United States
Environmental Protection
Agency

National Emission Inventory—Ammonia Emissions from Animal Husbandry Operations

Draft Report

January 30, 2004

DISCLAIMER

This is a draft report and does not contain final ammonia emission estimates. Data used in this report are subject to change until all ammonia estimates have been finalized.

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EXECUTIVE SUMMARY

EPA estimated ammonia emissions for the years 2002, 2010, 2015, 2020, and 2030 from U.S. animal husbandry operations for inclusion in EPA's National Emissions Inventory (NEI). This report describes the data collected and literature reviewed to develop the inventory, explains the methodology to estimate ammonia emissions, summarizes the results at the state level, and discusses the limitations associated with the data used. This report addresses beef, dairy, swine, poultry, sheep, goat, and horse operations that raise animals both in confined animal feeding operations or on pasture. EPA estimated annual ammonia emissions by animal group for each county in the United States. These results can be obtained from EPA's national emissions inventory web site at <http://www.epa.gov/ttn/chief/eiinformation.html>.

Ammonia Emissions

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 animal feces and as either urea (mammals) or uric acid (poultry) in urine. In this document, the term "manure" refers to the combination of feces and urine that is excreted. Urea and uric acid will hydrolyze rapidly to form ammonia and will be emitted soon after excretion. The formation of ammonia in feces is slower, but will continue with the microbial breakdown of manure under both aerobic and anaerobic conditions. The potential for ammonia emissions 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 manure management 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. A high pH and high temperature favors a higher concentration of ammonia and, thus, greater ammonia emissions. 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. However, there may be little difference in annual ammonia emissions between solid and liquid manure handling systems if liquid manure is stored over extended periods of time prior to land application.

Ammonia emissions are not constant over the year, but can change seasonally. The degree of seasonal variation depends on the geographic region, animal sector, and type of animal production practices used. For example, high temperature increases ammonia volatilization. Precipitation and humidity can either increase or decrease emissions depending on how manure is managed. Higher wind speeds can increase emissions from open manure storage facilities. The population of animals on a farm also varies throughout the year. The confluence of all these factors will affect regions of the country in different ways. While some work has been conducted to study these effects, at this point, additional work is needed to develop a methodology to credibly integrate all of these factors into an ammonia inventory.

Inventory Methodology

Ammonia emissions were estimated using a national inventory model. Emissions were estimated at the county level based on annual average animal populations for each county. The methodology did not take into account regional differences in climate that can affect emissions. Nor does this inventory estimate seasonal differences in ammonia emissions. EPA is investigating methods for developing a seasonal ammonia inventory, and seasonal patterns may be included in a later version of this inventory. The ammonia emission calculation methodology consisted of four general steps, as follows:

- Determine county-level population of animals (beef, dairy, swine, poultry, sheep, goats, horses) for 2002.

- For each county, apportion animal populations for beef, dairy, swine, and poultry to a manure management train (MMT). Animal populations for sheep, goats, and horses are not apportioned to MMTs.

- Estimate county-level emissions from each MMT using emission factors obtained from literature using a process-based inventory model that applies mass balance principles. A composite emission factor is used for sheep, goats, and horses.

- Estimate county-level population of animals and ammonia emissions for 2010, 2015, 2020, and 2030. This step is conducted only for beef, dairy, swine and poultry populations.

EPA estimated county-level populations using data from U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) and the *1997 Census of Agriculture*, and data from the Food and Agriculture Organization of the United Nations. The Agency developed and apportioned MMTs using data from a variety of sources including USDA, the *Census of Agriculture*, and EPA's Office of Water. References found during a series of extensive literature reviews provided emission factor data.

A MMT consists of an animal confinement area (e.g., housing, drylot, pasture); components used to store, process, or stabilize the manure (e.g., anaerobic lagoons, solid separators, deep pits); and a land application site where manure is applied to the land as a fertilizer source. Over 18 different MMTs were developed for this inventory. Although these MMTs do not capture every possible manure management scenario used at beef, dairy, swine, and poultry animal husbandry operations, they do capture the predominant systems in use around the country in terms of the factors that affect ammonia emissions. EPA apportioned the MMTs at the state level. Due to limited information on county-specific manure management practices at animal husbandry operations, EPA has applied the same state-level manure management practice distribution to all of the counties in that state.

The procedure for estimating emissions took into account the amount of nitrogen contained in the excreted manure and the way that the manure is managed. While there were some variations by animal type, depending on available data, the general procedure consisted of first estimating emissions from the animal confinement area. The nitrogen content of the manure was adjusted to reflect the ammonia loss from volatilization. Next, EPA determined the amount of nitrogen sent to each successive component of the MMT and computed the ammonia emission from each component using emission factors. These emission factors were based on the percent nitrogen loss in the manure or a fixed loss of ammonia per animal. This procedure accounts for regional differences in ammonia emissions caused by the different types of MMTs used across the U.S. while ensuring that ammonia emissions are constrained by the amount of available nitrogen in excreted manure.

These estimates assume no emission controls to limit ammonia emissions. While there are several methods to control ammonia such as, diet optimization to reduce excess nitrogen in manure, lagoon covers, and rapid incorporation of manure in the soil, none of these techniques are in widespread use today. Therefore, the extent to which ammonia controls are in place at some farms will have a negligible effect on this emission inventory.

Data Limitations

The tools and methodologies to estimate national emissions from animal agriculture are limited at this time. The major limitations include limited published data on ammonia emission factors for animal husbandry and county-level data on animal populations and manure management practices; an inability to conduct a full process-based modeling approach using a nitrogen mass balance; and an inability to address seasonal and regional influences on ammonia emissions from animal husbandry.

In particular, the availability of credible emission measurements upon which to develop ammonia emission factors is very limited. Because of the large number of variables that influence emissions from animal husbandry, emissions can vary substantially from site-to-site. These variables include climate and geography, diurnal and seasonal emission patterns, feeding practices, animal life stage, and individual animal management practices. The emission factors developed for this inventory do not account for all of these variables. Accordingly, it is not appropriate to use these emission factors to estimate emissions from individual farms. While the methods used for this inventory can be used for assessing emission trends and for general air quality planning, the information presented in this report should not be used for making regulatory determinations or for permitting of any particular facility.

Emission Estimates

Table E-1 presents the U.S. ammonia estimates by animal group. Overall, these estimates are about 33 percent lower than those presented in the 1999 NEI even though the population estimates for the 2002 NEI were about 19 percent higher than those used in the 1999 NEI. This difference is largely due to the differences in the emission estimation methodologies. The 1999 NEI primarily used composite emission factors for an animal type whereas the 2002 NEI apportioned the beef, dairy, swine, and poultry animal populations into the 18 different MMTs consisting of multiple emission factors.

Table E-1. Summary of Ammonia Emissions from U.S. Animal Husbandry Operations

Animal Group	Ammonia Emissions (tons/year)				
	2002	2010	2015	2020	2030
Dairy[1]	558,094	565,892	547,874	545,155	546,666
Beef [2]	656,648	691,174	689,669	705,659	733,662
Poultry[3]	664,238	648,200	720,449	770,068	869,348
Swine[4]	429,468	485,223	512,458	529,288	518,082
Sheep	24,835	NE	NE	NE	NE
Goats[5]	14,028	NE	NE	NE	NE
Horses	71,285	NE	NE	NE	NE
Total	**2,418,595**	**2,390,489**	**2,470,449**	**2,550,171**	**2,667,758**

[1] Includes dairy cows and dairy heifers.
[2] Includes beef cattle, bulls, and calves.
[3] Includes chickens and turkeys.
[4] Includes breeding and market pigs.
[5] Includes milking and Angora goats.
NE- Not estimated

Table E-2 presents percent of nitrogen lost as ammonia from the housing, production, and land application areas for the beef, dairy, swine, and poultry animal groups. Overall, the housing area has the greatest percentage loss of nitrogen as ammonia. This is driven by the fact that the housing area is where the majority of the manure and, in turn, nitrogen is excreted. Therefore, the housing area has the largest amount of nitrogen available for loss as ammonia. Since a composite emission factor was used for sheep, goat, and horse populations, only a total percent of nitrogen lost as ammonia is presented for these animal groups.

Table E-2. Summary of Nitrogen Lost as Ammonia from Animal Husbandry Operations

Animal Group	Percent Nitrogen Lost as Ammonia			
	Housing Area	Production Area	Land Application Area	Total
Dairy[1]	11%	14%	13%	38%
Beef [2]	10%	0%	3%	12%
Poultry[3]	31%	5%	15%	51%
Swine[4]	29%	24%	10%	63%
Sheep	67%			
Goats[5]	50%			
Horses	20%			

[1] Includes dairy cows and dairy heifers.
[2] Includes beef cattle, bulls, and calves.
[3] Includes chickens and turkeys.
[4] Includes breeding and market pigs.
[5] Includes milking and Angora goats.

[The final draft of this report will include a description of the external review process that was conducted to develop the report.]

1.0 INTRODUCTION

This chapter of the report presents a discussion of the forms of nitrogen in animal manure, a discussion of ammonia emissions from animal husbandry operations, and a listing of the information presented in this report.

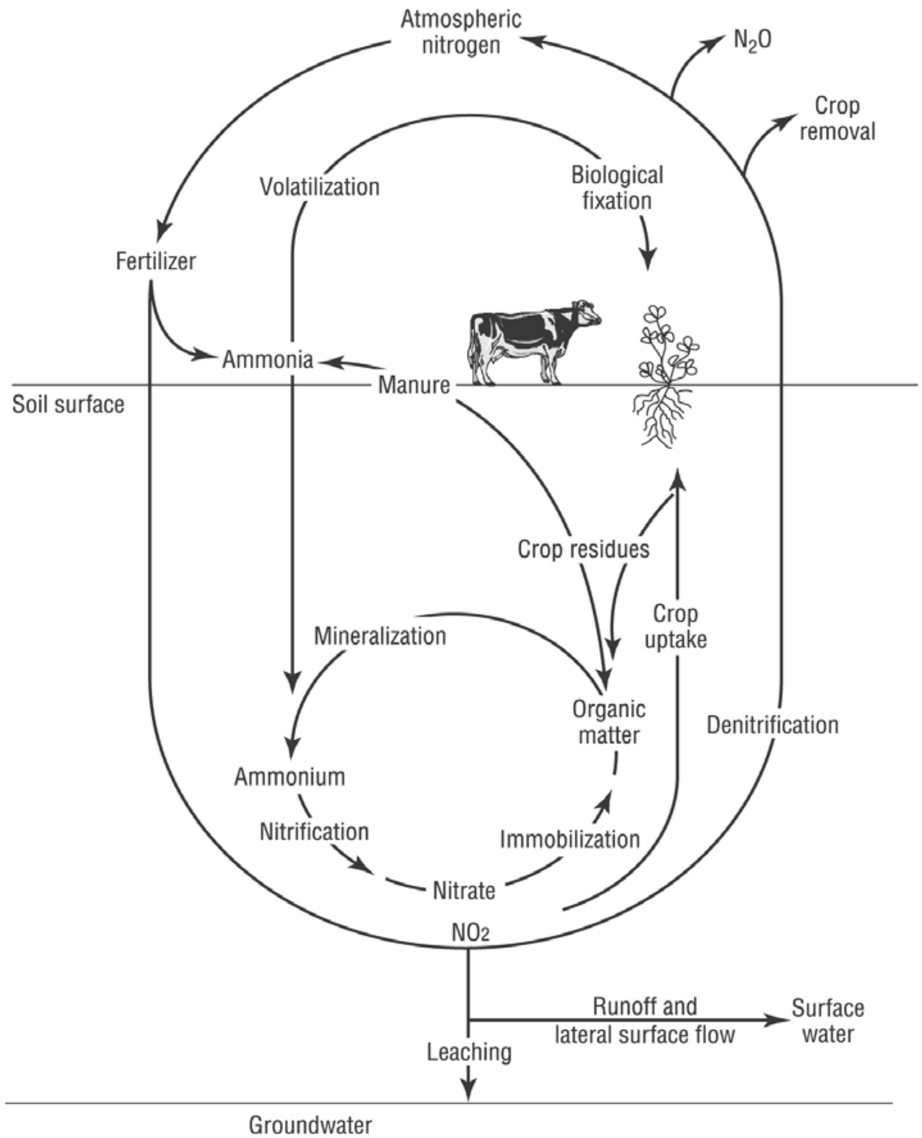
1.1 Nitrogen in Animal Manure

Essentially all of the nitrogen excreted in animal manure is contained in a variety of organic nitrogen compounds. If inorganic forms of nitrogen (ammonia, nitrites, and nitrates) are excreted, they usually are present in trace amounts. However, the conversion of organic nitrogen to inorganic nitrogen (mineralization) begins immediately after manure is excreted. Figure 1-1 illustrates this nitrogen cycle. The fraction of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage depends primarily on time and to a lesser degree temperature. Simple forms of organic nitrogen such as urea and uric acid, which make up about 50 percent of the nitrogen excreted, are rapidly mineralized to ammonia nitrogen while more complex forms of organic nitrogen mineralize more slowly and can be on the order of several years for some compounds.

The fraction of ammonia nitrogen emitted from livestock manure depends on several variables including concentration, pH, and temperature. These variables control the fraction of ammonia nitrogen that is in the form of unionized ammonia, the form of ammonia that is volatile. As concentration, pH, and temperature increase, the potential for ammonia emission also increase. The pH of livestock manure in manure management systems is typically above 7.0 which favors the volatilization and emission of ammonia. Nitrification, the microbial oxidation of ammonia nitrogen to nitrate nitrogen requires a source of oxygen to occur. Since aerobic conditions rarely exist in manure management systems, nitrification does not often occur at livestock operations.

The nitrogen emissions that occur at livestock land application sites are primarily emissions of ammonia. Most of these emissions occur from the ammonia which is present in the manure at the time of land application. A smaller and less significant amount of ammonia formed during mineralization may also be emitted. However, the rate of mineralization will be relatively slow because the organic nitrogen compounds remaining in the manure are most resistant to biodegradation. Therefore, manure that is collected and spread on the land immediately will contain a higher concentration of organic nitrogen than manure that has been stored for an extended period of time, such as settled solids in anaerobic lagoons. Although this organic nitrogen will eventually mineralize to ammonia, several transformations (e.g., fixation by clay minerals and organic matter, direct utilization by higher plants, immobilization by soil microorganisms, nitrification) limit emission potential.

Figure 1-1. The Nitrogen Cycle



Source: Adapted from National Research Council 1993.

1.2 Ammonia Emissions from Animal Husbandry Operations

Ammonia emissions to the atmosphere are an environmental quality concern because they can contribute to eutrophication of surface waters and nitrate contamination of ground waters, and impair air quality. Atmospheric ammonia impairs air quality by reducing visibility when it reacts with acid gases emitted from combustion sources.

Ammonia emissions have a relatively short life in the atmosphere before they enter terrestrial and aquatic ecosystems as a component of wet or dry deposition. Generally, ammonia emissions remain in the atmosphere from a few hours to no more than several days depending on atmospheric conditions. Therefore, reduction in visibility and deposition can occur in the immediate vicinity of or several hundred miles from the emission source.

In the United States, the largest source of ammonia emissions is livestock agriculture, the process of raising and maintaining livestock primarily for the purposes of producing milk, meat, and eggs. Currently, there are over one million livestock and poultry farms in the United States and roughly one-third of these farms raise animals in confinement. Ammonia emissions from animal manure occur everywhere manure is present including confinement and storage facilities, land where manure is applied, and pasture and rangeland where animals are raised. For the purposes of this report, the term “manure” refers to the combination of manure (i.e., the mixture of feces and urine), water directly or indirectly used in animal production activities (e.g., precipitation), and other wastes (e.g., hair, bedding, soil, feed) that are mixed with manure.

The National Emissions Inventory (NEI) currently includes ammonia air emission estimates from animal husbandry operations. The purpose of this report is to update the NEI ammonia inventory based on a more recent understanding of the emission mechanisms for this source category and to begin addressing some of the concerns raised by the National Research Council (NRC) Committee on Air Emissions from Animal Feeding Operations (AFOs) in the 2003 report entitled *Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs*. In this report, NRC indicated that the existing emission factors for AFOs are generally inadequate because of the limited number of measurements on which they are based, as well as the limited generality of the models for which the emission factors have been developed. Due to these data limitations, NRC recommends that EPA implement a process-based modeling approach for estimating air emissions from AFOs. A process-based approach would follow the fate of relevant elements (e.g., nitrogen) step-by-step through the animal feeding process and identify the chemical transformations that take place. It would provide estimates of the characteristics and amount of air emissions that occur at each step as controlled by a mass balance approach (i.e., the emissions plus exports of an element from the system, or from a part of the system, is equal to the input of that substance minus any accumulation that might occur). However, it may take several years of research before data are developed to support this type of modeling.

In the meantime, it is possible to make revised estimates of national and regional ammonia emissions that will be closer to the true emissions. Despite the uncertainties and limitations associated with current ammonia emission data, these revised estimates are an improvement upon the existing inventory, which is based on approaches that are several years old. Animal husbandry operations addressed in this report include dairy, beef, swine, poultry, sheep, goat, and horse that may be raised in confinement or on pasture. EPA updated most of the emission estimates for the ammonia inventory using an inventory model that applies available emission factor data using mass balance principles and assumes no controls specifically to limit air emissions. While this model is not a true and full process-based model as recommended by NRC, it takes into account a number of the principle recommendations of the NRC committee to the extent allowed by current data availability.

1.3 Report Contents

This report presents a summary of the data collected, methodology used, and results of EPA's updated NEI for ammonia from animal husbandry operations. Chapter 2 provides a summary of the data collected and literature reviewed to develop animal population estimates, manure management practices, and emission factors used in the inventory. Chapter 3 summarizes the methodology used to estimate county-level ammonia emissions for animal husbandry operations in the United States. Chapter 4 presents state-level ammonia emission estimates by animal type, compares the results of this inventory to other recent reports and studies, and describes the source category classification (SCC) codes for area nonpoint source ammonia emissions. Chapter 5 identifies and describes the limitations with the data used in developing the county-level ammonia emission estimates. Chapter 6 presents the references used in developing this inventory.

A detailed listing and summary of each emission factor data source is presented in Appendix A. Appendix B presents flow charts illustrating the manure management trains (MMTs) used in this inventory. State-level population data and MMT distribution data are presented in Appendix C. Additional detail on the development of individual emission factors is presented in Appendix D. Appendix E presents the new and existing SCC codes for animal husbandry operations. Appendix F presents a listing of all the counties in the United States and identifies those that had animal population data withheld to avoid disclosing data for individual farms by USDA in the *1997 Census of Agriculture*. These "undisclosed" counties are represented by a "D."

