities.

Table 5-5.

Typical Swine Housing Confinement Facilities

Facility Type[a]	Description	Applicability
Total confinement	Pigs are raised in pens or stalls in environmentally controlled building	Most commonly used in nursery and farrowing operations and all phases of very large operations. Particularly common in the Southeast
Open building with no outside access	Pigs are raised in pens or stalls but are exposed to natural climate conditions	Relatively uncommon but used by operations of all sizes
Open building with outside access	Pigs are raised in pens or stalls but may be moved to outdoors	Relatively uncommon, but used by some small to mid-sized operations
Lot with hut or no building	Pigs are raised on cement or soil lot and are not confined to pens or stalls	Used by small to mid-sized operations
Pasture with hut or no building	Pigs are raised on natural pasture land and are not confined to pens or stalls	Traditional method of raising hogs. Currently used only at small operations

[a] These are the main facility configurations contained in the Swine '95 Survey conducted by USDA, 1995

Farrowing operations require intense management to reduce piglet mortality. Houses will have farrowing pens (5 feet by 7 feet typically), and the piglets are provided a protected area of about 8 square feet. Nursery systems are typically designed to provide a clean, warm, dry, and draft-free environment in which animal stress is minimized to promote rapid growth and reduce injury and mortality. Nursery buildings are cleaned and disinfected thoroughly between groups of pigs to prevent transmission of disease from one herd to another. Finishing pigs require less intensive management and can tolerate greater variations in environmental conditions without incurring health problems. Finishing operations allow about 6 square feet per pig.

A typical confinement building is 40 feet by 300 to 500 feet. The buildings are either totally enclosed or open-sided with curtains. Totally enclosed facilities are mechanically ventilated throughout the year. Open-sided buildings are naturally ventilated during warm weather and mechanically ventilated during cold weather when curtains are closed. Swine houses have an integrated manure collection system as described in the next section. As shown in Table 5-6, smaller facilities tend to use open buildings.

Table 5-6.

Housing Frequency in 1995 (Percent of Farms)

Swine Production Phase	Size	Housing Type	USDA APHIS Region[a]		
			Midwest	North	Southeast
Farrowing	<5000 hogs marketed	Total confinement	22.6	53.1	56
		Open building; no outside access	13.1	8.0	8.8
		Open building; outside access	25.7	33.8	31.2
		Lot	16.2	3.2	1.1
		Pasture	22.4	1.9	2.8
	>5000 hogs marketed	Total confinement	98.3	100	100
Nursery	<5000 hogs marketed	Total confinement	52.3	55.4	62
		Open building; no outside access	9.1	11.5	8.8
		Open building; outside access	27.7	33.8	31.2
		Lot	7.0	Not available	3.7
	>5000 hogs marketed	Total confinement	99	100	96.4
Finishing	<5000 hogs marketed	Total confinement	19.9	36.5	23.4
		Open building; no outside access	15.4	14.1	9.5
		Open building; outside access	24.5	42.1	55.9
		Lot	17.1	4.6	9.3
		Pasture	23.0	2.5	1.9
	>5000 hogs marketed	Total confinement	96.8	95.5	83.9

[a] Midwest=SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast=MO, KY, TN, NC, GA
USDA, 1995

5.4 Swine Manure Management Practices

Although use of open lots for swine production still occurs, this method of confinement generally is limited to small operations. Swine manure produced in open lots is handled as a solid in similar fashion as at beef cattle feedlots and dairy cattle drylots. In enclosed confinement facilities, swine manure is handled as either a slurry or a liquid.

There are four principal types of waste management systems used with total and partially enclosed confinement housing in the swine industry: deep pit, pull-plug pit, pit recharge, and flush systems. The deep pit, pull-plug pit, and pit recharge systems are used with slatted floors whereas flush systems can be used with either solid or slatted floors. Brief descriptions of these management systems are presented below. These practices do not represent all of the practices in use today; however, they are the predominant practices currently used by swine operations.

5.4.1 Collection Practices

Flush Systems. Flush systems utilize either fresh water or, more commonly, supernatant from an anaerobic lagoon to transport accumulated wastes to an anaerobic lagoon. Flush frequency can be daily or as frequently as a every two hours. Frequency depends on flushed channel length and slope and volume of water used per flush. Because pigs will defecate as far away as possible from their feeding and resting areas, facilities with solid floors usually will have a flush channel formed in that area. With slatted floors, there usually are a series of parallel flush channels formed in the shallow pit under the slats. Methane emissions from flushed swine confinement facilities will be low but ammonia, hydrogen sulfide, and VOC emissions may be higher than from pit recharge and pull-plug pit systems due to turbulence during flushing.

Pit Recharge. Pit recharge systems utilize relatively shallow pits that are drained periodically by gravity to an anaerobic lagoon. The frequency of draining varies but between four and seven days is standard. Pit recharge systems generally use 16 to 18 inch deep pits located under slatted floors. Previously, 24-inch deep pits were preferred, but now shallower pits are used. Following draining, the empty pit is partially refilled with water, typically with supernatant from the anaerobic lagoon. Generally, about six to eight inches of water is added. With pit recharge systems, emissions of ammonia, hydrogen sulfide, methane and VOC from the confinement facility will be lower than those with deep pits. However, if the manure is sent to an anaerobic lagoon, facility-wide emissions of ammonia, hydrogen sulfide, and methane from pit recharge may be greater than those from deep pits.

Pull-Plug Pits. Pull-plug pits are similar to pit recharge in that pit contents are drained by gravity to a storage or stabilization system. Pits are drained about every one to two weeks. However, water is not added back into the pit. The system relies on the natural moisture in the manure. Manure drained from pull-plug pits may be discharged to a manure storage tank or earthen storage pond or an anaerobic lagoon for stabilization and storage. Gaseous emissions from confinement facilities with pull-plug pits will be similar in magnitude to those with pit recharge systems.

Deep Pit Storage. Deep pits normally are sized to collect and store six months of waste in a pit located directly under a slatted flooring system. Accumulated manure is emptied by pumping. The accumulated manure may be directly applied to land or transferred either to storage tanks or earthen storage ponds for land application later. Due to the relatively high total solids (dry matter) concentration in swine manure collected and stored in deep pits, irrigation is not an option for disposal. To reduce odor, ammonia, and hydrogen sulfide concentrations in confinement facilities with deep pits, ventilation air may flow through the animal confinement area, down through the slatted floor, and over the accumulated manure before discharge from the building. Alternatively, deep pits may be ventilated separately. In either case, emissions of ammonia, hydrogen sulfide, methane, and VOC from confinement facilities with deep pits at least theoretically should be higher than from facilities with other types of manure collection and storage systems.

5.4.2 Swine Manure Storage and Stabilization

Most large hog farms have from 90 to 365 days of manure storage capacity (NPPC, 1996). Storage is in either an anaerobic lagoon or a storage facility. Typical storage facilities include deep pits, tanks, and earthen ponds. Anaerobic lagoons provide both manure stabilization and storage. The use of storage tanks and ponds generally is limited to operations with deep pits and pull-plug pits where manure is handled as a slurry. Pit recharge and flush systems typically use anaerobic lagoons, because of the need for supernatant for use as recharge or flush water. Anaerobic lagoons emit less VOC and noxious odors than storage facilities, but emit more methane.

Storage facilities and anaerobic lagoons are operated differently. Storage facilities hold manure until the vessel is full and then are fully emptied at the next available opportunity. To maintain proper microbial balance, lagoons are never fully emptied, are sized for a design manure acceptance rate, and are emptied on a schedule. This section describes the types of lagoons and storage facilities used and the factors affecting their design.

Anaerobic Lagoons

The anaerobic lagoon has emerged as the overwhelmingly predominant method used for the stabilization and storage of liquid swine manure. Methods of aerobic stabilization (e.g., oxidation ditches or aerated lagoons) were abandoned many years ago due to high electricity costs and operational problems such as foaming.

Several factors have contributed to the use of anaerobic lagoons for swine waste management. One is the ability to handle the manure as a liquid and use irrigation for land application. A second is the potential to reduce noxious odors by maximizing the complete reduction of complex organic compounds to methane and carbon dioxide, which are odorless gases. Finally, the use of anaerobic lagoons in the swine industry was driven, in part, by the potential to maximize nitrogen losses through ammonia volatilization thereby reducing land requirements for ultimate disposal. With the shift to phosphorus as the basis for determining acceptable land application rates for animal manures, maximizing nitrogen loss is ceasing to be an advantage.

The design and operation of anaerobic lagoons for swine and other animal manure has the objective of maintaining stable populations of the microorganisms responsible for the reduction of complex organic compounds to methane and carbon dioxide. As discussed in Chapter 2, the microbial reduction of complex organic compounds to methane and carbon dioxide is a two-step process, in which a variety VOC are formed as intermediates. Many of these VOC, such butyric acid, are sources of noxious odors when not reduced further to methane. Methanogenic microorganisms have slower growth rates than the microbes responsible for the formation of VOC. Therefore, anaerobic lagoons must be designed and operated to maintain a balance between the populations of these microorganisms and methanogens to avoid accumulations of VOC and releases of associated noxious odors.