2.0 DATA COLLECTION AND LITERATURE REVIEW

EPA collected and evaluated data from a variety of sources to estimate animal populations and associated manure management systems. These data sources include the U.S. Department of Agriculture (USDA), previous EPA site visits at animal feeding operations (AFOs), previous EPA studies of AFOs, the Food and Agricultural Policy Research Institute (FAPRI), the Food and Agriculture Organization of the United Nations, and published literature. Each of these data sources is discussed below, and analyses of data collected by EPA are presented throughout the remainder of this document.

2.1 U.S. Department of Agriculture

EPA obtained most of its information on animal populations from USDA's National Agricultural Statistics Service (NASS). NASS is responsible for objectively providing accurate statistical information and data support services of structure and activities of agricultural production in the United States. Each year NASS conducts hundreds of surveys and prepares reports covering virtually every facet of U.S. agricultural publications with individual animal production operators being the primary source of data. NASS collects voluntary information using mail surveys, telephone and in-person interviews, and field observations. NASS also conducts a Census of Agriculture every 5 years. The most recent Census is for 1997.

To estimate county-level animal populations, EPA used the state-level animal population estimates obtained from NASS or other reports and applied the county-level distributions from the *1997 Census of Agriculture*. The data sources that were used for animal populations are described below. The specific methodology used for each animal type is described in Section 3.1.

EPA gathered state-level population information from the following published NASS reports:

- *Cattle* and *Cattle on Feed*. These reports provide national- and state-level data on the number of feedlots, number of dairy operations, dairy and cattle inventory, and number of cattle sold per year by size class. EPA used data from these reports to estimate the total annual dairy cow, heifer, and other cattle state populations for 2002. EPA also used data from these reports to identify the manure management practices for beef cattle housed in outdoor confinement areas and feedlots. The specific data used to estimate dairy cattle populations were "Cows That Calved—Milk" and "Heifers 500+Lbs—Milk Repl." The specific data used to estimate other cattle populations are "Cows That Calved—Beef," "Heifers 500+ Lbs—Beef Repl," "Heifers 500+ Lbs—Other," "Bulls 500+ Lbs," "Calves Less Than 500 Lbs," and "Steers 500+ Lbs." Additional data regarding the percent of beef steer and heifers on feedlots were obtained from contacts with the national USDA office. Section 3.1 describes how EPA developed its annual population estimates for dairy and other cattle operations.

- *Hogs and Pigs*. This report presents information on inventory, market hogs, breeding herds, and specifically, the number of farrowings, sows, and pigs per litter, and the number of operations with hogs. EPA used data from this report to estimate the annual swine populations for market pigs less than 60 pounds, market pigs 60 to 119 pounds, market pigs 120 to 179 pounds, market pigs greater than 180 pounds, and breeding pigs. Section 3.1 describes how EPA developed its annual population estimates for swine operations.

- *Chicken and Eggs Annual Summary* and *Poultry Production and Value Annual Summary*. These reports present national and state-level data for the top-producing states on chicken and eggs, production (number and pounds produced/raised), price per pound or egg, and value of production of broilers, chickens, egg, and turkeys. EPA used data from these reports to estimate the state-level annual poultry populations for layers 1 year old and older, total pullets and layers less than 1 year, other chickens, broilers, and turkeys. Section 3.1 describes how EPA developed its annual population estimates for poultry operations.

- *Sheep and Goats*. This report presents information on sheep and lamb inventories, market sheep and lambs, breeding sheep herds, and mohair and wool production. This report does not present state-level population or inventory data for goats. EPA used data from this report to estimate the annual sheep populations. Section 3.1 describes how EPA developed its annual populations estimates for sheep and goat operations.

- *1997 Census of Agriculture*. This is a complete accounting of U.S. agricultural production and is the only source of uniform, comprehensive agricultural data for every county in the nation. EPA used the county population distributions for each animal type for each year of the inventory, as described in Section 3.1. In addition, EPA used swine and dairy farm size distribution data from the Census to assist in identifying appropriate manure management practices for the different sized operations. EPA also used state-level goat population distributions to develop 2002 goat populations.

EPA also obtained animal manure management practice data from USDA’s National Animal Health Monitoring System (NAHMS). NAHMS is an information-gathering program to collect, analyze, and disseminate data on animal health, management, and productivity across the United States. NAHMS conducts national studies to gather data and generate descriptive statistics and information from data collected by other industry sources. EPA gathered manure management practice information from the following NAHMS reports:

- *Dairy ‘96 Part I: Reference of 1996 Dairy Management Practices and Dairy ‘96 Part III: Reference of 1996 Dairy Health and Health Management*. This report presents the results of a survey distributed to dairies in 20 major states to collect information on cattle inventories; dairy herd management practices; health management; births, illness, and deaths; housing; and biosecurity. NAHMS provided reaggregated results from the survey to EPA for use in the inventory.

- *Layers '99 Parts I and II: Reference of 1999 Table Egg Layer Management in the U.S.* This report presents data from 15 states that account for over 75 percent of the table egg layers in the U.S. Part I of the report summarizes the study results including descriptions of farm sites and flocks, feed, and health management. Part II of this report summarizes biosecurity, facility management, and manure handling practices. EPA supplemented information from this report with information from the *United Egg Producer Voluntary Survey Results* to determine the manure management practices used in the states not represented in the NAHMS survey results.

- *Swine '95 Part I: Reference of 1995 Swine Management Practices and Swine '95 Part III: Reference of Grower/Finisher Health and Management Practices.* This report presents information on productivity, preventative and vaccination practices, biosecurity issues, environmental programs, feed and manure management, health and productivity, marketing, and quality control.

EPA also used manure characteristic data from USDA's Natural Resources Conservation Services' Agricultural Waste Management Field Handbook (AWMFH). This handbook is an agricultural/engineering guidance manual that explains general manure management principles and provides detailed design information for particular manure management systems.

2.2 EPA Site Visits

EPA's Office of Water conducted approximately 116 site visits to collect information about AFOs and manure management practices during the course of developing the revised effluent limitations guidelines and standards for the concentrated animal feeding operation industry. Specifically, EPA visited beef feedlots, dairies, and swine, poultry, and veal operations throughout the United States. During the site visits, EPA typically collected the following types of information:

- General facility information including size and age of facility, number of employees, crops grown, precipitation information, and proximity to nearby waterways.

- Animal operational data including flock or herd size, culling rate, and method for disposing of dead animals.

- Description of animal holding areas such as barns or pens, and any central areas, such as milking centers.

- Manure collection and management information including the amount generated, removal methods and storage location, disposal information, and nutrient content.

- Wastewater collection and management information including the amount generated, runoff information, and nutrient content.

- Nutrient management plans and best management practices.

- Available wastewater discharge permit information.

EPA used this information along with the USDA data in developing MMTs for each animal type.

2.3 Other Agency Reports

EPA used data from several EPA reports to develop the emission factors used in this inventory. The OAQPS report entitled *Emissions from AFOs* (USEPA, 2001) summarizes data concerning air emissions from large AFOs including estimated emission factors that are used in this report. The Office of Air and Radiation report entitled *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2000 Final Version* (USEPA 2002) provides methodologies for estimating air emissions from manure management systems and agricultural land and for determining what manure management systems are used at different AFOs that are used in this report. The Office of Water report entitled *Non-Water Quality Impact Estimates for Animal Feeding Operations* (USEPA 2002a) provides methodologies for estimating ammonia emissions from manure management systems and agricultural land and information on the distribution of manure in manure management systems for large dairy operations and large beef and heifer feedlots that are used in this report.

2.4 Food and Agricultural Policy Research Institute (FAPRI)

FAPRI uses comprehensive data and computer modeling systems to analyze the complex economic interrelationships of agricultural production, food, and agribusiness industries. Since 1984, FAPRI programs have been conducted cooperatively by Iowa State University's Center for Agricultural and Rural Development and the University of Missouri-Columbia. One of FAPRI's main objectives is to prepare baseline projections for the U.S. agricultural sector and international commodity markets. EPA used FAPRI's *2003 Agricultural Outlook* report to help develop ammonia emission estimates for the years 2010, 2015, 2020, and 2030. This report presents final projections of FAPRI's agricultural outlook on world agricultural production, consumption, and trade. FAPRI projections assume average weather patterns worldwide, existing policy, policy commitments under current trade agreements, and recent policy changes such as the Farm Security and Rural Investment Act of 2002.

2.5 Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations (FAO) was founded in 1945 with a mandate to raise levels of nutrition and standards of living, to improve agricultural productivity, and to better the condition of rural populations. Today, FAO is one of the largest specialized agencies in the United Nations system and the lead agency for agriculture, forestry, fisheries and rural development. FAO develops and maintains numerous statistical databases including FAOSTAT, an on-line multilingual database currently containing over 1 million time-series records from over 210 countries and territories covering statistics on agriculture, nutrition, fisheries, forestry, food aid, land use and population. EPA used this database to obtain the total number of horses in the United States in 2002. This database is available at <http://apps.fao.org/>.

2.6 Literature Sources

EPA performed several Internet and literature searches to identify papers, presentations, and other applicable materials to use in developing the ammonia emission inventory. Literature sources were identified from library literature searches as well as through EPA contacts and industry experts. Literature collected by EPA covers such topics as housing practices, manure application practices, and general air emissions. However, the primary focus of the literature searches was to identify ammonia emission factors for animal husbandry operations. Appendix A to this report identifies all data sources reviewed with respect to the development of emission factors and identifies whether data were or were not used from that source.

EPA's first literature search included relevant peer reviewed journals and published conference proceedings and research reports available as of May 2001. EPA used the AGRICOLA (Agricultural Online Access) bibliographic data base to identify relevant articles. During this search over 480 references were identified, obtained, and reviewed. Articles were screened to identify emission data that included information on animal species, number of animals present, type of confinement facility, type of manure handling and storage system, phase of animal production, and specific emission points tested. EPA's second literature review was conducted using the Internet and included relevant journals, proceedings, and research reports produced between May 2001 and May 2003 and/or identified by EPA contacts and other industry experts.

3.0 ESTIMATION METHODOLOGY

EPA developed an Access® database to estimate annual ammonia emissions for animal husbandry operations using the following six step process. The ammonia emissions were estimated for each county in the United States for each animal type (cattle, swine, poultry, sheep, goats, horses) included in this analysis. EPA assumed that operations did not employ controls specifically to limit air emissions.

Step 1: Estimate average annual animal populations by animal group, state, and county. Currently, 2002 county-level animal populations estimates do not exist. Therefore, EPA determined county-level animal populations by applying the county distribution from USDA's *1997 Census of Agriculture* to the state-level population data obtained from USDA NASS reports for 2002 for beef, dairy, swine, poultry, and sheep; data from the *1997 Census of Agriculture* for goats; and data from the FAO database for horses.

Step 2: Identify MMTs used by each animal group and then estimate the distribution of the animal population using each MMT. The MMTs referred to in this report consists of an animal confinement area (e.g., housing, drylot, pasture); components used to store, process, or stabilize the manure (e.g., anaerobic lagoons, solid separators, deep pits); and a land application site where manure is applied to the land as a fertilizer source. Over 18 different MMTs were developed for this inventory for beef, dairy, swine, and poultry operations. Although these MMTs do not capture every possible manure management scenario used at animal husbandry operations, they do capture the predominant systems in use around the country in terms of the factors that affect ammonia emissions. Appendix B of this report illustrates each MMT used in this inventory. EPA derived state-level manure management practice data using regional-level data from USDA, EPA, and industry data sources described in Chapter 2. Due to limited information on county-specific manure management practices at animal husbandry operations, EPA applied the same state-level manure management practice distribution to all of the counties in that state. Due to data limitations, MMTs were not developed for sheep, goat, and horse operations.

Step 3: Estimate the amount of nitrogen excreted from the animals using each type of MMT, using general manure characteristics data. EPA used manure excretion data from USDA's AWMFH and average live weight data from personal communications with USDA staff and other sources described in Section 3.3.

Step 4: Identify or develop emission factors for each component of each MMT. All emission factors were obtained from or derived from emission factors presented in published literature sources. See Appendix A to this report for a listing of all literature sources reviewed.

Step 5: Estimate ammonia emissions from each animal group by MMT and county for 2002. The procedure for estimating emissions took into account the amount of nitrogen contained in the excreted manure and the way that the manure is managed. While there were some variations by animal type, depending on available data, the general procedure consisted of first estimating emissions from the animal confinement area. The nitrogen content of the manure was adjusted to reflect the ammonia loss from volatilization. Next, EPA determined the amount of nitrogen sent to each successive component of the MMT and computed the ammonia emission from each component using emission factors. These emission factors were based on the percent nitrogen loss in the manure. This procedure accounts for regional differences in ammonia emissions caused by the different types of MMTs used across the U.S. while ensuring that ammonia emissions are constrained by the amount of available nitrogen in excreted manure.

Step 6: Estimate future ammonia emissions for years 2010, 2015, 2020, and 2030. EPA used data on animal population cycles for beef cattle and poultry from 1990 to 2002 and for dairy cattle and swine from 1982 to 2002, as well as published population projections to 2012, to project future animal populations for the years 2010, 2015, 2020, and 2030. EPA projected the ammonia emissions for these four years using the projected populations for beef, dairy, swine, and poultry and the methodology used to calculate the 2002 ammonia estimates. Due to limited data, future ammonia emission estimates were not calculated for sheep, goat, and horse populations.

Sections 3.1 through 3.6 of this report describe the methodology and data used in each of the six steps described above. Section 3.7 presents an example calculation for ammonia emission from a swine operation with a lagoon.

3.1 Step 1: Animal Population Estimates

EPA developed average annual population estimates for all cattle, swine, poultry, sheep, goat, and horse operations in every U.S. county for the year 2002 using the U.S. Greenhouse Gas Inventory methodology (EPA 2002). This section first describes the methodology used to develop state-level population estimates and then the county-level estimates.

3.1.1 State-Level Populations

The approach used to develop average annual state-level populations for each animal group is described below.

Cattle

NASS data provide cattle inventories from January and July of each year for all beef cattle groups (i.e., cows, heifers, steer, bulls, and calves). Cattle inventory changes over the course of the year, sometimes significantly, as new calves are born and as fattened cattle are slaughtered. Therefore, to develop the best estimate for the annual animal population, the average inventory of cattle by state was calculated. USDA provides January inventory data for each state; however, July inventory data are presented only as a total for the United States. In order to estimate average annual populations by state, a "scaling factor" was developed that adjusts the January state-level data to reflect July inventory changes. This factor equals the average of the U.S. January and July populations divided by the January population. The scaling factor was derived for each cattle group and then applied to the January state-level data to arrive at the state-level annual population estimates. These factors are presented in Table 3-1. Additional data regarding the percent of beef steer and heifers on feedlots were used with the

NASS data to calculate the number of beef heifers and steer at cattle feedlots (Milton 2000). However, EPA obtained the total annual state population data for dairy cows from the January *Cattle* NASS report (USDA 2003a). Therefore, a scaling factor was not used in the calculation of dairy cow populations.

Table 3-1. Cattle Scaling Factors

Cattle Type	Scaling Factor
Dairy	
Dairy Cows	100.2 %
Dairy Heifers	95.6%
Other Cattle	
Beef Cows	101.0%
Bulls	96.8%
Calves	143.3%
Beef Heifers	91.4%
Other Heifers	89.3%
Steer	93.2%
Cattle Feedlots	
Heifers and Steer	94.7%

EPA developed average annual population estimates for 2002 for the cattle animal groups presented in Table 3-2.

Table 3-2. Cattle Animal Groups Used in Inventory

Cattle	Animal Group
Dairy	Dairy Cows
	Dairy Heifers
Other Cattle[1]	Beef Cows (Outdoor Confinement Area)
	Bulls (Outdoor Confinement Area)
	Calves (Outdoor Confinement Area)
	Heifers (Outdoor Confinement Area)
	Steer (Outdoor Confinement Area)
Cattle Feedlots	Beef Heifers (Cattle Feedlots)
	Beef Steer (Cattle Feedlots)

[1] Other cattle may be present at dairy operations, stand-alone heifer operations, cow-calf operations, and/or pasture-based operations.

Swine

For swine, the NASS data provide quarterly inventories for each type of swine, including: market pigs less than 60 pounds, market pigs 60 to 119 pounds, market pigs 120 to 179 pounds, market pigs greater than 180 pounds, and breeding pigs (USDA 2002c). EPA averaged the quarterly data to estimate the average annual swine population for each category. However, quarterly data were not available for all states. In the instances where only December inventory data were reported, EPA used the December data directly to represent the annual average.

EPA developed average annual population estimates for 2002 for the swine groups presented in Table 3-3.

Table 3-3. Swine Animal Groups Used in Inventory

Swine	Animal Group
Breeding Pigs[1]	Breeding Pigs
Market Pigs	Less Than 60 Pounds
	60-119 Pounds
	120-179 Pounds
	Greater Than 180 Pounds

[1] Includes gestating and farrowing sows and boars.

Poultry

State-level average annual poultry population data for the various animal categories (layers 1 year old and older, total pullets and layers less than 1 year, other chickens, broilers, and turkeys) were obtained from USDA NASS reports (USDA 2003d-e). For broiler and turkey operations, the NASS data provide the number of animals that were sold over the year. To estimate annual average populations for these animal groups, the sales data were divided by the typical number of animal cycles. For example, it was estimated that on average there are 5.5 cycles of broilers each year (Lange 2000). Therefore, if 5,500,000 broilers were sold in a year, the equivalent average annual population of broilers was 1,000,000 birds.

For all poultry animal categories, a number of states did not disclose poultry population data. The total number of non-disclosed animals were listed in a category called "Other States." To estimate populations in the non-disclosed states, the total number of non-disclosed animals was distributed equally among the non-disclosed states.

EPA developed average annual population estimates for 2002 for the poultry groups presented in Table 3-4.

Table 3-4 Poultry Animal Groups Used in Inventory

Poultry	Animal Group
Chickens	Layers, 1 Year Old and Older
	Total Pullets (and Layers Less Than 1 Year)
	Other Chickens
	Broilers
Turkeys	Turkeys

Sheep

State-level average annual sheep population data were obtained from USDA's NASS report *Sheep and Goats* (USDA 2003g). A number of states did not disclose sheep population data. The total number of non-disclosed animals were listed in a category called "Other States." To estimate populations in the non-disclosed states, the total number of non-disclosed animals was distributed equally among the non-disclosed states.