Emissions of methane and VOC from anaerobic lagoons vary seasonally. Since reaction rates of all microbial processes are temperature dependent, microbial activity decreases as the temperature approaches freezing. Therefore, emissions can be very low during winter. Where there is significant seasonal variation in lagoon water temperature, an imbalance in the microorganisms will occur in late spring and early summer, leading to high VOC emissions and associated odors. This variation is unavoidable and the severity depends on seasonal temperature extremes.

Storage Facilities

Storage facilities include deep pits (beneath confinement buildings), in-ground tanks, above-ground tanks, and earthen ponds. Most storage facilities are open to the atmosphere.

Manure storage tanks and earthen ponds not only must have adequate capacity to store the manure produced during the storage period but also any process wastewaters or runoff that require storage. In addition, provision for storage of the volume of settled solids that will accumulate for the period between solids removal is necessary. Due to the size of storage structures for liquid and slurry type manures, it is difficult to completely mix and empty these facilities during draw down at the end of each storage period. Thus, an accumulation of settled solids will occur requiring a complete clean out of the facility periodically. Estimates of rates of settled solids accumulation for various manures can be found in the Agricultural Waste Management Field Handbook (USDA, 1992).

The microbial processes responsible for methane and VOC formation also occur in storage tanks and ponds. However, the necessary balance in microbial populations for the complete reduction of organic carbon to methane and carbon dioxide never is established due to higher organic loading rates and accumulations of high concentrations of VOC, which inhibit methane formation. Thus, emissions of methane from manure storage tanks and ponds will be lower than at anaerobic lagoons, and emissions of VOC will be higher. Rates of formation of ammonia and hydrogen sulfide will not differ, but emission rates may differ depending on hydraulic retention time, pH and the area of the liquid-atmosphere interface. The pH of storage facilities normally will be acidic due to the accumulation of organic acid, which will reduce the rate of ammonia emission but increase the rate of hydrogen sulfide emission. The reverse is true for anaerobic lagoons, which have pH values that typically are slightly above neutral. However, time and surface area probably are the more significant variables controlling the masses of ammonia and hydrogen sulfide emitted.

Anaerobic Lagoon Design

Both single cell and two cell systems are used for the stabilization and storage of swine manure. In single cell systems, stabilization and storage are combined. In a two-cell system, the first cell has a constant volume and provides stabilization while the second cell provides storage. With two cell systems, water for pit recharge or flushing is withdrawn from the second cell. In climates with low precipitation and high evaporation rates, there may be one or more additional cells for the ultimate disposal of excess liquid by evaporation. Anaerobic lagoons use bacterial digestion to decompose organic carbon into methane, carbon dioxide, water, and residual solids. Periodic removal of settled solids will be necessary. Typically, lagoons are dredged every 10 to 15 years, and the sludge is applied to land.

The design of lagoon treatment cells is similar to storage ponds with one exception. Lagoons are never completely emptied, except when accumulated solids are removed. Lagoons require permanent retention of what is known as the minimum treatment volume that should be reflected in design. Thus, lagoons must be larger in total volume than ponds that provide storage for the same volume of manure.

Determination of minimum treatment volume for lagoons is based on Natural Resources Conservation Services recommended total volatile solids (TVS) loading rates and the daily TVS loading to the lagoon. For anaerobic lagoons, recommended rates range from 3 lb TVS per 1,000 ft^3 per day in northern parts of Montana and North Dakota to 12 lb TVS per 1,000 ft^3 per day in Puerto Rico and Hawaii. This is a reflection of the effect of temperature on the rate of microbial activity. The calculation of minimum treatment volume is simply the daily TVS loading to the lagoon divided by the recommended TVS loading rate for the geographical location of the lagoon (USDA, 1992).

With open manure storage tanks, ponds, and lagoons, provision also is necessary to store the accumulation of normal precipitation directly falling into the structure less evaporation during the storage period. The storage requirement for normal precipitation less evaporation varies geographically. In addition, there are provisions for storage of precipitation from a

25-year, 24-hour storm event, which also varies geographically, with a minimum of one foot of free board remaining. Design values used for the accumulation of normal precipitation less evaporation are based on mean monthly precipitation values for the location of the storage facility obtained from the National Oceanic and Atmospheric Administration.

In some situations, manure storage ponds or lagoons also may be used for the storage of runoff captured from open confinement areas. In these situations, provision for storage of runoff collected from normal precipitation during the storage period as well as from a 25-year, 24-hour storm event must be included in the design storage capacity of the pond. Expected annual and monthly runoff values for the continental U.S., expressed as percentages of normal precipitation, for paved and unpaved open lots can be found in the Agricultural Waste Management Field Handbook (USDA, 1992).

Regional Differences in Manure Management Systems

There are regional differences in methods of swine manure management driven primarily by climate but also influenced by size of operation. For example, small operations with less than 500 head of confinement capacity commonly use drylots that are scraped periodically for manure removal. Manure storage is rare, but there may be a runoff collection and storage pond that also may be used for storage of any confinement facility wash water. Operations with greater than 500 head of confinement capacity typically will use one of the management systems described above. As confinement capacity increases, the probability that either a pull-plug pit or flush system with an anaerobic lagoon will be used also increases.

However, there still are regional differences even among operations with greater than 1,000 head confinement capacity. For example, use of flushing generally is limited to the Central and Southern Regions of the U.S. because freezing of flush water is not a problem, and use of deep pits generally is limited to the Mid-Atlantic, Midwest, and Pacific regions (Table 5-7). In contrast, pit recharge systems are used in all regions. The data base used to create Table 5-7 did not include frequency of use of pull-plug pits. However, pull-plug pits generally are used primarily in climates where winter temperatures severely impact anaerobic lagoon performance.

Table 5-7.

Frequency (in percent) of Operations in 1995 that Used Certain Manure Storage Systems for Operations that Marketed 5,000 or More Hogs in a Twelve Month Period (Percent of Farms)

Manure Storage System	USDA APHIS Region[a]		
	Midwest	North	Southeast
Deep pit storage	21.5	28.5	85.7
Above ground storage	NA	NA	27.2
Below ground storage	NA	NA	43.3
Anaerobic lagoon	91.2	4.8	33.3
Aerated lagoon	NA	b	NA
Solids separated from liquids	NA	NA	14.4

[a] Midwest=SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast=MO, KY, TN, NC, GA
[b] Aerated lagoons were reported on 70% of the operations. The standard error of the data as reported by NAHMS exceeds 21% and therefore was determined by NAHMS not to be statistically valid.
USDA, 1995

5.4.3 Swine Manure Land Application

Essentially all swine manure is disposed of by application to cropland. Manure from deep pits and pull-plug pits typically is surface applied and may be incorporated by disking or plowing. Subsurface injection also may be used but is a less common practice. Incorporation following application and injection are used most commonly when odors from land application sites are a concern. Irrigation is the most common method of disposal of supernatant from anaerobic lagoons. In arid areas, evaporation is another option for disposal of lagoon liquids. Methods of swine manure disposal by USDA region are summarized in Table 5-8.

5.4.4 Swine Mortality

A variety of methods are used for the disposal of mortalities in the swine industry (Table 5-9). Commonly used methods for disposal of young pig carcasses are burial, composting, and incineration. However, burial is becoming less common because of water

Table 5-8.

Method of Manure Application on Land in 1995

Variable	Size	USDA APHIS Region[a]		
		Midwest	North	Southeast
Irrigation	<5000 hogs marketed	47.6	11.2	2.9
Broadcast		18.4	57.8	69.0
Slurry-surface		33.0	55.7	46.6
Slurry subsurface		NA	26.6	22.9
Irrigation	>5000 hogs marketed	100	74.8	16.4
Broadcast		NA	NA	39.4
Slurry-surface		NA	6.3	68.1
Slurry subsurface		NA	23.6	72.1

a Midwest=SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast=MO, KY, TN, NC, GA
USDA, 1995.
Note: Swine farms use more than one method of disposal, totals will add to more than 100%.

Table 5-9.

Method of Mortality Disposal

Method of disposal	Size	USDA APHIS Region[a]		
		Midwest	North	Southeast
Burial on operation	<2500 hogs marketed	73.2	71.6	46.6
Burn on operation		9.1	7.2	15.2
Renderer entering operation		2.1	14.1	38.7
Renderer at perimeter of operation		2.7	4.2	8.7
Composting		10.3	6.4	13.0
Other		7.0	9.8	6.8
Burial on operation	>2500 hogs marketed	23	21	20.8
Burn on operation		9.9	10.2	17.1
Renderer entering operation		39.9	50.1	37.5
Renderer at perimeter of operation		27.9	23.2	31.4
Composting		NA	NA	11.1
Other		3.4	NA	1.8