Goats

USDA NASS goat population data were only available for a few states. Therefore, EPA used 1997 Census data (USDA 1999) as the 2002 state-level population data for goats.

Horses

USDA NASS does not have a recent annual horse report. Therefore, to derive 2002 state-level horse populations, EPA started with the total number of horses present in the United States in 2002 that was obtained from FAO's database (FAO, 2002). EPA estimated state-level population distributions for the 2002 total horse population using the state-level distributions from the *1997 Census of Agriculture*.

3.1.2 County-Level Populations

After developing the annual average state-level population estimates for all animal groups, EPA distributed the data across all counties in the state. The only identified source of county-level farm data is the 1997 *Census of Agriculture*. The distribution of animal populations by county from the 1997 *Census of Agriculture* were applied to the 2002 state-level populations to estimate the 2002 county-level populations. However, the animal groups presented in the Census data do not exactly match the animal groups used by EPA in this report based on the animal population data obtained from USDA/NASS. Table 3-5 illustrates how the animal population distributions from the Census were matched to the animal populations used in the ammonia inventory.

Table 3-5. Crosswalk Between Animal Groups in USDA's *Census of Agriculture* and the Ammonia Inventory

Animal Groups from *Census of Agriculture*	Ammonia Inventory Animal Groups
Cows and heifers that have calved, milk cows	Dairy Cows Dairy Heifers
Cattle fattened on grain and concentrates, sold	Beef Heifers (Feedlots) Beef Steer (Feedlots)
Cows and heifers that have calved, beef cows	Beef Cows (Outdoor Confinement Area)
Heifer and heifer calves	Heifers (Outdoor Confinement Area)
Steers, steer calves, bulls, and bull calves	Steer (Outdoor Confinement Area) Bulls (Outdoor Confinement Area) Calves (Outdoor Confinement Area)
Hogs and pigs used or to be used for breeding	Breeding Swine
Other hogs and pigs	Market Swine 60-119 lbs Market Swine 120-179 lbs Market Swine greater than 180 lbs
Any poultry, layers and pullets 13 weeks old and older	Layers, 1 Year Old and Older Total Pullets Other Chickens

Table 3-5. Crosswalk Between Animal Groups in USDA's *Census of Agriculture* and the Ammonia Inventory (Cont.)

Animal Groups from *Census of Agriculture*	Ammonia Inventory Animal Groups
Any poultry, broilers and other meat-type chickens	Broilers
Any poultry, turkeys	Turkeys
Sheep and lambs inventory	Sheep
Milk goats, inventory Angora goats, inventory	Goats
Horses and ponies inventory	Horses

Using Table 3-5, EPA matched its animal groups to available county-level animal population data in the *1997 Census of Agriculture*. For each animal group in the Census identified in Table 3-5, EPA accessed the county-level population data (from Volume 1B of the Census of Agriculture CD). Using a database, EPA evaluated which counties have non-disclosed population data. The population data reported for all counties were subtracted from the reported state population. The population that was unaccounted for by county was evenly distributed among those counties with non-disclosed populations. Appendix F presents a listing of all the counties in the United States and identifies those classified as non-disclosed by USDA for a specific animal group. Next, EPA created tables that present the fraction of the population in each county for each animal group using Equation 1.

$$\% Pop_{County} = \frac{County\,Pop_{1997\,Census}}{State\,Pop_{1997\,Census}} \qquad Eq.\,1$$

Where:

$\%Pop_{County}$	=	Percent of the state population in the county
$County\ Pop_{1997\ Census}$	=	County population from *1997 Census of Agriculture*
$State\ Pop_{1997\ Census}$	=	State population from *1997 Census of Agriculture*

Next, EPA calculated average annual county-level populations for 2002 by multiplying the state-level population estimates by the fraction of the population in each county for that animal group as illustrated in Equation 2.

$$Avg\ Annual\ Pop_{County} = Avg\ Annual\ State\ Pop_{NASS} \times \%\ Pop_{County} \qquad Eq.2$$

Where:

Avg Annual Pop_{County}	=	Average annual county population
Avg Annual State Pop_{NASS}	=	Average annual state population from NASS reports
$\%Pop_{County}$	=	Percent of the state population in the county (calculated in Eq.1)

State-level population estimates for each animal group are presented in Appendix C to this report.

3.2 Step 2: Distribution of MMTs

The MMTs identified for beef, dairy, swine, and poultry operations are presented in Table 3-6. MMTs were not developed for sheep, goat, and horse operations.

Table 3-6. MMT Components for Each Animal Type

Animal Type	MMT	Components of System
Swine	Swine Houses with Lagoon Systems	Swine House with Flush, Pit Recharge, or Pull Plug pit, Solids Separator*, Solid Storage, Lagoon, and Land Application
	Swine Houses with Deep Pit Systems	Swine House with Deep Pit and Land Application
	Outdoor Confinement Area	Outdoor Confinement Area
Dairy	Flush Barn	Milking Center, Flush Barn, Drylot, Solids Separator*, Lagoon, Dry Storage of Solids, and Land Application
	Scrape Barn	Milking Center, Scrape Barn, Drylot, Solids Separator*, Lagoon, Dry Storage of Solids, and Land Application
	Outdoor Confinement Area	Milking Center, Outdoor Confinement Area, Manure Storage Tank, and Land Application
	Daily Spread (Scrape Barn)	Milking Center, Scrape Barn, Drylot, Manure Storage Tank, and Land Application
	Barn with Deep Pit	Milking Center, Barn with Deep Pit, Drylot, Manure Storage Tank, and Land Application
	Drylot	Drylot, Storage Pond, and Land Application
	Dairy Barns with Slurry Systems	Scrape Barn with Milking, Slurry Tank/Basin, and Land Application

Table 3-6. MMT Components for Each Animal Type (Cont.)

Animal Type	MMT	Components of System
	Dairy Barns with Solid Storage Systems	Barn with Milking, Dry Storage of Solids, and Land Application
Poultry	Dry Layers	Dry Layer House and Land Application
	Wet Layers	Wet Layer House, Lagoon, and Land Application
	Broiler House	Broiler House, Cake Storage, and Land Application
	Turkey House	Turkey House, Cake Storage, and Land Application
	Broiler/Turkey Outdoor Confinement Area	Outdoor Confinement Area
Beef	Feedlot	Drylot, Settling Basin*, Storage Pond*, Solid Storage, and Land Application
	Outdoor Confinement Area	Outdoor Confinement Area

*These components are not present at all operations.

EPA developed distributions of the beef, dairy, swine, and poultry animal groups using each MMT. These estimates were based on the manure management system data obtained for the U.S. Greenhouse Gas Inventory (EPA 2002). The distributions of MMTs vary geographically and were assigned using regional data on manure management practices. The distribution of each MMT is described below for beef, dairy, swine, and poultry operations. See Appendix C of this report for state-level MMT distributions for beef, dairy, swine, and poultry operations.

The MMT distributions for each animal type were multiplied by the animal populations to determine the number of animals present in each MMT, as shown in Equation 3.

$$\text{Population}_{\text{County, MMT}} = \%\text{MMT} \times \text{Avg Annual Pop}_{\text{County}} \qquad \text{Eq. 3}$$

Where:

$\text{Population}_{\text{County, MMT}}$	=	2002 population that use specific MMT
%MMT	=	Percent of population in specific MMT
$\text{Avg Annual Pop}_{\text{County}}$	=	Calculated in Equation 2

Beef Cattle and Dairy Heifers

The majority of beef operations use outdoor confinement areas (USDA 2003a, b). The beef feedlot and dairy heifer MMT data were developed using information from EPA's Office of Water's engineering cost analyses conducted to support the development of effluent limitations guidelines and standards for concentrated animal feeding operations (ERG 2003a). For these animal groups, the percent of manure deposited in drylots was assumed to be 100 percent. In addition, there was a small amount of manure contained in runoff, which may or may not be collected in runoff ponds. The runoff from feedlots was calculated in *Calculations: Percent Distribution of Manure for Waste Management Systems* (ERG 2003) and was used to estimate the percentage of manure managed in runoff ponds in addition to drylots; this percentage ranges from 0.003 to 0.010 percent.

Mature Dairy Cows

The MMT data for dairy cows were developed using data from the *Census of Agriculture*, EPA's Office of Water, and expert sources described below. Farm-size distribution data were reported in the *1997 Census of Agriculture* (USDA 1999). Due to lack of more recent data, EPA assumed that the data provided for 1997 are the same as that for 2002. Based on data from EPA's Office of Water, the type of MMTs for medium (200 to 700 head) and large (greater than 700 head) farms and the percent of farms that use each type of system (by geographic region) were used to estimate the percent of manure managed in each type of system (ERG 2000). MMT data for small (less than 200 head) dairies were obtained from USDA (USDA 2000a). Information regarding the state distribution of daily spread and outdoor confinement (pasture, range, and paddock) operations for dairy cattle was obtained from personal communication with personnel from state Natural Resource Conservation Service offices, state universities, NASS, and other experts (Deal 2000, Johnson 2000, Miller 2000, Milton, 2000, Poe 1999, Stettler 2000, Sweeten 2000, Wright 2000). Census farm-size distribution data were used in conjunction with the estimated percent of manure managed in the various systems (including daily spread and outdoor confinement areas) to calculate the percent distribution of manure by MMT for each year for each state.

Swine

MMT data for medium (200 to 2,000 head) and large (greater than 2,000 head) swine farms were obtained from USDA (USDA 1996). It was assumed that operations with less than 200 head were outdoor confinement operations. The percent of manure by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the *1997 Census of Agriculture* (USDA 1999) were used to determine the percentage of all swine utilizing the various manure MMT. Due to lack of more recent data, EPA assumed that the data provided for 1997 were the same as that for 2002.

Poultry

MMT data for layers were estimated using USDA/NAHMS and the United Egg Producers' voluntary industry survey data for 1999 (USDA 2000b, UEP 1999). Due to lack of more recent data for other years, the 1999 data were used to represent 2002. EPA derived the MMT data for broilers and turkeys based on information in EPA's 1992 document: *Global Methane Emissions from Livestock and Poultry Manure*. The same MMT distribution was assumed for 2002.

3.3 Step 3: Estimate Nitrogen Excretion

Next, EPA developed estimates of the nitrogen excreted or managed by the animals and subsequently managed in each MMT using the following equation:

$$N_{\text{excreted MMT}} = \text{Population}_{\text{County, MMT}} \times ALW \times N_{rate} \qquad \text{Eq. 4}$$

Where:

$N_{\text{excreted MMT}}$	=	Nitrogen excreted in a particular MMT (lbs/day)
$\text{Population}_{\text{County, MMT}}$	=	2002 animal population associated with specific MMT (calculated in Eq. 3) (animals/year)
ALW	=	Average live weight (lb/head)
N_{rate}	=	Nitrogen excretion rate (lb/1000lb animal mass/day)

EPA used estimates of nitrogen excretion rates from USDA's AWMFH (USDA 1996). Information regarding average live weight was obtained from personal communications with USDA staff and other experts (Safely 2000, Anderson 2003), as well as NRC nutrition requirements (NRC, 2000) and American Society of Agricultural Engineer (ASAE) data (ASAE, 1999). Other national recognized sources for nitrogen excretion data include the ASAE and Midwest Plan Service. However, EPA chose to use AWMFH data to distinguish nitrogen excretion between various animal subpopulations, such as breeding swine from market swine and lactating dairy cows from dry cows, so as to not overestimate nitrogen excretion.

It should be noted that ASAE released a proposed revision to its data in September 2003. The revised standard provides three methods to estimate characteristics using 1) "as excreted" typical values based on diets and performance levels in 2002; 2) equations based on animal performance dietary feed and nutrient uptake; and 3) "as removed" typical values from storage and housing. When this new standard is finalized later this year, EPA will reevaluate the data to determine the best source for the national inventory. Table 3-7 presents both the average live weight and the nitrogen excretion rates by animal group that were used in this analysis.

Table 3-7 Average Live Weight and Nitrogen Excretion Rate Data

Animal Group	Average Live Weight (lb)	Nitrogen Excretion Rate (lb N/1000 lb animal mass/day)
Lactating Dairy Cows	1332	0.45
Dry Dairy Cows	1332	0.36
Dairy Heifers	1049	0.31
Beef Cows (Outdoor Confinement Area)	1175	0.33
Bulls (Outdoor Confinement Area)	1653	0.31
Calves (Outdoor Confinement Area)	260	0.30
Heifers (Outdoor Confinement Area)	926	0.31
Steer (Outdoor Confinement Area)	701	0.31
Beef Heifers (Cattle Feedlots)	926	0.30
Beef Steer (Cattle Feedlots)	926	0.30
Market Swine less than 60 lbs	35	0.60
Market Swine 60-119 lbs	90	0.42
Market Swine 120-179 lbs	149	0.42
Market Swine greater than 180 lbs	200	0.42
Breeding Swine[1]	437	0.24
Layers, 1 year and older and Other Chickens	4	0.83
Total Pullets	4	0.62
Broilers	2	1.10
Turkeys	15	0.74
Sheep	60	0.42
Goats	141	0.42
Horses	992	0.30

[1] Assumed that breeding swine are comprised of 80 percent gestating sows, 15 percent farrowing sows, and 5 percent boars (Safely, 2000).

3.4 Step 4: Identify and Develop Emission Factors

EPA obtained a number of the emission factors used in this inventory from EPA's 2001 report entitled *Emissions from Animal Feeding Operations*. However to meet the purposes of the 2001 report, EPA rejected certain data for use in emission factor development because the quality of data was insufficient or because the data were not representative of the type of farm operations evaluated in that study. For this ammonia inventory, EPA reassessed these references as a secondary check to the validity of the data selected to derive emission factors. In response to recommendations of the NRC report on air emissions from AFOs, EPA also reviewed the data in the 2001 report to address the possible duplication of studies between original references and literature review references. As a result of the reassessment, some data sources from the 2001 report were rejected for inclusion in the ammonia inventory as either duplicative or non-representative, such as experimental systems or farm operations from other countries that are significantly different from U.S. operations. On the other hand, some new data were added. New data represented sources previously overlooked or data to represent farm operations (e.g., pasture systems) that were not the subject of the 2001 study. All of these data sources are described in Appendix A to this report.

To estimate the ammonia emissions associated with each MMT, emission factors were developed for each component of the MMT. EPA used two types of emission factors: factors based on the pounds of ammonia emitted per head (lbs NH_3/year/head) and factors based on the percentage of nitrogen lost as ammonia. If there were insufficient data to estimate an emission factor for a particular component of an animal operation, a similar emission factor from another animal group was transferred, adjusting for differences in manure characteristics. Separate emission factors associated with the land application of the animal manure were developed for large and small swine and dairy operations to account for the different practices used by the operations. Appendix D explains the development of the emission factors, including the equations used. Table 3-8 presents the emission factors developed by animal type for each MMT component. The MMTs and emission factors are presented graphically in Figures 1 through 18 located in Appendix B to this report. Although only 18 MMTs are presented in these figures, permutations of some of the MMTs (e.g., with or without a solids separator) result in more than 18 MMTs used in the inventory model.

Table 3-8. Ammonia Emission Factors by Animal Type and MMT Component

Animal Type	Operation	Ammonia Emission Factor	
		lb NH_3/head/year	Percent N loss*
Swine	Houses with Lagoons	6.0	NA
	Houses with Deep Pits	7.3	NA
	Outdoor Confinement Area	NA	16.6%
	Lagoons	NA	71%
	Stockpile	NA	20%
	Liquid Land Application (>2,000 head)	NA	20%
	Liquid Land Application (<2,000 head)	NA	23%
	Solid Land Application (>2,000 head)	NA	19%
	Solid Land Application (<2,000 head)	NA	17%
Dairy	Flush Barn	NA	23.5%
	Scrape Barn	18.5	NA
	Outdoor Confinement Areas	NA	8%
	Drylots	18.58	NA
	Deep Pits	NA	28.5%
	Lagoons	NA	71%
	Tanks	NA	6.6%
	Stockpile	NA	20%
	Liquid Land Application (>200 head)	NA	20%
	Solid Land Application (>200 head)	NA	17%
	Liquid Land Application (100-200 head)	NA	22%
	Solid Land Application (100-200 head)	NA	18%
	Liquid Land Application (<100 head)	NA	24%
	Solid Land Application (<100 head)	NA	19%

Table 3-8. Ammonia Emission Factors by Animal Type and MMT Component (Cont.)

Animal Type	Operation	Ammonia Emission Factor	
		lb NH_3/head/year	Percent N loss*
Poultry	Dry Layer Houses	0.89	NA
	Wet Layer Houses	0.25	NA
	Broiler Houses	0.22	NA
	Turkey Houses	1.12	NA
	Outdoor Confinement Area	NA	8%
	Lagoon	NA	71%
	Cake Storage	NA	20%
	Wet Layer Land Application	NA	41.5%
	Dry Layer Land Application	NA	7%
	Broiler Land Application	NA	25%
	Turkey Land Application	NA	25%
Beef and Heifers	Drylots	25.2	NA
	Outdoor Confinement Area	NA	8%
	Stockpile	NA	20%
	Storage Pond	NA	71%
	Liquid Land Application	NA	20%
	Solid Land Application	NA	17%
Sheep	All Types	7.43	NA
Goats	All Types	14.1	NA
Horses	Al Types	26.9	NA

NA- Not applicable.
* Refers to the percent of nitrogen entering the operation.