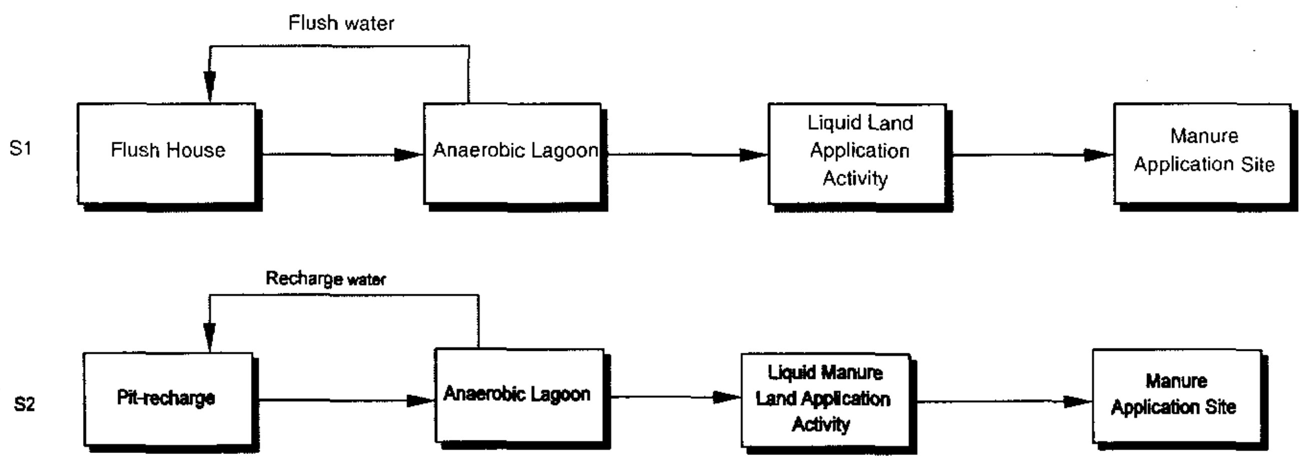
[a] Midwest=SD, NE, MN, IA, IL; North=WI, MI, IN, OH, PA; Southeast=MO, KY, TN, NC, GA
USDA, 1995

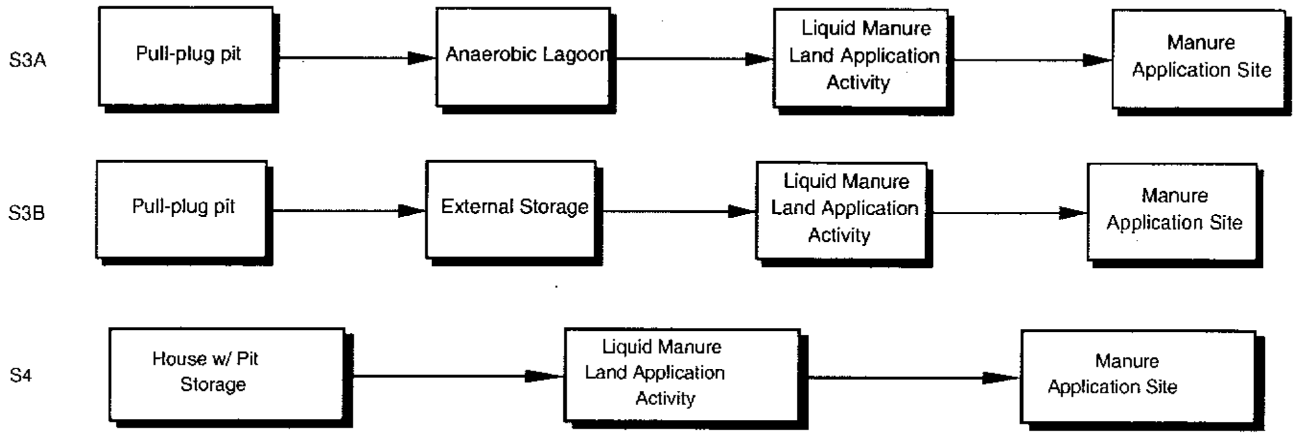
quality concerns and is being replaced primarily by composting. Incineration is more expensive due to equipment and fuel costs, but requires less labor. Carcass composting is a mixed aerobic and anaerobic process, and therefore is a source of those gaseous compound emissions associated aerobic and anaerobic microbial decomposition of organic matter. Land application is used for the disposal of composted carcasses. Larger animals usually are disposed of off-site by rendering although they also may be buried or composted.

5.5 Swine Model Farms

Four basic model farms were identified for swine. These models represent grow-finish operations. The components of the model farms include the confinement houses, manure storage facilities (anaerobic lagoons, external storages, or pit storages), and land application. The four models represent the most common manure collection methods: flush, pit-recharge, pull-plug pit, and pit storage (S1, S2, S3, and S4). For the pull-plug pit model, two variations were developed to account for different manure storage practices (S3A and S3B). The four swine model farms differ in the type of manure management systems in the confinement area and the method of storage.

Swine Models





5.5.1 Confinement

Swine are kept in confinement buildings, usually with slatted floors to separate the manure from the animals. The manure falls through the slats where it is stored for a period of time. Periodically, manure is removed to a storage/stabilization site. The time that the manure is stored in the confinement house depends on the type of manure management system. For storage pits, the storage time varies from several days to several months. For flush systems, manure is removed several times a day. The model swine farms that were developed are differentiated by their manure management systems, which are flush house (S1), pit recharge (S2), pull-plug pit (S3A and S3B), and pit storage (S4). The models with pit storage are sources of emissions of ammonia, hydrogen sulfide, methane, and VOC. The flush house model emits ammonia and hydrogen sulfide. All models emit particulate matter from feed and swine dander.

5.5.2 Storage and Stabilization

In model farms S1 and S2, manure is sent to an anaerobic lagoon. Two types of lagoon systems were considered: (1) an anaerobic lagoon (sometimes referred to as a combined lagoon and storage pond or one-cell lagoon), or (2) an anaerobic lagoon followed by a separate storage pond (two-cell lagoon). Review of industry practices indicated that the one-cell anaerobic lagoon was the most commonly used method. Additionally, a review of emission mechanisms and existing emission data indicated that total emissions would not be substantially different between the one-cell and two-cell systems. Therefore, the model farms only include an anaerobic lagoon. The supernatant from the lagoon is used as flush water or pit recharge water.

In the pull-plug pit model farms, the manure is either sent to an anaerobic lagoon (S3A) or to external storage (S3B). For the pit storage model (S4) manure is sent directly from the confinement facility (i.e., pit storage) to be land applied.

5.5.3 Land Application

Land application includes the manure application activity and the manure application site (i.e., cropland or other agricultural land). All manure from the swine model farm is land applied in a liquid form. Three types of liquid land application activities were considered in developing the model farms; land application by: (1) liquid surface spreader, (2) liquid injection manure spreader, or (3) irrigation. Information was not available to estimate or differentiate emissions from the three activities. Therefore, the model farms do not distinguish among methods of liquid land application.

5.6 References

NPPC. 1996. Swine Care Handbook. National Pork Producers Council, Des Moines, Iowa.

USDA. 1995. Swine '95 Part 1: Reference of 1995 Swine Management Practices. U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS). Fort Collins, Colorado.

USDA. 1999a. 1997 Census of Agriculture. U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS). Washington, D.C.

USDA. 1999b. Hogs and Pigs: Final Estimates 1993-1997. Statistical Bulletin 951. U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS). Washington, D.C.

USDA. 1992. Agricultural Waste Management Field Handbook, National Engineering Handbook, Part 651. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Washington, D.C.

USEPA. 2001. Development Document for the Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations. EPA-821-R-01-003. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

7.0 LAND APPLICATION

Essentially all the manure from livestock and poultry production is applied to cropland for ultimate disposal. A small percentage is composted and sold for horticultural and landscaping use, which merely constitutes another form of land application. Also, a very small percentage of broiler and turkey manure and litter is used in the cow-calf and backgrounding sectors of the beef cattle industry as a supplemental feed.

In the aggregate, livestock and poultry manure contain a substantial fraction of the primary plant nutrients (nitrogen, phosphorus, and potassium) required for plant growth. Manure also is a valuable source of organic matter. Organic matter has value in maintaining the productivity of agricultural soils by increasing water holding capacity and contributing to the maintenance of soil structure, which is critical for oxygen transfer into the root zone. Because crop production substantially reduces soil organic matter levels, application of manure to cropland provides the opportunity for replenishment.

Theoretically, livestock and poultry manure is applied to cropland only at rates adequate to supply crop nutrient needs. Historically, the determination of application rates has been based on crop nitrogen requirements, which has led to the over-application of phosphorus and potassium. This practice was based a primary concern about the impacts of excess nitrogen on surface and ground waters and the belief that soils had an essentially infinite capacity to immobilize the excess phosphorus being applied. It has, however, become apparent that many soils used for livestock and poultry manure disposal have become saturated with phosphorus and transport of significant quantities of soluble phosphorus in surface runoff to adjacent surface waters is occurring. Therefore, the use of crop phosphorus requirements is emerging as the basis for determining rates of manure application to cropland. For soils with high plant available phosphorus concentrations, manure application probably will be prohibited in the future.

It should be recognized, however, that there has been a trend toward applying livestock and poultry manure to cropland at rates in excess of crop requirements as consolidation in the various sectors of animal agriculture has occurred. This is a reflection of the ongoing separation of animal and crop production activities in U.S. agriculture and the limited land resources commonly associated with animal production activities.