3.5 Step 5: Emission Estimate Calculations

Ammonia emissions from each MMT component were estimated using an emission factor based on either pounds of ammonia per head or percent of nitrogen loss as ammonia from manure. To calculate the ammonia emissions from a MMT component with a emission factor expressed as a fixed amount of ammonia lost per animal, Equation 5 was used:

$$\text{Ammonia}_{\text{MMT component A}} = \text{Population}_{\text{County, MMT}} \times \text{EF}_{\text{MMT component A}} \qquad \text{Eq. 5}$$

Where:

$\text{Ammonia}_{\text{MMT component A}}$	=	Ammonia emissions from a particular MMT component (lbs/year)
$\text{Population}_{\text{County, MMT}}$	=	Animal population in particular MMT, calculated in Eq. 3
$\text{EF}_{\text{MMT component A}}$	=	The emission factor (lbs NH_3/head/year)of the MMT component

To calculate ammonia emissions from a MMT component with an emission factor expressed as a percentage of nitrogen lost as ammonia, Equation 6 was used:

$$\text{Ammonia}_{\text{MMT component B}} = N_{\text{MMT}} \text{ x } \text{EF}_{\text{MMT component B}} \times 17\ NH_3/14\ N \qquad \text{Eq. 6}$$

Where:

$\text{Ammonia}_{\text{MMT component B}}$	=	Ammonia emissions from a particular MMT component (lbs/year)
N_{MMT}	=	Nitrogen excreted/managed in a particular MMT (calculated in Eq. 4)
$\text{EF}_{\text{MMT component B}}$	=	The emission factor (% of N) of the MMT component
$17\ NH_3/14\ N$	=	Conversion factor

When a MMT component follows another component, the amount of nitrogen lost by the preceding component is taken into account. For example, if MMT component B (Equation 6) follows manure management component A (Equation 5):

$$\text{Ammonia}_{\text{MMT component B}} = [N_{MMT} - (\text{Ammonia}_{\text{MMT component A}} \times 14\ N/17\ NH_3)] \times EF_{\text{MMT component B}} \times 17\ NH_3/14\ N \qquad \text{Eq. 7}$$

Where:

$\text{Ammonia}_{\text{MMT component B}}$	=	Ammonia emissions from MMT component B (lbs/year)
N_{MMT}	=	Nitrogen managed in a particular manure management component (calculated in Eq. 4)
$\text{Ammonia}_{\text{MMT component A}}$	=	Ammonia emissions from MMT component A
$14\ N/17\ NH_3$	=	Conversion factor
$EF_{\text{MMT component B}}$	=	Emission factor for MMT component B (%N loss)
$17\ NH_3/14\ N$	=	Conversion factor

To determine the emissions from a complete MMT, the emission from each component of the train are summed. The basic equation for calculating emissions from a MMT is:

$$\text{Ammonia Emission}_{MMT} = \Sigma\ \text{Ammonia Emissions}_{\text{MMT components}} \qquad \text{Eq. 8}$$

3.6 Step 6: Future Emission Estimates

Animal populations vary over time based on a variety of conditions, including feed availability, climate conditions, production changes, and competition. EPA developed animal population projections for beef, dairy, swine, and poultry for the years 2010, 2015, 2020, and 2030 using data available from USDA and FAPRI. These sources provide projections through 2012. Using population data from 1990 through 2002, and the projected populations through 2012, EPA performed regression analyses to develop estimated populations for 2015, 2020, and 2030. These future projections do not account for any changes in animal populations or regional dislocations associated with EPA's revised effluent limitations guidelines and standards for concentrated animal feeding operations promulgated in December 2002 (68 *FR* 7176, February 12, 2003). Due to limited data, animal population projections and future emission estimates were not developed for sheep, goats, and horses.

Annually, both USDA's Economic Research Service (ERS) and FAPRI publish a 10-year projection for the agricultural sector, including projections of total beef cattle and hog inventories, broiler and turkey production, egg production, milk production, and milk cows. The USDA projections may look at changes in some animal populations, but focus on expected changes in overall production and both domestic and foreign supply and demand. The most recent report was published in February 2003 and contains projections from 2001 to 2012 (USDA 2003f). The FAPRI projections cover 2002 to 2012, and provide actual data from earlier years (FAPRI 2003).

Available data sources for each animal type and the methodology used for projections are discussed below. Unless otherwise specified, projections of national U.S. populations have been applied to each state equally. For example, if the national animal population is expected to grow 5 percent between 2001 and 2010, EPA inflated each state's 2001 population by 5 percent to obtain state-level projections.

Dairy Cattle. The USDA and FAPRI projections provide estimated national milk cow inventory numbers as well as milk production for 2001 through 2012. Consistent with the USDA projections, the FAPRI report shows an overall decline in U.S. dairy cow populations throughout the time period. There is a corresponding increase in milk production per cow, resulting in increased milk production throughout the projection. However, due to differing economic variables and assumptions from USDA, the projected populations from FAPRI are not exactly the same as the USDA projections. One benefit of the FAPRI report is that it presents projected milk cow inventory by state rather than just a national total. So, for example, even though the national population of dairy cows will decline by 0.75 to 1 percent each year, certain states (e.g., California, New Mexico, Idaho) are projected to have an increase in dairy cow population. Both USDA and FAPRI projections depict an essentially linear relationship between 2001 milk cow populations and subsequent years. EPA estimated future dairy cattle populations using a linear regression analysis of the state population data available from the FAPRI, covering 1982 through 2012. Figure 3-1 illustrates the linear projection of the dairy cow population in California.

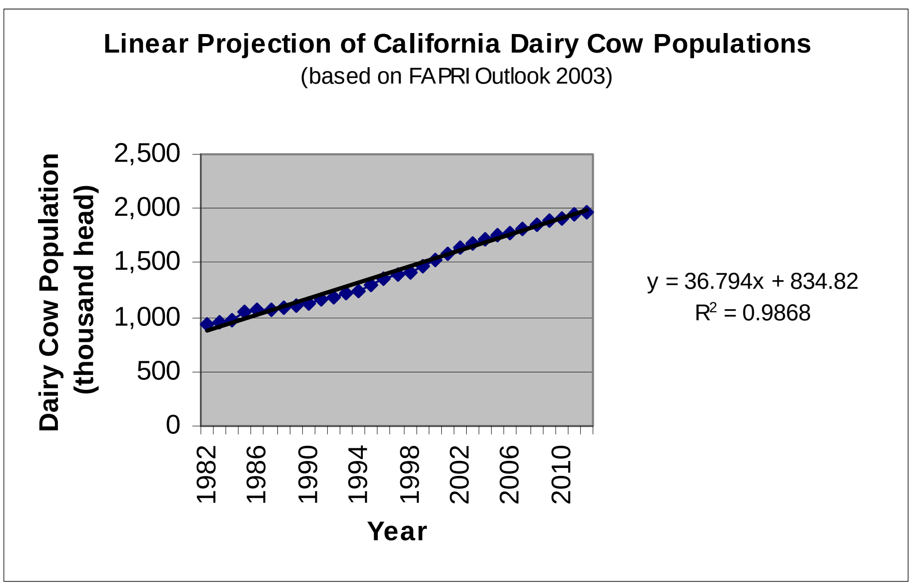


Figure 3-1. Dairy Cow Population Projections for California

Beef Cattle. The USDA projections provide estimated national cattle inventory numbers for total cattle, beef cows, and other cows from 2001 to 2012. The FAPRI projections report also presents total cattle inventory and beef cow inventory. Beef production has a clear cycle generated by producers' expectations about future prices, grain market cycles, and other economic conditions. The pace of the cycle is limited by the reproductive capacity of the animal. Cattle inventories can expand only as fast as cows can reproduce. This has historically resulted in an 8 to 12 year cycle from peak to peak (Kohls 1998). Peaks and troughs of the cycle are 5 to 6 percent higher or lower than the general trend in cattle populations so the stage of the cycle can make a significant difference in population at any given future date.

EPA decomposed the beef cow inventory time series into a trend line, a cyclical component, and a random error component (Bowerman 1987). The trend line was estimated by linear regression of the inventory data from 1990 to 2012 on a time variable. The trend indicates a 0.65 percent growth rate per year. The cyclical component was then estimated as the percentage deviation from the trend line in the historical data. A graph of that information appeared to show a 7-year inventory cycle (trough to peak). (The robust U.S. economy of the 1990s may explain the longer than average cycle.) With so little data, EPA assumed the down side of the cycle was symmetrical with the up side, so the data set would contain three values for each stage of the cycle. The average of the absolute value of the three observations represents the cyclical component. EPA forecasted the trend line out to 2030 and adjusted it by the average percentage deviation from the trend for that stage of the cycle, as illustrated in Figure 3-2.

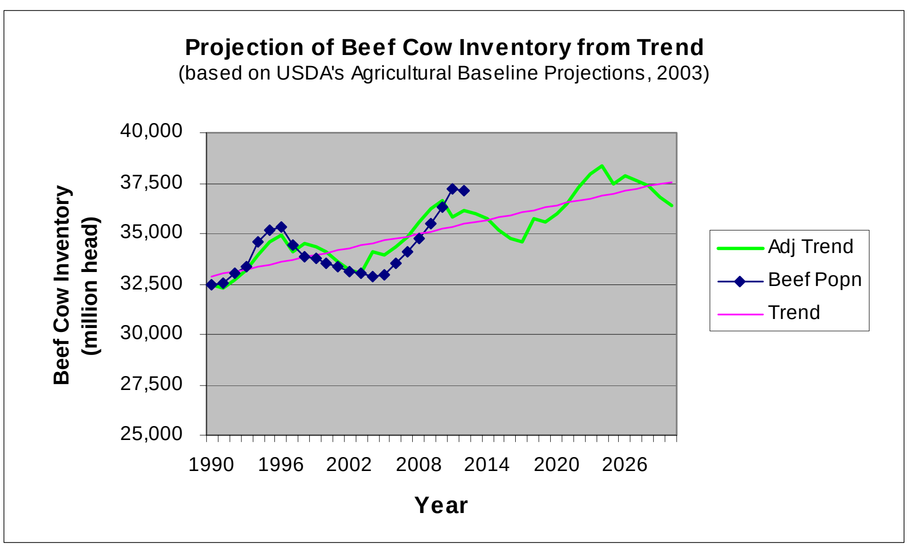


Figure 3-2. Beef Cow Inventory Population Projections

The projections data for beef cattle inventory show some difference in growth cycle of beef cows versus other cattle (e.g., steers, bulls). EPA conducted a separate analysis on these animal populations. Other cattle populations appear to follow similar cycles and were forecasted using the same technique as illustrated in Figure 3-3.

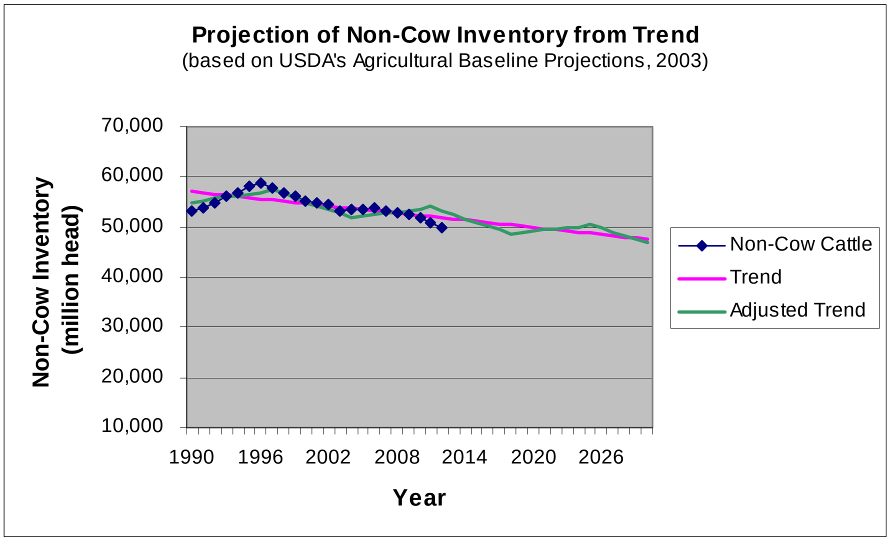


Figure 3-3. Non-Cow Inventory Population Projections

Following development of projected inventories for cattle, EPA estimated projected populations using the scaling factors presented in Section 3.1.1.

Swine. Annual swine populations are categorized by breeding and market swine. Market swine are further subcategorized into four weight categories. The USDA projections provide estimated national December hog inventory numbers for total hogs and pigs for 2001 through 2012. Consistent with the USDA projections, the FAPRI report presents December inventory data and shows an overall increase in swine production over time; however, the FAPRI projections result in lower estimations of swine populations due to different assumptions regarding economic conditions. One benefit of the FAPRI report is that it presents both projected breeding swine and market swine inventories rather than just one combined total. Due to increasing productivity (i.e., increased number of pigs per litter), breeding swine populations are expected to decline over the long term.

EPA estimated future swine populations using a cycle and trend decomposition analysis. Breeding and market swine population projections from the FAPRI report and December inventory data capture the variability of the swine production cycle. Changes in the pork industry in the 1990s have made recent data atypical and inconsistent. For example, EPA replaced the 1996 market hog cyclical deviation with the average of all of the other data because it was so far out of line with the hog cycle. EPA estimated the trend and deviations from the trend as in the cattle analysis. It was not possible to apply the identical technique from the cattle industry to the hog industry because there was no well-defined periodic cycle evident in the annual data. EPA evaluated a 3-year moving average of the deviation to further reduce the random component. As the smoothed cycle continued to appear irregular, EPA assumed that the 2010's will repeat the pattern of the 1990's. Breeding hog populations were estimated using a similar approach. See Figures 3-4 and 3-5 for an illustration of the swine projections for the market hog and breeding hog inventories, respectively.

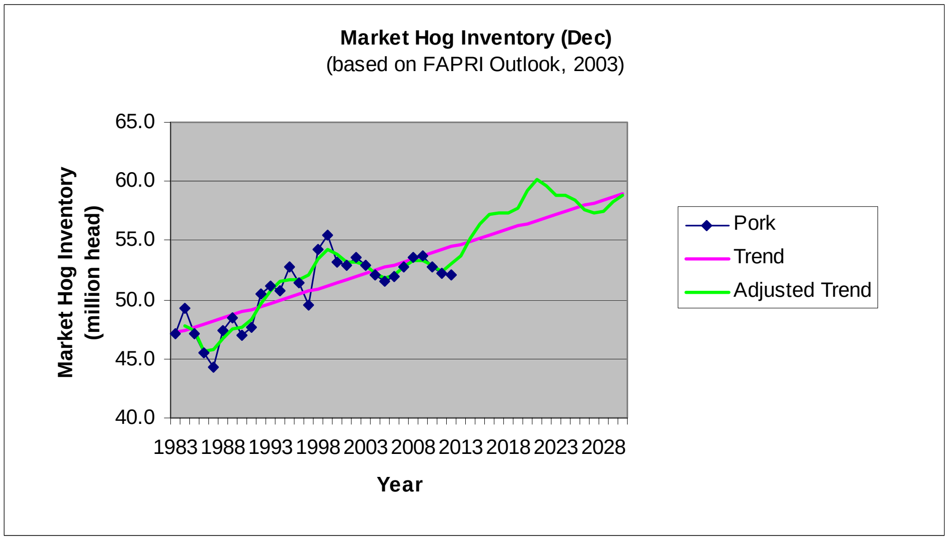


Figure 3-4. Market Hog Inventory Population Projections

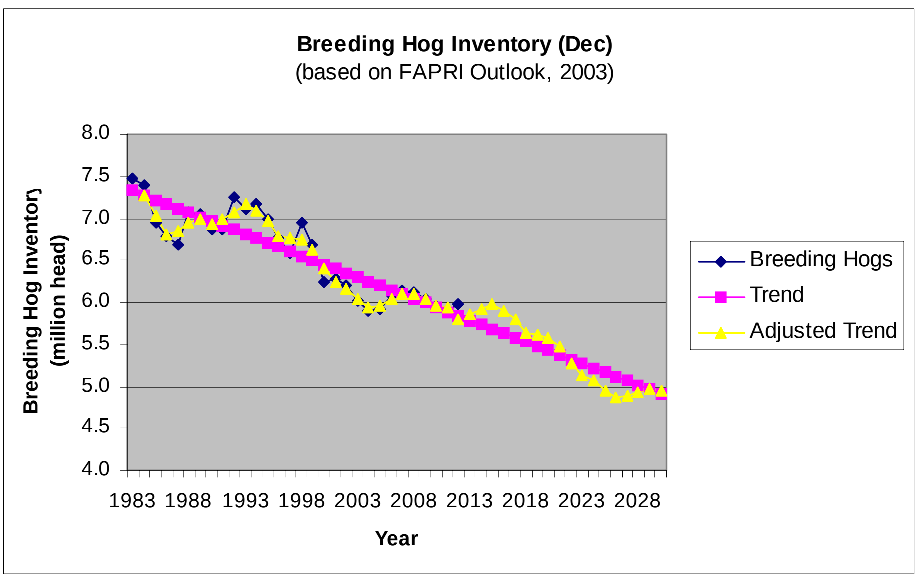


Figure 3-5. Breeding Hog Inventory Population Projections

Poultry – Broilers and Turkeys. Annual poultry populations in the NEI are broken out by broilers, turkeys, and layers. Average annual broiler and turkey populations are estimated by dividing the total birds grown for the year by the estimated turnover of flocks. For example, broiler chickens are typically grown between 45 and 60 days; therefore, an estimated 5.5 flocks of birds are grown each year. The USDA projections do not include projections of animal populations, only national projections of the weight of federally inspected meat slaughtered and total weight of meat produced for 2001 to 2012. The FAPRI projections provide similar data.

In order to project populations of broilers and turkeys, EPA determined the number of animals related to the pounds of broilers and turkeys produced. USDA/NASS publishes an annual summary of broiler and turkey production data in the *Poultry – Production and Value* report. This report provides data on both the number and pounds of layers or turkeys produced. With these data, EPA calculated a national average weight of broilers and turkeys produced from 1990 to 2002 and used a linear regression analysis to develop a relationship between pounds of poultry produced and the number of birds, as illustrated in Figure 3-6. This relationship was used to convert USDA's projections for 2005 and 2010 to number of birds. EPA also used a linear regression analysis to predict the pounds of poultry produced for 2015, 2020, and 2030 and converted these estimates to number of birds.

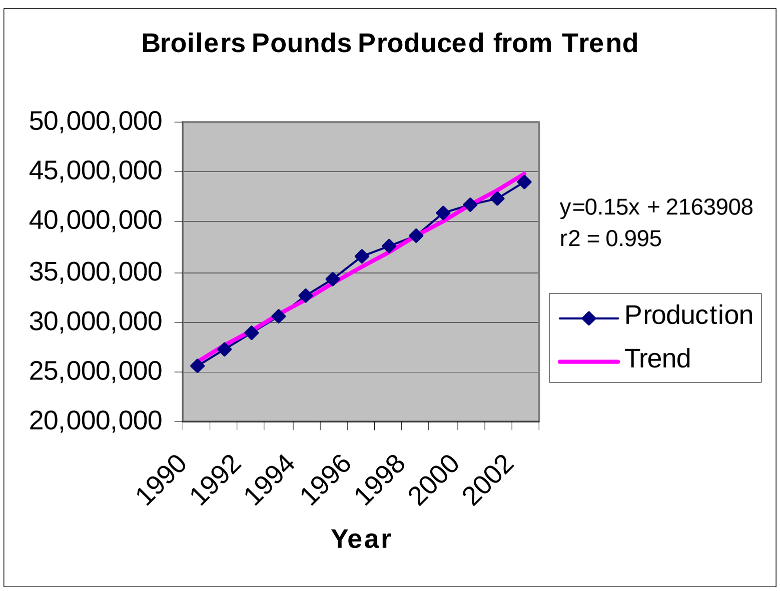


Figure 3-6. Broiler Population Projections

Poultry – Layers. Annual poultry populations in the NEI are broken out by broilers, turkeys, and layers. Layer populations are divided further into hens greater than one year (laying birds), pullets (adolescent laying birds), and other chickens. The USDA projections do not include projections of animal populations, only national projections of egg production for 2001 to 2012. The FAPRI projections provide similar data.