7.1 Methods of Land Application

Manure can be land applied in solid, liquid, or slurry form. Application in a solid form has several advantages. Weight and volume are reduced as water content is reduced; however, most operations prefer to handle and dispose of waste in a liquid form because of the reduced labor costs of handling the waste in this manner (USDA, 1992). Chapters 3-6 discuss the physical states of manure from AFOs. Beef and dairy AFOs represented by the model farms have both solid and liquid (or slurry) manure. Veal model farms only have liquid manure, and swine model farms only have liquid (or slurry) manure. Poultry model farms without flush houses have only solid manure, while poultry model farms with flush houses have both solid and liquid manure.

Solid manure can either be applied to the surface or applied to the soil surface followed by incorporation. Liquid and slurry manure can be applied to the surface of soil, applied to the soil surface and followed by incorporation, or injected into the soil. Chapters 3-6 discuss methods of land application most common for waste produced from each animal type. Methods of applying manure to soil are discussed in the following sections.

7.1.1 Surface Application

Manure such as broiler, turkey, and drylot dairy manure are handled as solids and spread by broadcasting on the soil surface. The spreading device used is known as a box type manure spreader. As the name implies, this type of spreader simply is a rectangular box that is either tractor-drawn or truck-mounted with a spreading device at the rear end. During spreading, manure moves to the rear of the box by either a belt or chain-and-flight conveyor. Box type manure spreaders are loaded using skid-steer or tractor-mounted front-end loaders. Large beef cattle feedlots also use pay-loaders (USDA, 1992).

Manure handled as slurries, such as scraped dairy manure from a free-stall barn and swine manure from a deep pit, are spread using tractor-drawn or truck-mounted tanks known collectively as liquid manure spreaders. With closed tanks, the manure may be forced out of the tank under pressure against a distribution plate to create a spray pattern. Another option is to force the manure from the tank under pressure through a manifold with a series of hanging or trailing pipes to create parallel strips of manure on the soil surface. A second type of spreader for manure slurries is a flail-type spreader. This is a partially open tank with chains attached to a rotating shaft positioned parallel to the direction of travel. Manure is discharged perpendicular to the direction of travel by the momentum transferred from the rotating chains (USDA, 1992).

Closed tank type liquid manure spreaders also may be used for the application of anaerobic lagoon liquids to cropland. However, irrigation is commonly used to reduce the labor requirements for disposal. Both traveling gun and center pivot irrigation systems are used with specially designed spray nozzles to allow passage of manure solids and prevent clogging. Solid set irrigation systems also are rarely used due to the labor required for moving the system (USDA, 1992).

With the exception of irrigation systems, manure spreaders are rather crude devices with respect to uniformity of manure distribution. In addition, application rates vary substantially with speed of travel, and spreader calibration is necessary for even a relatively uniform application rate. The inherent variability in the composition of manure especially among different methods of collection and storage/stabilization also contribute to variability in nutrient application rates (USDA, 1992).

7.1.2 Incorporation

Surface applied solid and slurry type manure may be incorporated into the soil by either disking or plowing. Incorporation by these methods or direct injection will reduce odors from the manure application site. Incorporation also provides surface water quality benefits by reducing the potential for run-off of nutrients, oxygen demanding organic compounds, and pathogens in adjacent surface waters. It also serves to conserve nitrogen by reducing nitrogen loss via ammonia volatilization. Incorporation is not practiced with irrigation (USDA, 1992).

7.1.3 Injection

Subsurface injection is probably the best incorporation method because it occurs immediately as manure is spread and only minimally disturbs the soil surface. This makes it attractive for reduced till and no-till cropping systems. Variously shaped devices are used to cut vertical slots in the soil into which slurry is placed. The slots can be left open or fully covered by closing the slots with press wheels or rollers. (USDA, 1992).

7.2 Emissions From Land Application

Due to the numerous variables affecting the nature and emission rates of PM, ammonia, nitrous oxide, hydrogen sulfide, methane, and VOC, even generally quantifying emissions of these substances from land application sites. Adding to this problem is the effect of emissions of these substances prior to land application. For example, a high rate of ammonia loss from an anaerobic lagoon due to warm summer temperatures will translate into lower emissions from the land application site. Conversely, a low rate of ammonia loss from an anaerobic lagoon will translate into a higher loss during land application. Thus, the lack of consistent estimates of emissions from land application sites found in the literature is understandable.

Emissions from land application occur in two phases. The first phase occurs during and immediately following application. These short-term emissions are influenced by the type of manure application method used. The second phase is the release from the soil that occurs over a longer term from the microbial breakdown of substances in the applied manure.

7.2.1 Short-Term Emissions

Particulate Matter

If manure is handled as a solid and has a relatively low moisture content, PM emissions will occur during the spreading process and also may occur immediately after spreading as the result of wind action. The duration of PM emissions due to wind action after spreading depends on weather conditions and is highly variable. For example, a precipitation event occurring immediately after spreading can essentially eliminate PM emissions after spreading. Irrigation, obviously, will have the same effect. Conversely, a period of windy, dry weather after spreading will increase PM emissions.