In order to project populations of layers, EPA determined the number of animals related to the number of eggs produced. USDA/NASS publishes an annual summary of layer data in the *Chickens and Eggs* report. This report provides state-level data on the average number of layers for a year, the eggs per layer, and the total egg production. Data for Alaska, Arizona, Nevada, New Mexico, and North Dakota have been combined to avoid disclosing individual operations. With these data, EPA calculated a national average number of eggs produced per layer from 1990 to 2002 and used a linear regression analysis to develop a relationship between number of eggs produced and the number of birds. This relationship was used to convert USDA's projections to number of birds. EPA also used a linear regression analysis to predict the number of eggs produced in the U.S. for 2015, 2020, and 2030. Next, EPA assumed the state-level distribution of eggs produced would be the same as in 2002 and used the state-level data on number of eggs produced per bird to calculate state-level bird inventories.

There are little data available to specifically estimate pullet populations. EPA developed projections for pullets by performing a linear regression analysis on the existing state inventory estimates for 1990 to 2002.

3.7 Example Ammonia Emission Calculation

This section presents an example ammonia emission calculation for swine managed in houses with lagoons in Beaufort County North Carolina. The animal populations used in this calculation are presented in Table 3-9. These populations represent the annual average number of swine, by subgroup, in Beaufort County. Following the methodology described in this report, the ammonia emissions are calculated using the following six step process:

1. Calculate the population of swine that are managed in houses with lagoon systems;
2. Calculate the amount of nitrogen excreted by the animals;
3. Calculate ammonia emissions from the housing area;
4. Calculate ammonia emissions from the lagoon system;
5. Calculate ammonia emissions from land application; and
6. Calculate total ammonia emissions.

The calculations associated with each of these steps are provided below.

Table 3-9. Beaufort County North Carolina Swine Population

Swine Subgroup	Description	Annual Average Population (head)
Swine <60	Market pigs less than 60 pounds	33,857
Swine 60-119	Market pigs 60-119 pounds	20,410
Swine 120-179	Market pigs 120-179 pounds	16,929
Swine >180	Market pigs greater than 180 pounds	14,287
Swine Breed	Breeding pigs	18,991
Total		104,474

3.7.1 Step 1: Calculate Swine Population Managed in Swine Houses with Lagoon Systems

The percent of North Carolina swine operations using swine houses with lagoon systems is 89 percent. This value was obtained from Table C-2. To determine the swine population in Beaufort County that use swine houses with lagoon systems the annual average population by subgroup is multiplied by 89 percent. Table 3-10 presents the swine population in Beaufort County that are assumed to be managed in swine houses with lagoon systems.

Table 3-10. Beaufort County North Carolina Swine Population Managed in Houses with Lagoon Systems

Swine Subgroup	Annual Average Population (head)	Distribution of Swine Managed in Houses with Lagoon Systems	Population Managed in Houses with Lagoon Systems (head)
Swine <60	33,857	89%	30,133
Swine 60-119	20,410	89%	18,165
Swine 120-179	16,929	89%	15,067
Swine >180	14,287	89%	12,715
Swine Breed	18,991	89%	16,902
Total	104,474	89%	92,982

3.7.2 Step 2: Calculate Nitrogen Excreted by the Animals

The amount of nitrogen excreted by the animals is calculated by estimating the annual amount of nitrogen excreted by each population subgroup and summing them for a total amount excreted. Annual nitrogen excreted values were calculated for each of the swine subgroups using the following equation:

$$N_{excreted} = Population \times N_{rate} \times ALW \times 365$$

Where:

$N_{excreted}$	=	Nitrogen excreted by population subgroup, lbs/day
Population	=	Swine population, head (from Table 3-9)
N_{rate}	=	Nitrogen excretion rate, lb N/1000lb animal mass/day (from Table 3-7)
ALW	=	Average live weight, lb/head (from Table 3-7)
365	=	Conversion factor, days to years

$N_{excreted\ Swine<60}$ = 30,133 head × 0.60 lb N/1000 lb animal mass/day × 35 lb/head × 365 days/year = 230,969 lbs N/yr

$N_{excreted\ Swine60-119}$ = 18,165 head × 0.42 lb N/1000 lb animal mass/day × 90 lb/head × 365 days/year = 250,622 lbs N/yr

$N_{excreted\ Swine120-179}$ = 15,067 head × 0.42 lb N/1000 lb animal mass/day × 149 lb/head × 365 days/year = 344,156 lbs N/yr

$N_{excreted\ Swine>180}$ = 12,715 head × 0.42 lb N/1000 lb animal mass/day × 200 lb/head × 365 days/year = 389,842 lbs N/yr

$N_{excreted\ SwineBreed}$ = 16,902 head × 0.24 lb N/1000 lb animal mass/day × 437 lb/head × 365 days/year = 647,029 lbs N/yr

Next, to calculate the amount of nitrogen excreted for the entire Beaufort County swine population managed in swine houses with lagoon systems, the nitrogen excreted values for the five swine population subgroups were summed.

$$N_{excreted,\ Swine\ House\ with\ Lagoon\ System} = N_{excreted\ Swine<60} + N_{excreted\ Swine60-119} + N_{excreted\ Swine120-179} + N_{excreted\ Swine>180} + N_{excreted\ SwineBreed}$$

$$= 230{,}969 + 250{,}622 + 344{,}156 + 389{,}842 + 647{,}029$$

$$= 1{,}862{,}618 \text{ lbs N/yr}$$

3.7.3 Step 3: Calculate Ammonia Emissions from Housing Area

Ammonia emissions from swine houses were calculated by multiplying the swine population in Beaufort County managed in houses with lagoon systems by the NH_3 emission factor for swine houses with lagoon systems.

$$NH_{3\ House} = Population_{Swine\ house\ with\ lagoon} \times EF_{Swine\ house\ with\ lagoon}$$
$$= 92{,}982\ head \times 6\ lbs\ NH_3/head/yr$$
$$= 557{,}892\ lbs\ NH_3/yr$$

Where:

$NH_{3\ House}$	=	NH_3 emissions from swine houses with lagoon systems in Beaufort County NC, lbs NH_3/yr
$Population_{Swine\ house\ with\ lagoon}$	=	Swine population in Beaufort County NC managed in houses with lagoon systems, head (from Table 3-9)
$EF_{Swine\ house\ with\ lagoon}$	=	NH_3 emission factor for swine houses with lagoon systems, lbs NH_3/head/yr (from Table 3-8)

3.7.4 Step 4: Calculate Ammonia Emissions from Lagoon Systems

Ammonia emissions from lagoons were estimated by determining the amount of nitrogen lost as ammonia in the swine house, determining the amount of nitrogen excreted remaining to go to the lagoon, and multiplying the amount of nitrogen in the lagoon by the emission factor for swine lagoons.

$$N_{house\ loss} = NH_{3\ House} \times 14N/17NH_3$$
$$= 557{,}892\ lbs\ NH_3/yr \times 14N/17NH_3$$
$$= 459{,}440\ lbs\ N/yr$$

Where:

$N_{house\ loss}$	=	Amount of nitrogen lost in the swine house as ammonia, lbs N/yr
$NH_{3\ House}$	=	NH_3 emissions from swine houses with lagoon systems in Beaufort County NC, lbs NH_3/yr
$14N/17NH_3$	=	Conversion factor N to NH_3

$$N_{Lagoon} = N_{excreted,\ Swine\ House\ with\ Lagoon\ System} - N_{House\ loss}$$
$$= 1{,}862{,}618\ lbs\ N/yr - 459{,}440\ lbs\ N/yr$$
$$= 1{,}403{,}178\ lbs\ N/yr$$

Where:

N_{Lagoon}	=	Amount of nitrogen managed in the lagoon, lbs N/yr
$N_{excreted, Swine House with Lagoon System}$	=	Amount of nitrogen excreted by the swine population, lbs N/yr
$N_{house loss}$	=	Amount of nitrogen lost in the swine house, lbs N/yr

$$NH_{3\ Lagoon} = N_{Lagoon} \times EF_{Swine\ lagoons} \times 17NH_3/14N$$
$$= 1{,}403{,}178 \text{ lbs N/yr} \times 71\% \times 17NH_3/14N$$
$$= 1{,}209{,}740 \text{ lbs } NH_3\text{/yr}$$

Where:

$NH_{3\ Lagoon}$	=	NH_3 emissions from lagoons in Beaufort County NC, managed in swine house with lagoon systems, lbs NH_3/yr
N_{Lagoon}	=	Amount of nitrogen managed in the lagoon, lbs N/yr
$EF_{Swine\ lagoons}$	=	NH_3 emission factor for swine lagoons, 71% of N loss (from Table 3-7)
$17NH_3/14N$	=	Conversion factor NH_3 to N

3.7.5 Step 5: Calculate Ammonia Emissions from Land Application

Ammonia emissions from land application were estimated by determining the amount of nitrogen lost in the swine house and lagoon, determining the amount of nitrogen excreted remaining to go to land application, and multiplying the amount of nitrogen available for land application by the appropriate emission factor for swine liquid land application.

$$N_{House+lagoon\ loss} = (NH_{3\ House} + NH_{3\ Lagoon}) \times 14N/17NH_3$$
$$= (557{,}892 \text{ lbs } NH_3\text{/yr} + 1{,}209{,}740 \text{ lbs } NH_3\text{/yr}) \times 14N/17NH_3$$
$$= 1{,}455{,}697 \text{ lbs N/yr}$$

Where:

$N_{House+lagoon\ loss}$	=	Amount of nitrogen lost as ammonia in the swine house and lagoon, lbs N/yr
$NH_{3\ House}$	=	NH_3 emissions from swine houses with lagoon systems in Beaufort County NC, lbs NH_3/yr
$NH_{3\ Lagoon}$	=	NH_3 emissions from lagoons in Beaufort County NC, managed in swine house with lagoon systems, lbs NH_3/yr
$14N/17NH_3$	=	Conversion factor N to NH_3

$$N_{LandApp} = N_{excreted,\ Swine\ House\ with\ Lagoon\ System} - N_{House+lagoon\ loss}$$
$$= 1{,}862{,}618 \text{ lbs N/yr} - 1{,}455{,}697 \text{ lbs N/yr}$$
$$= 406{,}921 \text{ lbs N/yr}$$

Where:

$N_{LandApp}$	=	Amount of nitrogen available for land application, lbs N/yr
$N_{excreted, Swine House with Lagoon System}$	=	Amount of nitrogen excreted by the swine population, lbs N/yr
$N_{House+lagoon loss}$	=	Amount of nitrogen lost as ammonia in the swine house and lagoon system, lbs N/yr

$$NH_{3\ Land} = (N_{LandApp} \times EF_{Swine\ LandAp\ Liquid\ Large} \times SD_{>2000} \times 17NH_3/14N) + (N_{LandApp} \times EF_{Swine\ LandAp\ Liquid\ Small} \times SD_{<2000} \times 17NH_3/14N)$$

$$= (406{,}921 \text{ lbs N/yr} \times 20\% \times 94.9\% \times 17NH_3/14N) + (406{,}921 \text{ lbs N/yr} \times 23\% \times 5.09\% \times 17NH_3/14N)$$

$$= 99{,}569 \text{ lbs } NH_3\text{/yr}$$

Where:

$NH_{3\ Land}$	=	NH_3 emissions from the land application of swine manure managed in houses with lagoon systems in Beaufort County NC, lbs NH_3/yr
$N_{LandApp}$	=	Amount of nitrogen available for land application, lbs N/yr
$EF_{Swine\ Land\ Ap\ Liquid\ Large}$	=	NH_3 emission factor for liquid land application of swine manure from operations with greater than 2,000 head, % of N loss (from Table 3-8)
$EF_{Swine\ Land\ Ap\ Liquid\ Small}$	=	NH_3 emission factor for liquid land application of swine manure from operations with less than 2,000 head, % of N loss (from Table 3-8)
$SD_{>2000}$	=	Percent of swine operations that are greater than 2000 head, %
$SD_{<2000}$	=	Percent of swine operations that are less than 2000 head, %
$17NH_3/14N$	=	Conversion factor NH_3 to N

3.7.6 Step 6: Calculate Total Ammonia Emissions

Total ammonia emissions were calculated by summing the emissions from the house, lagoon, and land application, as follows:

$$
\begin{aligned}
NH_{3\ Total} &= NH_{3\ House} + NH_{3\ Lagoon} + NH_{3\ Land} \\
&= 557{,}892 \text{ lbs } NH_3/yr + 1{,}209{,}740 \text{ lbs } NH_3/yr + 99{,}569 \text{ lbs } NH_3/yr \\
&= 1{,}867{,}201 \text{ lbs } NH_3/yr
\end{aligned}
$$

Where:

$NH_{3\ Total}$ = Total NH_3 emissions from swine houses with lagoons systems, lbs NH_3/yr

$NH_{3\ House}$ = NH_3 emissions from swine houses in Beaufort County NC, managed in swine house with lagoon systems, lbs NH_3/yr

$NH_{3\ Lagoon}$ = NH_3 emissions from lagoons in Beaufort County NC, managed in swine house with lagoon systems, lbs NH_3/yr

$NH_{3\ Land}$ = NH_3 emissions from land applications of manure in Beaufort County NC, managed in swine house with lagoon systems, lbs NH_3/yr

4.0 SUMMARY OF NATIONAL AMMONIA INVENTORY

This chapter summarizes the estimated ammonia emissions for animal husbandry operations for the years 2002, 2010, 2015, 2020, and 2030, identifies where the results can be obtained for further review, describes the format of the NEI ammonia emission estimates, and provides a comparison between these results and other recent ammonia emission efforts and recommendations.

4.1 NEI Results for Ammonia Emissions from Animal Husbandry Operations

Using the data and methodology discussed in Chapters 2 and 3, annual ammonia emissions were estimated for animal husbandry operations across the country. The estimated national ammonia emissions, by animal group and MMT, are presented in Table 4-1. State-level estimates by animal type for 2002 are presented in Table 4-2. County-level estimates for all animal groups and all projected years can be obtained from EPA's national emissions inventory web site at http://www.epa.gov/ttn/chief/eiinformation.html. EPA is maintaining the Access® database used to develop these estimates.

4.2 Comparison to Other Recent Ammonia Emission Efforts and Recommendations

This section provides a comparison of the results presented in this report to other recent ammonia emission efforts and recommendations. The studies included in this comparison consist of:

- EPA's 1999 *NEI for Ammonia Emissions from Animal Husbandry Operations*;
- EPA's 2002 report entitled *Review of Emission Factors and Methodologies to Estimate Ammonia Emissions from Animal Waste Handling*;
- Sonoma Technology, Inc's 2003 report prepared for Lake Michigan Air Directors Consortium (LADCO) entitled *Recommended Improvements to the CMU Ammonia Emissions Inventory Model for Use by LADCO*; and
- Robert Pinder's 2003 report entitled *Ammonia Emissions from Dairy Farms: Development of a Farm Model and Estimation of Emissions from the United States*.

Table 4-1. National Ammonia Emission Estimates

Animal Type	Type of Operation	Ammonia Emissions (tons/yr)				
		2002	2010	2015	2020	2030
Swine	Swine Lagoon	260,625	303,297	320,004	329,890	322,389
	Swine Deep Pit	167,844	180,725	191,188	198,092	194,416
	Outdoor Confinement	999	1,200	1,267	1,307	1,278
	Total Swine	**429,468**	**485,223**	**512,458**	**529,288**	**518,082**
Poultry	Dry Layers	169,290	142,038	155,565	165,473	185,288
	Wet Layers	33,206	27,245	29,887	31,847	35,808
	Broilers	359,042	375,344	431,529	469,482	545,390
	Turkeys	101,869	102,712	102,505	102,236	101,697
	Broiler Outdoor Confinement	647	676	778	846	983
	Turkey Outdoor Confinement	183	185	185	184	183
	Total Poultry	**664,238**	**648,200**	**720,449**	**770,068**	**869,348**
Dairy	Flush Barn	167,571	189,113	201,959	215,447	243,048
	Scrape Barn	77,483	83,472	85,765	89,051	96,441
	Outdoor Confinement Area	13,329	11,067	8,593	6,920	5,002
	Daily Spread	50,677	45,468	39,969	36,062	29,789
	Deep Pit	10,063	8,877	7,592	6,640	5, 054
	Solid Storage	91,730	78,260	64,286	53,819	36,174
	Slurry	31,593	27,428	23,005	19,728	14,263
	Drylot	115,647	122,207	116,704	117,487	116,895
	Total Dairy	**558,094**	**565,892**	**547,874**	**545,155**	**546,666**
Beef and Heifers	Feedlot	300,385	332,923	352,763	372,602	412,281
	Outdoor Confinement	356,263	358,251	336,906	333,057	321,381
	Total Beef	**656,648**	**691,174**	**689,669**	**705,659**	**733,662**
Sheep	**Total Sheep**	**24,835**	**NE**	**NE**	**NE**	**NE**
Goats	**Total Goats**	**14,028**	**NE**	**NE**	**NE**	**NE**
Horses	**Total Horses**	**71,285**	**NE**	**NE**	**NE**	**NE**
TOTAL		**2,418,595**	**2,390,489**	**2,470,449**	**2,550,171**	**2,667,758**

NE- Not estimated

Table 4-2. 2002 State-Level Ammonia Emission Estimates by Animal Type

State	2002 Ammonia Emission Estimates (tons/yr)										
	Dairy	Cattle Feedlots	Other Cattle	Swine	Layers	Broilers	Turkeys	Sheep	Goats	Horses	TOTAL
AK	68	1	53	9	0	0	0	36	1	70	**238**
AL	677	84	7,178	1,333	7,344	41,113	0	36	194	1,249	**59,209**
AR	1,137	317	9,229	4,651	10,362	46,392	10,084	36	120	1,177	**83,506**
AZ	11,526	6,658	1,943	1,144	0	0	0	498	289	1,109	**23,167**
CA	136,184	10,470	9,739	1,167	12,374	7,918	6,051	2,972	283	3,322	**190,479**
CO	6,845	26,384	8,900	6,427	2,409	0	2,231	1,375	91	2,398	**57,059**
CT	1,254	3	109	26	1,739	0	2	29	10	200	**3,372**
DE	450	3	58	157	686	10,066	1	36	5	95	**11,558**
FL	10,282	44	8,775	283	6,444	4,485	0	36	171	1,612	**32,131**
GA	3,332	64	5,801	2,960	14,301	50,467	0	36	258	1,037	**78,257**
HI	544	13	750	182	304	34	0	36	23	145	**2,033**
IA	11,548	20,243	11,281	99,659	21,116	7,918	2,325	929	87	1,774	**176,880**
ID	28,109	7,303	5,526	136	624	0	0	966	44	1,749	**44,456**
IL	6,312	4,212	5,181	27,254	1,837	0	991	260	76	1,518	**47,643**
IN	8,059	2,442	2,564	20,785	13,312	7,918	4,444	212	82	1,722	**61,541**
KS	5,103	55,161	18,913	12,785	0	0	2,231	372	51	1,551	**96,168**
KY	3,954	314	11,068	3,284	2,838	10,555	0	36	98	2,817	**34,965**
LA	1,712	36	4,375	173	1,281	7,918	0	36	59	885	**16,475**

Table 4-2. 2002 State-Level Ammonia Emission Estimates by Animal Type (Cont.)

State	2002 Ammonia Emission Estimates (tons/yr)										
	Dairy	Cattle Feedlots	Other Cattle	Swine	Layers	Broilers	Turkeys	Sheep	Goats	Horses	TOTAL
MA	1,039	3	89	103	154	0	23	29	18	276	**1,733**
MD	4,016	271	527	324	1,990	11,454	149	36	37	662	**19,467**
ME	1,938	4	156	36	2,658	0	0	29	16	169	**5,005**
MI	17,365	4,033	1,359	5,690	3,746	0	1,641	267	75	1,944	**36,120**
MN	28,109	5,771	6,180	35,624	6,717	1,728	15,041	594	55	1,641	**101,460**
MO	7,440	1,481	21,233	25,008	3,914	7,918	8,717	260	160	2,517	**78,648**
MS	1,170	72	5,617	2,421	5,234	30,093	0	36	130	928	**45,700**
MT	1,224	1,506	14,213	1,167	232	0	0	1245	35	2,091	**21,712**
NC	2,280	106	4,371	86,675	8,172	28,751	15,554	36	260	1,209	**147,416**
ND	2,084	1,314	10,505	970	0	0	649	539	45	1,031	**17,136**
NE	3,557	51,470	20,832	18,786	6,266	145	2,231	375	37	1,346	**105,045**
NH	899	2	59	22	105	0	2	29	17	137	**1,272**
NJ	660	42	106	112	999	0	12	36	28	664	**2,658**
NM	21,109	2,356	5,690	21	0	0	0	854	319	1,140	**31,490**
NV	1,940	427	2,426	55	0	0	0	372	13	418	**5,649**
NY	34,443	532	1,426	527	2,247	94	178	223	101	1,402	**41,173**
OH	13,872	3,827	3,241	9,165	17,343	1,525	1,846	520	141	2,239	**53,720**
OK	4,968	7,958	23,086	20,097	2,786	9,104	2,231	223	225	2,752	**73,431**

Table 4-2. 2002 State-Level Ammonia Emission Estimates by Animal Type (Cont.)

State	2002 Ammonia Emission Estimates (tons/yr)										
	Dairy	Cattle Feedlots	Other Cattle	Swine	Layers	Broilers	Turkeys	Sheep	Goats	Horses	TOTAL
OR	5,922	1,084	6,489	200	1,631	7,918	2,231	1,059	117	2,005	**28,656**
PA	29,128	1,593	2,656	7,064	13,327	5,209	3,384	319	144	1,911	**64,735**
RI	68	1	17	19	0	0	0	29	2	33	**169**
SC	679	85	2,092	2,902	3,262	7,544	3,384	36	191	675	**20,850**
SD	4,917	7,579	19,031	8,003	1,226	0	1,641	1,486	36	1,521	**45,441**
TN	3,112	211	10,657	1,925	1,007	7,290	0	36	351	2,614	**27,202**
TX	23,119	63,103	54,101	7,856	11,825	22,999	2,231	4,198	9,027	7,107	**205,565**
UT	6,166	538	3,968	5,479	1,965	0	2,231	1,356	42	1,442	**23,187**
VA	4,275	573	7,281	2,675	2,097	10,383	6,837	219	140	1,477	**35,956**
VT	7,608	6	249	17	93	0	16	29	18	260	**8,297**
WA	15,229	5,447	2,690	151	3,049	7,918	0	208	67	1,726	**36,486**
WI	71,654	3,341	4,359	3,141	2,574	1,322	2,231	297	142	1,540	**90,601**
WV	744	167	2,080	72	896	3,508	1,231	137	53	493	**9,381**
WY	264	1,732	8,032	748	9	0	0	1,783	44	1,485	**14,096**
Total	**558,094**	**300,385**	**356,263**	**429,468**	**202,496**	**359,689**	**102,052**	**24,835**	**14,028**	**71,285**	**2,418,595**

4.2.1 Comparison to 1999 Ammonia NEI

The last ammonia NEI for animal husbandry operations was conducted in 1999. Table 4-3 presents the animal populations, total ammonia emissions, and ammonia emission factors from the 1999 and 2002 ammonia NEI.

Table 4-3. Comparison of 1999 and 2002 Ammonia NEIs

Animal Group	1999 NEI			2002 NEI		
	Population	Emission Factor (lb/head/yr)	Emissions (tons/yr)	Population	Emission Factor (lb/head/yr)	Emissions (tons/yr)
Cattle and Calves Composite	100,126,106	50.5	2,528,184	100,939,728	24.1	1,214,742
Hogs and Pigs Composite	63,095,955	20.3	640,424	59,978,850	14.32	429,468
Poultry and Chickens Composite	1,754,482,225	0.394	345,633	2,201,945,253	0.60	664,238
Sheep	6,768,448	7.43	25,144	6,685,000	7.43	24,835
Goats	1,820,268	14.1	12,833	1,989,799	14.1	14,028
Horses	2,578,238	26.9	34,677	5,300,000	26.9	71,285
Total	**1,928,871,240**	NA	**3,586,896**	**2,376,838,630**	NA	**2,418,595**

NA = Not applicable

4.2.2 Comparison to 2002 EPA Emission Factor Report

EPA's 2002 report entitled *Review of Emission Factors and Methodologies to Estimate Ammonia Emissions from Animal Waste Handling* was prepared by the National Risk Management Research Laboratory (NRML) for EPA's Office of Air and Radiation and the North Carolina Department of Environmental and Natural Resources, Division of Air Quality. This report summarizes and discusses recent available U.S. and European information on ammonia emissions from swine farms and assesses the applicability for general use in the U.S. and North Carolina in particular. Specifically, this report presents ammonia emission factors and rates based on field measurements from a full-scale swine farm consisting of 7,480 finishers, 1,212 sows and boars, and 1,410 piglets; average weights are 135, 400, and 25 pounds, respectively. The average animal weight was 151 pounds. Table 4-4 presents the emission factors from the full-scale swine farm and the swine emission factors used in the 2002 ammonia NEI.

Table 4-4. Comparison of EPA's Ammonia Emission Factors for Swine from the 2002 Ammonia NEI and the 2002 NRML Report

2002 Ammonia NEI Parameters		2002 NRML Report Parameters	
Operation	**NH_3 Emission Factor**	**Operation**	**NH_3 Emission Factor**
Composite (house, lagoon, land application)	14.32 lb NH_3/head/yr	Swine farm	7 kg NH_3/head/yr (15.4 lb NH_3/head/yr)
Houses with lagoons (house and lagoon)	19.9 lb NH_3/head/yr	Finisher house	3.69 kg NH_3/head/yr (8.1 lb NH_3/head/yr)
		Lagoon - finisher pigs	1.6 kg NH_3/head/yr (3.5 lb NH_3/head/yr)
Liquid land application	20% to 23% N loss	Spray fields	56% NH_3 volatilization rate

4.2.3 Comparison to Sonoma Technology, Inc. Report

The Sonoma Technology, Inc (STi) 2003 report entitled *Recommended Improvements to the CMU Ammonia Emissions Inventory Model for Use by LADCO* provides guidance and recommendations for revisions that improve the performance of the Carnegie Mellon University (CMU) ammonia emissions model version 2.1 for the LADCO region. Sonoma derived its recommended ammonia emission factors from the 1994 Battye et al. report. Table 4-5 presents a comparison of the 2002 ammonia NEI and Sonoma's recommended ammonia emission factors for livestock operations.

Table 4-5. Comparison of Ammonia Emission Factors from the 2002 Ammonia NEI and the 2003 STi Report

2002 Ammonia NEI Parameters		2003 STi Report Parameters	
Animal Type	**NH_3 Emission Factor**	**Animal Type**	**NH_3 Emission Factor**
Dairy	84 lb NH_3/head/yr	Milk cows	25 kg NH_3/cow/yr (55.1 lb NH_3/cow/yr)
Beef and heifers - On feed - Not on feed (grazing)	 45.76 lb NH_3/head/yr 9.53 lb NH_3/head/yr	Beef cattle	9 kg NH_3/cow/yr (19.8 lb NH_3/cow/yr)
Swine	14.32 lb NH_3/head/yr	Hogs and pigs	7 kg NH_3/pig/yr (15.4 lb NH_3/pig/yr)
Poultry	0.60 lb NH_3/head/yr	Poultry	0.22 kg NH_3/poultry/yr (0.485 lb NH_3/poultry/yr)

4.2.4 Comparison to Pinder's Report

Robert Pinder from Carnegie Mellon University (CMU) has developed monthly, county-level ammonia emission estimates from dairy farms throughout the U.S. His 2003 report entitled *Ammonia Emissions from Dairy Farms: Development of a Farm Model and Estimation of Emissions from the United States* summarizes his methodology for conducting the ammonia estimates. Dr. Pinder has estimated monthly, county-level emission factors by combining two models, one that estimates emission factors and one that predicts farming practices. The emissions model (called the Farm Emissions Model) uses sets of manure management practices and yearly climatic conditions at dairy farms to predict monthly emission factors for a dairy cow. The farming practices model (called the National Practices Model) is a statistical model used to predict the most common farming practices for each county in the United States using the distribution of farm sizes in a county, milk production, historical farming practices, and climate data. CMU intends to include Dr. Pinder's modeling results in the next version of the CMU model. To date, Dr. Pinders's approach and modeling results have not been peer reviewed and his model is not available for distribution to outside parties. Therefore, a comparison on the emission factors developed by Pinder to EPA's 2002 ammonia NEI can not be done at this time.

4.3 New Source Category Classification Codes

The results of this ammonia inventory are reported in a greater level of detail than is provided for in the current Source Category Classification (SCC) codes for area nonpoint sources. As a result, EPA has developed a recommended new set of SCC codes for the category of Miscellaneous Area Sources, Agricultural Production-Livestock (28-05). All SCC codes that are currently being used in the NEI are being preserved, but several hundred new codes are being added. The new SCC codes were developed for county-level reporting of area nonpoint source ammonia emissions, as well as to be useful for other pollutants and for facility-level reporting to the point source inventory.

The goal of the new codes is to accommodate the current emissions reporting and provide additional reporting detail for future inventory development. For many of the pollutants and animal sectors, inventory tools are not yet available to develop accurate emission estimates to the level allowed by the new codes. However, the codes are designed to facilitate future efforts as more refined methodologies are developed for estimating emissions from animal production operations. For example, the codes will accommodate the recommendations of the National Research Council Committee regarding process-based approaches for estimating emissions, and are consistent with the planned outputs of the CMU Ammonia Emissions Model.

The new codes allow substantial flexibility in reporting emissions at four different levels of detail. Within each animal sector, emissions maybe reported at any of the following levels: (1) the entire animal sector, (2) the types of farms, (3) the major categorical operations within a farm (confinement, manure storage/handling, land application, and on-site feed preparation), or (4) by individual emission points (e.g., barn, solids separation, lagoon, open solids storage, covered solids storage, land application with manure incorporation into the soil). For specifying the types of farms, the new SCC codes allow for the identification of the general type of farming operation (e.g., feedlot operations versus pasture-based operations; flush dairy versus scrape dairy), even if the inventory does not break down emissions below the whole farm level. The codes also allow some degree of identification of the size or age of animals confined (e.g., the poultry codes can distinguish pullet operations from layer operations; for swine, the codes distinguish nursery, farrow/nursery, nursery/finish, farrow/finish, and finishing operations).

The first four digits of the recommended new SCC codes remain the same (28-05). The changes are made at the SCC7 and SCC10 level. The SCC7-level digits are used to designate the animal sector, type of farming operation, and animal age. The SCC10-level digits are used to designate the processes on the farm that generate the emissions. Appendix E presents the new SCCs and descriptions for Miscellaneous Area Sources, Agricultural Production-Livestock that are used in the ammonia inventory. For perspective, the existing SCC codes are shown in Table E-2.

5.0 DATA LIMITATIONS

The degree and accuracy of the estimates presented in this report of ammonia emissions from animal husbandry operations on a county, state, or even a national basis is limited at this time for a variety of reasons including:

- The limited amount of published data that could be used to develop emission factor estimates for the various ammonia emission sources on a common and rationale basis;

- Imperfect knowledge of the frequency of use of various manure management practices even on a national but more importantly on a state or county basis;

- The need to estimate county and in some cases state animal populations based on distributions derived from the *1997 Census of Agriculture* statistics;

- The lack of the necessary data to use a detailed mass balance approach to estimate ammonia emissions; and

- The inability to assess the impact of climate as it affects annual and seasonal variations in ammonia emissions due to the lack of the necessary data.

In particular, the availability of usable emission measurements upon which to develop ammonia emission factors is very limited. Because of the large number of variables that influence emissions from animal husbandry operations, emissions can vary substantially from site-to-site. These variables include climate and geography, diurnal and seasonal emission patterns, feeding practices, animal life stage, and individual animal management practices. The emission factors developed for this inventory do not account for all of these variables. Accordingly, it is not appropriate to use these emission factors to estimate emissions from individual farms. While the methods used for this inventory can be used for assessing emission trends and for general air quality planning, the information presented in this report should not be used for making regulatory determinations or for permitting of any particular facility.

5.1 Limited Published Data

EPA’s comprehensive review of applicable literature revealed that ammonia emission factor data and county-level population and manure management practice data for animal husbandry operations is very limited. As a result, some of the emission factors used in this report are based on relatively few data points and thus may not represent the range of emissions variability expected from the complex mechanisms that influence emissions from animal husbandry operations. In absence of emissions data, some of the emission factors were based on transferring emission factors from one animal sector to another using knowledge of fundamental microbial mechanisms and available emissions information. Also, some emission factors, such as those found for land application, are based on general trends that may not address the actual land application practices being used by individual farms.

A substantial number of studies have measured the impacts of animal husbandry operations on air quality. Many of these studies, however, had the objective of characterizing ambient concentrations either within confinement facilities or in the general vicinity of such facilities. Given the objective of these studies, the facility design and operating information (e.g., building ventilation rates) necessary to translate concentrations into mass emissions usually was lacking. Even when mass emissions could be determined, information necessary to relate emissions to a unit of production capacity frequently was lacking or vague. Examples of such missing information included confinement facility size, type of manure management system, animal population, and animal age or live weight. Therefore, for many of the emission points at a MMT, the emission factor was based on only a few data points.

An important implication of the limited data is the inability to quantitatively characterize the statistical uncertainty of the emission estimates. With the limited number of data points associated with each emission factor, it was not possible to determine if the emissions data represent random samples of a normally distributed population. Thus, the average emission factors calculated may not be true mean values and may over- or underestimate emissions on an annual basis.

Due to the lack of published data on county-level animal populations and manure management practices at animal husbandry operations, EPA had to make some broad assumptions to develop county-level ammonia emission estimates. With respect to the lack of animal population data, EPA had to apply the county-level animal population distributions from the *1997 Census of Agriculture* to 2002 state-level animal populations obtained from NASS reports. Since the livestock agricultural industry is continually evolving over time it is possible that there have been some shifts in animal populations within counties during the last five years. Therefore, any given county-level ammonia emission estimate may not reflect the current animal populations in that county. The availability of *2002 Census of Agriculture* data in early 2004 could improve the county-level populations estimates in later versions of this inventory.

EPA's distribution of MMTs among the animal types is based on regional data on the use of manure management practices for each animal type. This regional data may not adequately reflect the manure management practices being used in a given state, let alone each county within the state. At this time, however, EPA is not aware of any better state-level or county-level manure management practice data for animal husbandry operations.

5.2 Inability to Conduct a Full Process-Based Modeling Approach

As stated earlier in this report, the NRC's Ad Hoc Committee on Air Emissions from AFOs recommended that EPA develop a process-based modeling approach for estimating air emissions from AFOs. EPA acknowledges that a process-based modeling based on the nitrogen mass balance at animal husbandry operations would most likely result in better estimates.

However, due to limited emission data and the requirement to update the NEI for ammonia emissions from animal husbandry operations for the year 2002, EPA could not implement a process-based modeling approach. EPA believes, however, that by ensuring that the total amount of nitrogen lost as ammonia is not greater than the total amount of nitrogen excreted by the animals, this inventory is one step closer to the mass balance approach.

Furthermore, due to limitations in available data and the fact that this is a national inventory, EPA did not address the losses of nitrogen in other forms from animal husbandry operations such as nitrogen and nitrous oxide emissions to the atmosphere or leaching of nitrate into soil and ground water. For example, some manure and in turn, manure nitrogen is retained on the surface of a beef feedlot after the manure is scraped from the feedlot and applied to the land. Due to the complexity of estimating ammonia emissions for every county in the United States, EPA has assumed that 100 percent of the nitrogen excreted by the animals could be converted and lost as ammonia. These assumptions, therefore, may overestimate the amount of ammonia emitted from animal husbandry operations.

5.3 Inability to Address Seasonal and Regional Influences

This inventory does not address emission variability due to climate and seasonal temperature variation due to the absence of continuous, long-term studies to assess emissions variability. EPA acknowledges that the inability to delineate regional variability in ammonia emissions due to differences in climate and seasonal variability within a region may result in under or over estimates of actual emissions given the known impact of temperature on the responsible microbial processes and chemical reactions. Ammonia emissions may vary regionally due to differences in feeding and production practices. EPA is currently researching the impact of seasonality on ammonia emissions from animal husbandry operations in terms of varied animal populations over the course of the year and regional differences in climate and temperature.