Nitrogen Compounds, Hydrogen Sulfide, and VOC

If ammonia, hydrogen sulfide, or VOC are present in the manure being spread, emissions will occur by volatilization to the air. The magnitudes of these emissions primarily will depend on whether or not the manure is incorporated into the soil by disking, plowing, or direct injection. Theoretically, injection should be the most effective technique for minimizing the emissions of these compounds, because it prevents exposure to the atmosphere. Efficiency depends to a degree, however, on subsequent closure of the channel or slit in the soil formed by the injector. With disking and plowing, efficiency depends on the time between spreading and incorporation. Plowing is more effective than disking in reducing emissions, because disking will leave some manure exposed to the atmosphere. Precipitation or irrigation immediately following manure spreading also will reduce emissions of ammonia, hydrogen sulfide, and VOC by the transport of these water-soluble compounds into the soil. In the short-term, nitrification, and consequently nitrous oxide emissions, will not occur (Alexander, 1977; Brock and Madigan, 1988; Tate, 1995).

Methane

Little or no methane will be emitted in the short-term because methane is essentially insoluble in water. Only methane in manure will have volatilized prior to land application. Therefore, any short-term methane emissions from land applications sites will be limited to small amounts that are formed immediately following application of manure slurries and liquid manure. Drying and aerobic conditions will limit additional formation of methane to negligible amounts.

7.2.2 Long-Term Emissions

Land application sites used for the disposal of livestock and poultry manure are potential short-term sources of emissions of particulate matter, ammonia, hydrogen sulfide, and VOC. Given the number of variables with the potential to influence the magnitude of actual emissions, developing typical emission factors is problematic. Long-term emissions should be limited to possibly some nitrous oxide emissions. However, these emissions should not be substantially different from those resulting from the use of inorganic nitrogen fertilizers.

Cropland soils are generally aerobic microbial environments except for transient periods of saturation associated with precipitation and possibly irrigation events. Therefore, manurial ammonia, hydrogen sulfide, and VOC not lost by volatilization during or immediately after manure spreading and entering the soil profile should be oxidized microbially to nitrate, sulfate, and carbon dioxide and water, respectively. The nitrogen, sulfur, and carbon in organic compounds subsequently mineralized also will be oxidized.

Nitrogen Compounds

Under transient periods of saturation and anaerobic conditions, any nitrate remaining after plant uptake and leaching to groundwater may undergo microbially mediated denitrification. As discussed earlier in Chapter 2.0, the principal end product of denitrification, is dinitrogen gas. However, small amounts of nitrous oxide and nitric oxide also may be emitted under certain environmental conditions. Therefore, land used for manure disposal can be considered as a potential source of nitrous oxide emissions. However, nitrous oxide also is generated when denitrification follows the application of inorganic nitrogen fertilizer materials. Thus, it appears nitrous oxide emissions would be no greater than if commercial fertilizer are used if nitrogen (in manure) application rates are based on crop requirements. However, application rates in excess of crop requirements would result in higher emissions.

Hydrogen Sulfide

Hydrogen sulfide is oxidized to sulfate in the soil, but subsequently may be reduced back to hydrogen sulfide during transient saturated soil conditions. The high solubility of hydrogen sulfide and other reduced sulfur compounds, however, should preclude any significant emissions. Reoxidation will occur following the return to aerobic conditions (Alexander, 1977; Brock and Madigan, 1988; Tate, 1995).

Methane and VOC

Under transient saturated conditions, any remaining organic compounds in manure may be reduced to VOC and methane. However, any VOC formed will be oxidized to carbon dioxide when aerobic conditions are reestablished. Given that methanogenic bacteria are obligate anaerobes, (i.e., microorganisms that do not grow in the presence of oxygen) the presence of a population sufficient to generate any significant quantity of methane under transient anaerobic conditions is highly unlikely. In addition, if methane is formed, a population of methanotrophic (methane oxidizing) microorganisms capable of oxidizing methane to carbon dioxide may be present (Alexander, 1977; Brock and Madigan, 1988; Tate, 1995).

7.3 References

Alexander, M. 1977. Introduction to Soil Microbiology, 2nd Ed. John Wiley and Sons, New York, New York.

Brock, T.D. and M.T. Madigan. 1988. Biology of Microorganisms, 5th Ed. Prentice Hall, Englewood Cliffs, New Jersey.

Tate, R.L. 1995. Soil Microbiology. John Wiley and Sons, New York, New York.

USDA. 1992. Agricultural Waste Management Field Handbook, National Engineering Handbook, Part 651. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Washington, D.C.