6.0 REFERENCES

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Miller, P. (2000) Telephone conversation between Lee-Ann Tracy of ERG and Paul Miller, Iowa Natural Resource Conservation Service, 12 June.

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USDA (2003b) *Cattle on Feed Cattle*, U.S. Department of Agriculture, National Agriculture Statistics Service, Washington, DC. January 17. (Data also available from <http://www.nass.usda.gov:81/ipedb/>).

USDA (2003c) *Hogs and Pig*, U.S. Department of Agriculture, National Agriculture Statistics Service, Washington, DC. March 28. (Data also available from <http://www.nass.usda.gov:81/ipedb/>).

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APPENDIX A
References for the Development of Emission Factors

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors

Author	Article Report Title	Comment
Al-Kanani, et al., 1992b	Organic and Inorganic Amendments to Reduce Ammonia Losses from Liquid Hog Manure	Data not used. The reference dealt with manure amendments and was therefore considered not representative of the manure management trains (MMTs).
Amon, B., Th. Amon, J. Boxbeaper, Ch. Alt, 2001	Emissions of NH_3, N_2O, and CH_4 from Dairy Cows Housed in a Farmyard Manure Tying Stall	Data not used. The data in the reference were not representative of the MMTs.
Amon, M., M. Dobeic, R.W. Sneath, V.R. Phillips, T.H. Misselbrook, B.F. Pain, 1997	A Farm-scale Study on the Use of Clinoptilolite Zeolite and De-odorase® for Reducing Odour and Ammonia Emissions from Broiler Houses	Data not used. The reference dealt with litter amendments and was therefore considered not representative of the MMTs.
Andersson, M., 1998	Reducing Ammonia Emissions by Cooling of Manure in Manure Culverts	Data used in the development of the emission factor for swine houses with lagoon systems.
Aneja et al., 2000	Characterization of Atmospheric Ammonia Emissions from Swine Waste Storage and Treatment Lagoons	Data used in the development of the emission factor for lagoons at swine operations.
Asman, W.A.H., 1992	Ammonia Emission in Europe: Updated Emission and Emission Variations, National Institute of Public Health and Environmental Protection, Bilthoven, Netherlands These data are presented in Battye, et al., 1994.	Data used in the development of the emission factors for swine houses with deep-pit systems, turkey houses, broiler houses, and sheep, goat, and horse operations.
Battye, et al., 1994 (cited as USEPA, 1994 in 8/15/01 report)	Development and Selection of Ammonia Emission Factors: Final Report	Data not used. This is a secondary source with respect to emission factors.
Bonazzi, et. al., 1988	Controlling Ammonia Emission from Poultry Manure Composting Plants	Data not used. The reference did not contain sufficient data to develop an emission factor.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Bouwman, et al., December 1997	A Global High-Resolution Emission Inventory for Ammonia	Data used in the development of the emission factors for dairy and beef and heifer outdoor confinement areas.
Cabera, M.L., S.C. Chiang, O.C. Merka, O.C., Pancorbo, and S.C. Thompson, 1994	Pelletizing and Soil Water Effects on Gaseous Emissions from Surface-Applied Poultry Litter. Soil Science Society of America Journal 58, 807-811.	Data used in the development of the emission factor for poultry manure land application.
Chinkin, L.R., Ryan, P.A., Coe, D.L of Sonoma Technology Inc., 2003	Recommended Improvements to the CMU Ammonia Emission Inventory Model for Use by LADCO prepared for Michael Koerber at the Lake Michigan Air Directors Consortium	Data not used. This is a secondary source with respect to emission factors.
Collins, 1990	Ammonia Emissions from a Large Swine Production Complex	Data not used. The reference did not provide sufficient data to relate the emissions to standardized units (e.g., animal units, head).
Cure et al., 1999	Nitrogen Emissions in North Carolina	Data not used. The reference did not provide information on the confinement practices.
Demmers et al., 2001	Validation of Ventilation Rate Measurement Methods and the Ammonia Emission from Naturally Ventilated Dairy and Beef Buildings in the United Kingdom	Data used in the development of the emission factor for scrape barns at dairy operations.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Doorn, M.R.J., D.F. Natschke, and P.C. Meeuwissen, 2002 prepared for USEPA/ National Risk Management Research Laboratory	Review of Emission Factors and Methodologies to Estimate Ammonia Emissions from Animal Waste Handling, Report No. EPA-600/R-02-17, Office of Research and Development, Air Pollution Prevention and Control Division, U.S. Environmental Protection Agency, Research Triangle Park, NC. 74 pp.	Data not used. This is a secondary source with respect to emission factors.
Elzing, A., G.J. Monteny, 1997	Ammonia Emission in a Scale Model of a Dairy-cow House	Data not used. The data in the reference were obtained from an experimental study.
European Environmental Agency, 1999	European Environmental Agency Emissions Inventory Guidebook for Agriculture	Data not used. The reference did not provide sufficient information to determine if the reported emissions were representative of land application emissions.
Fulhage, C.D., 1998	Gaseous Emissions from Manure Management Systems	Data used in the development of the emission factor for lagoons at swine operations.
Gilliland, Dennis, and Pierce, not yet published	Seasonal NH_3 Emission Estimates for the Eastern United States	Data not used. The reference contains is insufficient information to develop emission factors.
Goebes, Strader, and Davidson, January 2003	An Ammonia Emission Inventory for Fertilizer Application in the United States	Data not used. The reference does not contain information on animal manure emissions.
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Grelinger, M., 1997	Improved Emission Factors for Cattle Feedlots	Data used in the development of the emission factor for cattle drylots.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Grelinger and Page, 1999	Air Pollution Emission Factors for Swine Facilities	Data not used. The reference did not specify the type of operation.
Groenestein, 1996	Volatilization of Ammonia, Nitrous Oxide and Nitric Oxide in Deep-litter Systems for Fattening Pigs	Data not used. The practice described in the reference (use of deep litter with microbial stimulants) was not considered representative of the MMTs.
Groot Koerkamp et al., 1998a	Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe	Data used in the development of the emission factor for broiler houses.
Harper, L.A., R.R. Sharpe, 1998	Ammonia Emissions from Swine Waste Lagoons in the Southeastern U.S. Coastal Plains	Data not used. The data in the reference were obtained using experimental measurement techniques.
Harper, L.A., R.R. Sharpe, and T.B. Parkin, 2000	Gaseous Emissions from Anaerobic Swine Lagoons: Ammonia, Nitrous Oxide, and Dinitrogen Gas	Data not used. The data in the reference were obtained using experimental measurement techniques.
Harris, D.B. and E.L. Thompson, Jr., 1998	Evaluation of Ammonia Emissions from Swine Operations in North Carolina, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC Data included in the following reference: Doorn, M.R.J., D.F. Natschke, and P.C. Meeuwissen, 2002 (USEPA/ NRML)	Data used in the development of the emission factor for swine houses with lagoon systems.
Hartung, J.V., R. Phillips, 1994	Control of Gaseous Emissions from Livestock Buildings and Manure Stores	Data used in the development of the emission factor for wet layer houses.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Heber, A.J., R.K. Duggirala, J. Ni, M.L. Spence, B.L. Haymore, V.I Adamchuck, D.S. Bundy, A.L. Sutton, D.T. Kelly, K.M. Keener, 1997	Manure treatment to reduce gas emissions from large swine houses. In: Voermans J.A.M., G. Monteny, editors, Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities. Vinkeloord, The Netherlands. Data included in Univ. of Minn, 1999.	Data used in the development of the emission factor for swine houses with lagoon systems.
Hobbs, P.J., T.H. Misselbrook, T.R. Cumby, 1999	Production and Emission of Odours and Gases from Aging Pig Waste	Data not used. The reference did not provide information on the number of animals included in the study.
Hoeksma, P., N. Verdoes, G.J. Monteny, 1993	Two Options for Manure Treatment to Reduce Ammonia Emission from Pig Housing	Data used in the development of the emission factor for swine houses with deep-pit systems.
Hutchinson et al., 1982	Ammonia and Amine Emissions from a Large Cattle Feedlot	Data used in the development of the emission factor for cattle drylots.
Iowa State University and The University of Iowa Study Group, 2002	Ammonia Emissions from a Mechanically Ventilated Swine Building During Warm Weather	Data not used. The data in the reference represent emissions from operations with high ventilation rates during warm weather. Therefore, this operation is not representative of the MMTs.
Jacobson et al., 1999 (University of Minnesota Report)	Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to Air Quality and Odor	Data not used. The reference did not specify the type of operation.
Jarvis, S., 1991	Grazed Pastures as Sources of Ammonia	Data not used. The reference does not contain sufficient information to develop emission factors.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Jarvis, S.C., B.F. Pain, 1997	Gaseous Nitrogen Emissions from Grasslands	Data not used. This is a secondary source with respect to emission factors.
Jungbluth, T., E. Hartung, 1997	Determination of the Odor Plume Boundaries from Animal Houses. In Bottcher, R.w., S.j. Hoff Editors, Livestock Environment V: 5th International Symposium. Bloomington, Mn. American Society of Agricultural Engineers.	Data used in the development of the emission factor for scrape barns at dairy operations.
Koelliker and Miner, 1971	Desorption of Ammonia from Anaerobic Lagoons	Data used in the development of the emission factor for lagoons at swine operations.
Koerkamp et al., 1998	Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe	Data not used. The practice described in the reference (cubicles with litter) was not considered representative of the MMTs.
Kroodsma et al., 1988	Ammonia Emission from Poultry Housing Systems	Data used in the development of the emission factors for wet layer houses and broiler houses.
Kulling, D.R., H. Menzi, T.F. Krober, A. Neftel, F. Sutter, P. Lischer, M. Kreuzer, 2001	Emissions of Ammonia, Nitrous Oxide, and Methane from Different Types of Dairy Manure During Storage as Affected by Dietary Protein Content	Data not used. The data in the reference were obtained from an experimental study.
Latimier and Dourmand, 1993	Effect of Three Protein Feeding Strategies, for Growing-Finishing Pigs, on Growth Performance and Nitrogen Output in the Slurry and in the Air	Data not used. The data in the reference were from experimental feeding studies.
Lockyer, D.R. and B.F. Pain., 1989	Ammonia Emissions from Cattle, Pig, and Poultry Wastes Applied to Pasture. Environmental Pollution 56 (1989): 19-30.	Data used in the development of the emission factor for poultry manure land application.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
MARAMA/NESCAUM, December 2001 (CMU Ammonia Emission Model)	Development of an Improved Ammonia Emissions Inventory for the United States	Data not used. This is a secondary source with respect to emission factors.
Martin, J., 2000	A Comparison of the Performance of Three Swine Waste Stabilization Systems	Data used in the development of the emission factor for lagoons at swine operations.
McCulloch, 1999	An Observation-Based Gaussian Dispersion Model for Determining Ammonia emissions from a Commercial Hog Farm	Data not used. The reference did not provide information on the confinement practices.
Misselbrook, T.H., B.F. Pain, D.M. Headon, 1998	Estimates of Ammonia Emission from Dairy Cow Collecting Yards	Data used in the development of the emission factors for scrape barns and drylots at dairy operations.
Moore, et al., 1995	Poultry Manure Management: Environmentally Sound Options	Data not used. The reference did not provide sufficient data to relate the emissions to standardized units (e.g., animal units, head).
Nahm, K.H., 2002	Efficient Feed Nutrient Utilization to Reduce Pollutants in Poultry and Swine Manure	Data not used. The reference did not provide sufficient information to develop an emission factor.
NCDENR, 1999	Status Report on Emissions and Deposition of Atmospheric Nitrogen Compounds from Animal Production in North Carolina	Data not used. The data presented in the reference were considered outliers (an order of magnitude greater than all other data for this type of operation).
Neeteson, J.J., 2000	Nitrogen and Phosphorus Management on Dutch Dairy Farms: Legislation and Strategies Employed to Meet the Regulations	Data not used. The reference did not contain information on emission factors.
Ni, J.Q., A.J. Heber, C.A. Diehl, T.T. Lim, 2000	Ammonia, Hydrogen Sulphide and Carbon Dioxide Release from Pig Manure in Under Floor Deep Pits	Data used in the development of the emission factor for swine houses with deep-pit systems.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Ni, J.Q., A.J. Heber, T.T. Lim, C.A. Diehl, R.K. Duggirala, B.L. Haymore, and A.L. Sutton, 2000	Ammonia Emission from a Large Mechanically Ventilated Swine Building During Warm Weather	Data used in the development of the emission factor for swine houses with deep-pit systems.
Oosthoek, J., W. Kroodsma, P. Hoeksma, 1991	Ammonia Emissions from Dairy and Pig Housing Systems	Data used in the development of the emission factors for swine houses with lagoon systems and swine houses with deep-pit systems.
Pfeiffer, et al., 1993	The Influence of Various Pig Housing Systems and Dietary Protein Levels on the Amount of Ammonia Emissions in the Case of Fattening Pigs	Data not used. The reference did not provide information on confinement practices.
Pinder, R.W., Anderson, N.J., Strader, R., Davidson, C.I., Adams, P.J., 2003	Ammonia Emissions from Dairy Farms: Development of a Farm Model and Estimation of Emissions from the United States	Data not used. Emission factors used in the models are from previously identified and described data sources. Emission factor data were not presented in the paper.
Pollet, I., J. Christiaens, H. Van Langenhove, 1998	Determination of the Ammonia Emission from Cubicle Houses for Dairy Cows Based on a Mass Balance	Data not used. The data in the reference were obtained from an experimental study.
Safley, L.M., Jr. 1980	An Analysis of a Metal Above-Ground Storage tank for Handling As-Produced Dairy Manure. In: Livestock Wastes: A Renewable Resource. American Society of Agricultural Engineers, St. Joseph, Michigan. pp. 410-411.	Data used in the development of the emission factor for dairy manure storage tanks.
Schmidt, D., 2000	Odor, Hydrogen Sulfide, and Ammonia Emission from the Composting of Caged Layer Manure	Data not used. The practice described in the reference (composting) was not considered representative of the MMTs.
Secrest, C., 1999	Field Measurement of Air Pollutants Near Swine Confined Animal feeding Operations using UV DOAS and FTIR	Data used in the development of the emission factor for swine houses with deep-pit systems.

Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
Sherlock, R.R., K.M Goh, 1983	Dynamics of Ammonia Volatilization from Simulated Urine Patches and Aqueous Urea Applied to Pasture	Data not used. The data in the reference were obtained from sheep operations which are not representative of the animal populations.
Sommer and Hutchings, July 2001	Ammonia Emission from Field Applied Manure and Its Reduction	Data not used. This is a secondary source with respect to emission factors.
Sommer, S.G., N. J. Hutchings, 1997	Components of Ammonia Volatilization from Cattle and Sheep Production	Data not used. The reference did not provide sufficient information to develop an emission factor.
Sutton, A.L., D.D. Jones, B.C. Joern, and D.M. Huber. 2001	Animal Manure as a Plant Resource. http://www.agcom.purdue.edu/AgCom/Pubs/ID/ID-101.html. Purdue University. West Lafayette, IN.	Data not used. The reference did not provide sufficient information to develop emission factors.
Swierstra, D., C.R. Braam, M.C. Smits, 2001	Grooved Floor System for Cattle Housing: Ammonia Emission Reductions and Good Slip Resistance	Data not used. The reference did not provide sufficient information to develop emission factors.
Tamminga, S., 1992	Gaseous Pollutants by Farm Animal Enterprises.	Data used in the development of the emission factor for broiler houses.
Thelosen, et al., 1993	Nitrogen Balances of Two Deep Litter Systems for Finishing Pigs	Data not used. The reference did not provide sufficient data to relate the emissions to standardized units (e.g., animal units, head).
Todd, 1999	Site Characterization Using Open-Path Fourier Transfrom Infrared (OP-FTIR) Spectroscopy	Data not used. The reference did not provide sufficient data to relate the emissions to standardized units (e.g., animal units, head).
University of Minnesota, 1999 (Minnesota Environmental Quality Board). Hugoson, G., Commissioner., September 1999	Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to Air Quality and Odor (H). Prepared for the Minnesota Environmental Quality Board	Data not used. This is a secondary source with respect to emission factors.

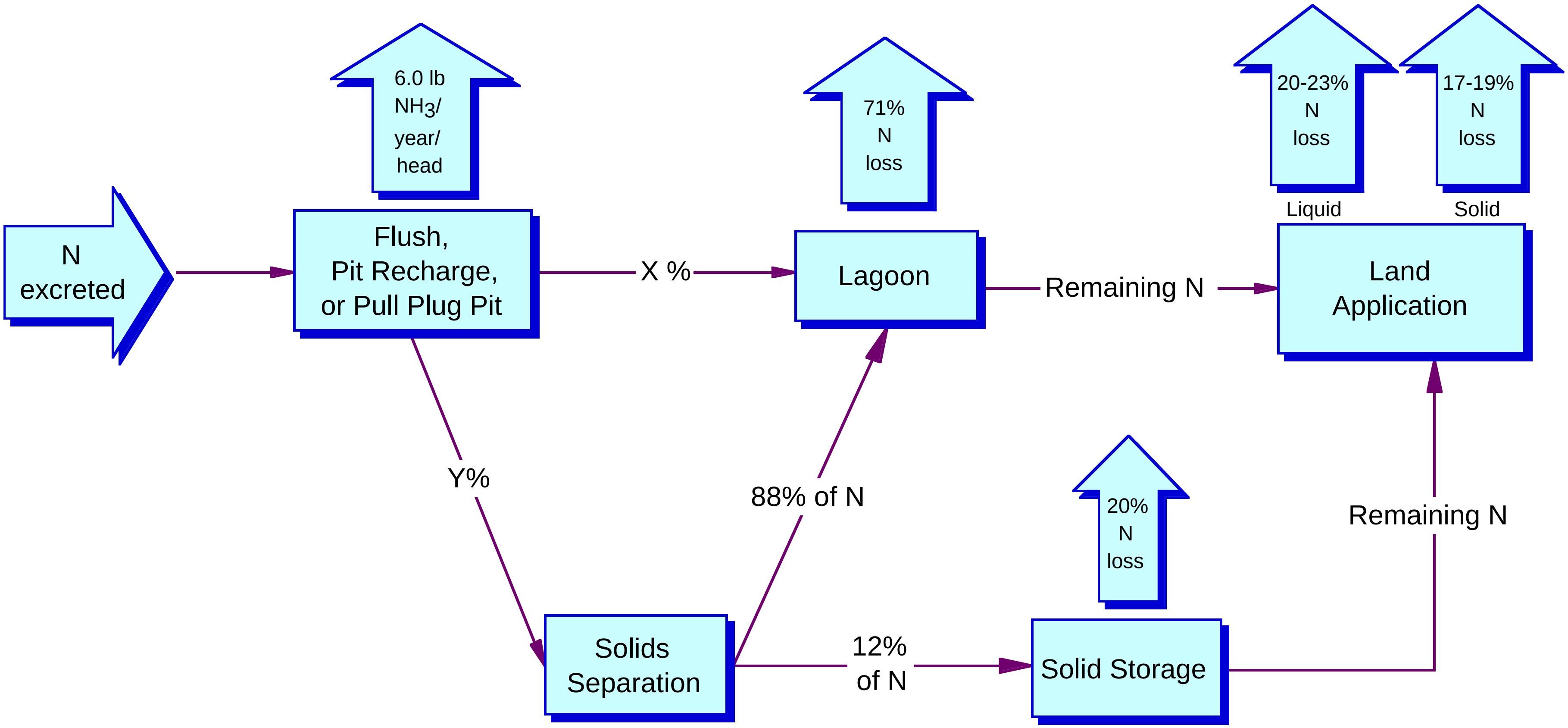
Table A-1. References for the Development of Animal Husbandry Operation Emission Factors (Cont.)

Author	Article Report Title	Comment
USDA, 2000	Air Quality Research & Technology Transfer Programs for Concentrated Animal Feeding Operations	Data used in the development of the emission factors for drylots at dairy operations, cattle drylots, and swine houses with deep-pit systems.
Valli, L., S. Piccinini, G. Bonazzi, 1991	Ammonia Emission from Two Poultry Manure Drying Systems	Data used in the development of the emission factor for dry layer houses.
Van der Hoek, K.W., 1998	Estimating Ammonia Emission Factors in Europe: Summary of the Work of the UNECE Ammonia Expert Panel	Data used in the development of the emission factors for scrape barns at dairy operations, broiler houses, and turkey houses.
Wathes, C.M., M.R. Holden, R.W. Sneath, R.P. White, V.R. Phillips	Concentrations and Emission Rates of Aerial Ammonia, Nitrous Oxide, Methane, Carbon Dioxide, Dust and Endotoxin in UK Broiler and Layer Houses	Data not used. The reference contained data from the United Kingdom that were not considered representative our the MMTs.
Witter, E., 1991	Use of $CaCl_2$ to Decrease Ammonia Volatilization after Application of Fresh and Anaerobic Chicken Slurry to Soil	Data not used. The data in the reference were from a laboratory experiment.
Yang, P., J.C. Lorimore, and H. Kim, 2000	Nitrogen Losses from Laying Hen Manure in Commercial High-Rise Layer Facilities. Transactions of the ASAE 43(6): 1771-1780.	Data used in the development of the emission factor for dry layer houses.
Zhu, J., L. Jacobson, D. Schmidt, R. Nicolai, 2000	Daily Variations in Odor and Gas Emissions from Animal Facilities	Data not used. The reference did not contain sufficient data to develop emission factors.

APPENDIX B
MMT Diagrams

Figure 1

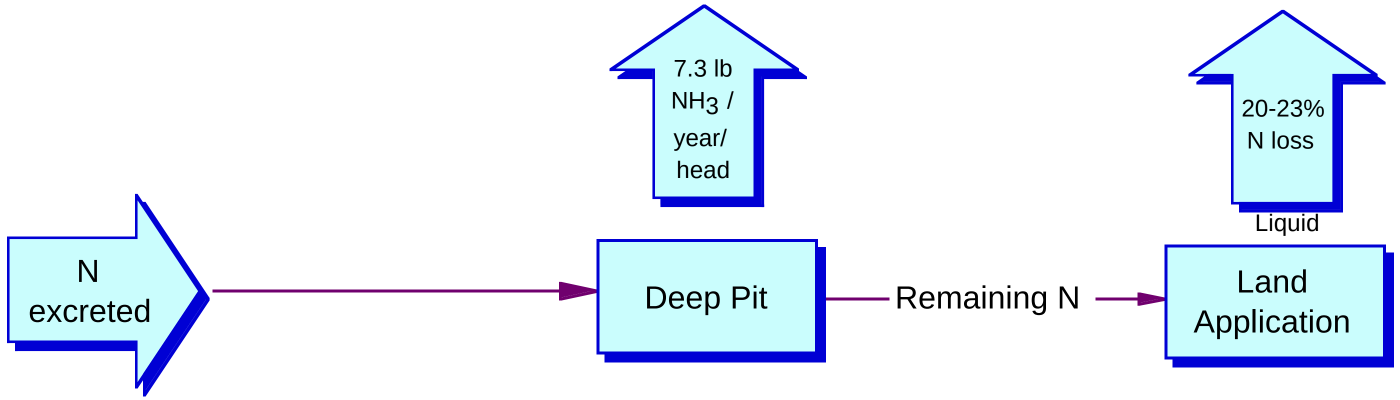
Swine House with Lagoon System



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.
X% and Y% vary by size of operation, and represent the proportion of operations using each type of system.

Figure 2

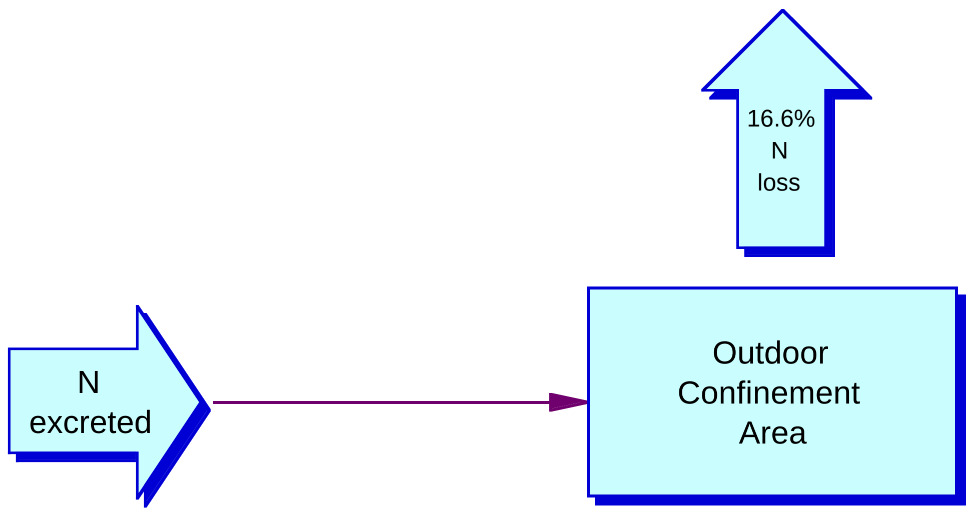
Swine House with Deep Pit System



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 3

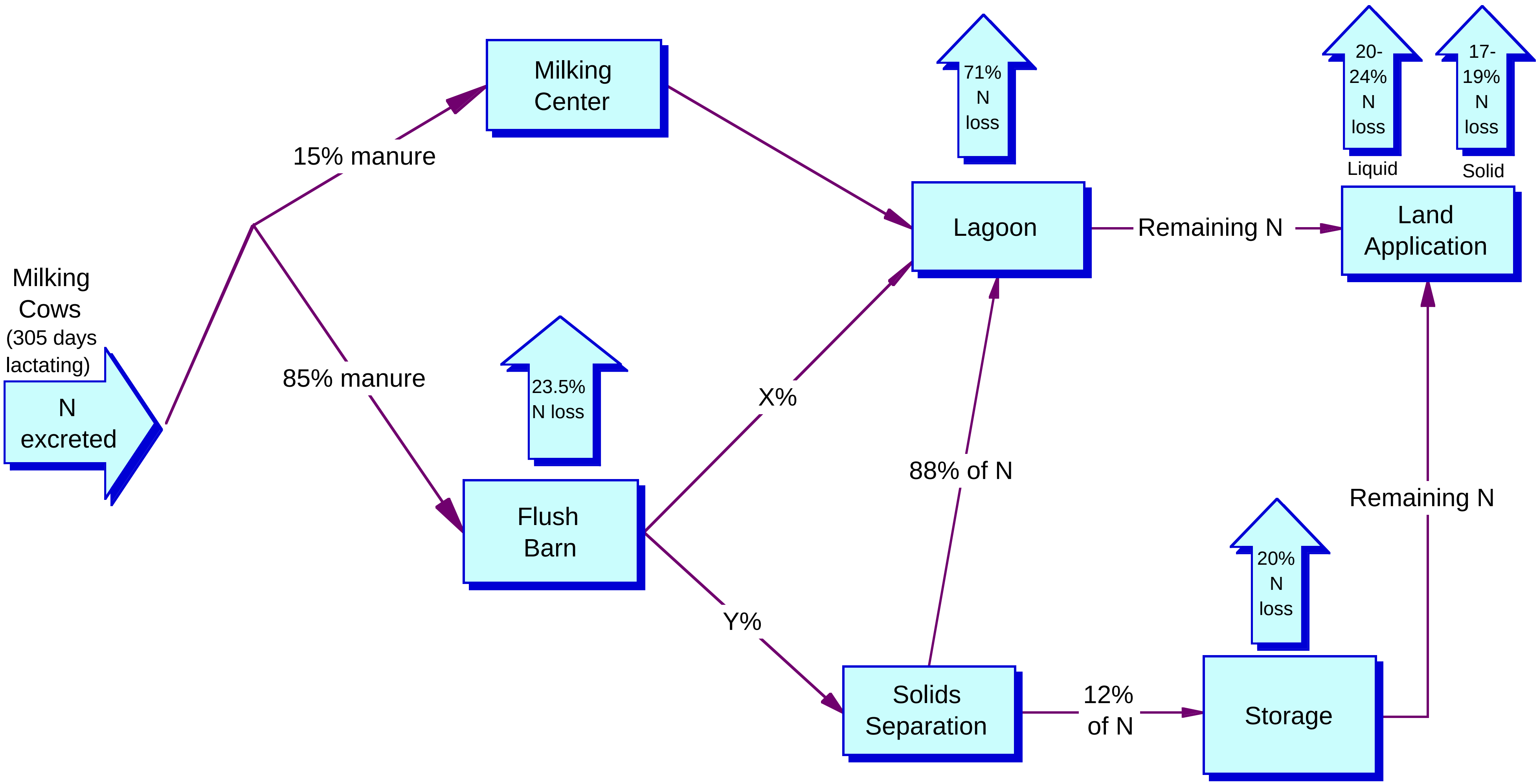
Swine - Outdoor Confinement Area



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 4

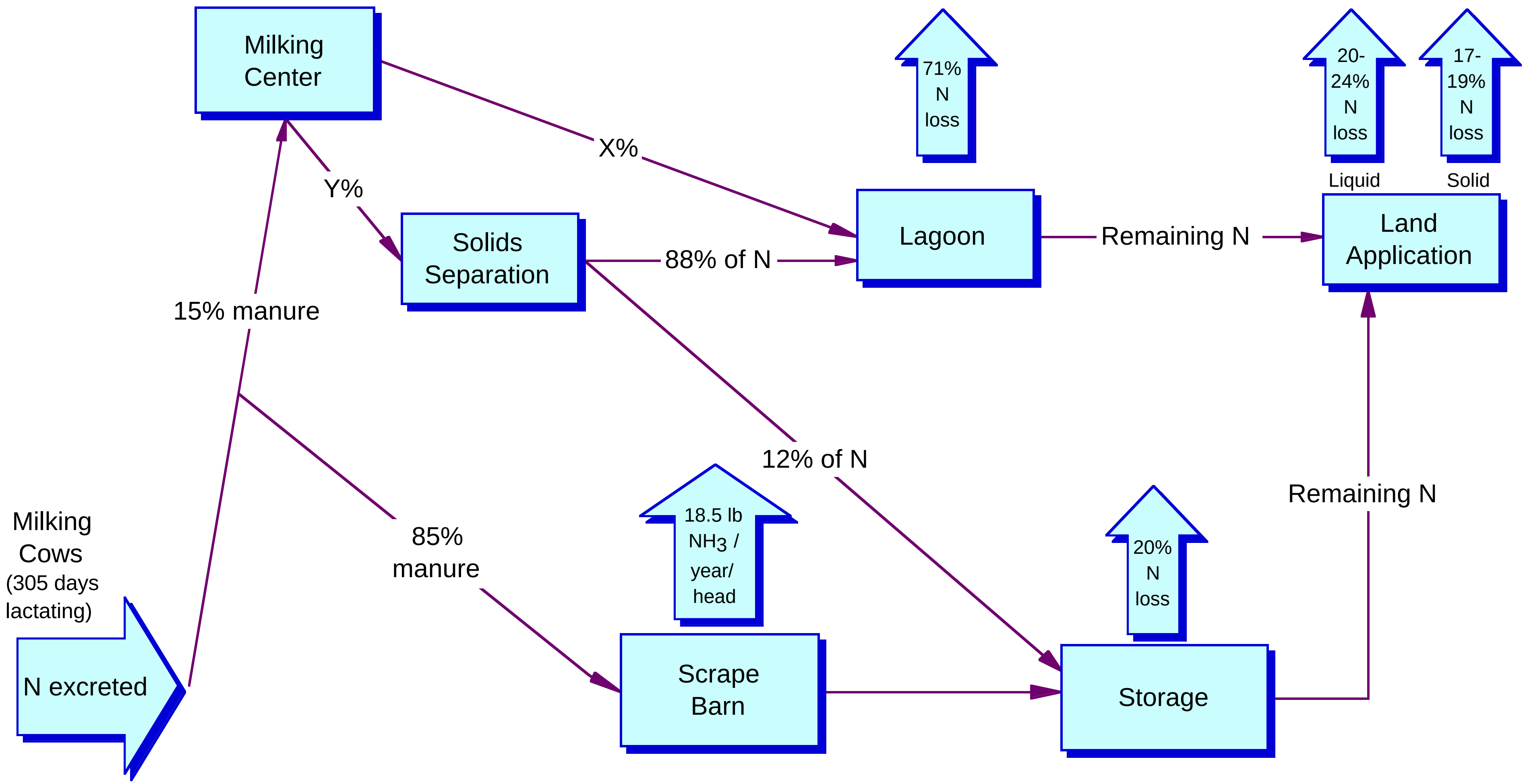
Dairy - Flush Barn



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.
The amount of nitrogen leaving the solids separator is based on the amount of nitrogen managed in the separator.
X% and Y% vary by size of operation, and represent the proportion of operations using each type of system.

Figure 5

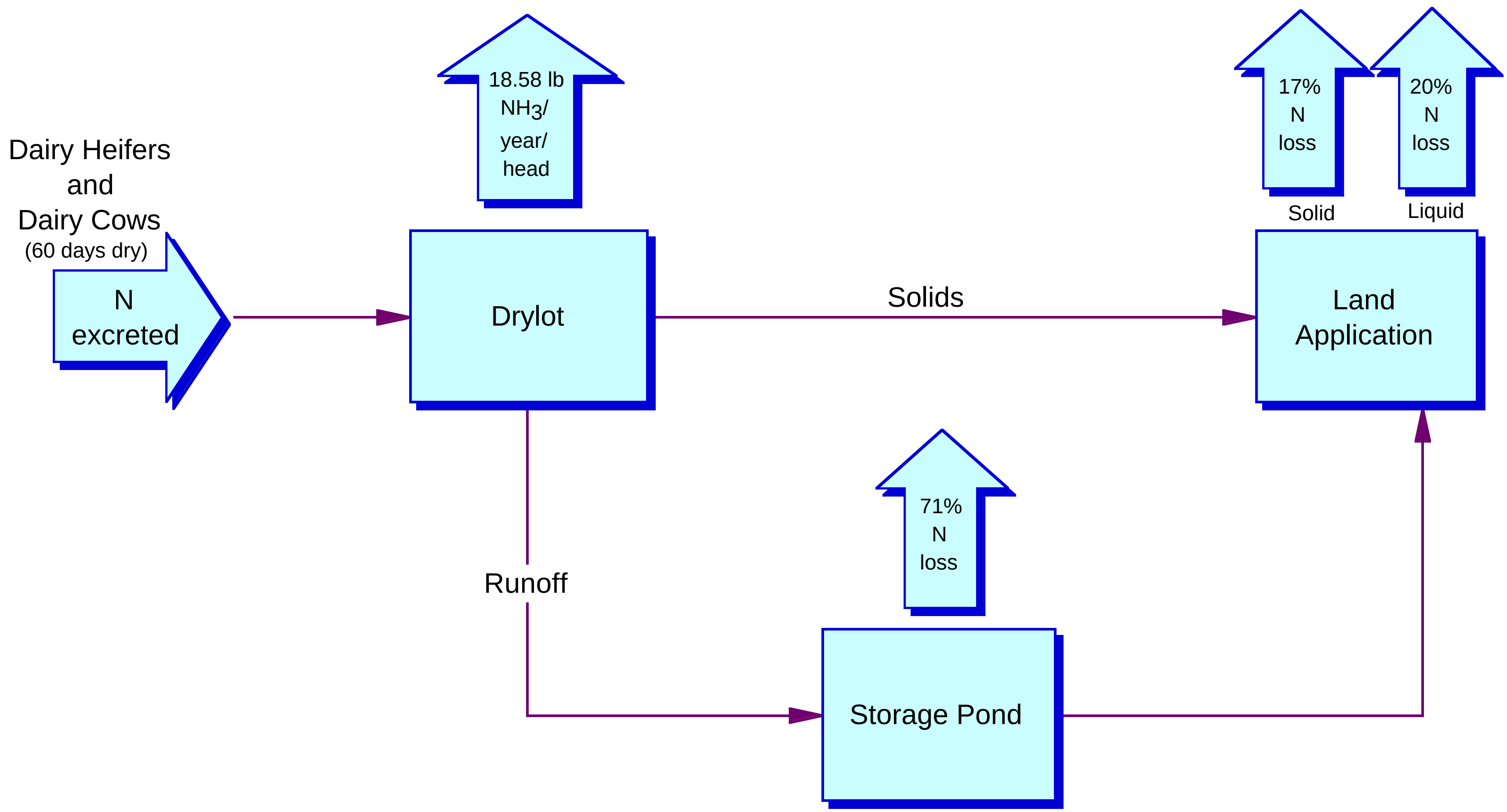
Dairy - Scrape Barn



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.
The amount of nitrogen leaving the solids separator is based on the amount of nitrogen managed in the separator.
X% and Y% vary by size of operation, and represent the proportion of operations using each type of system.

Figure 6

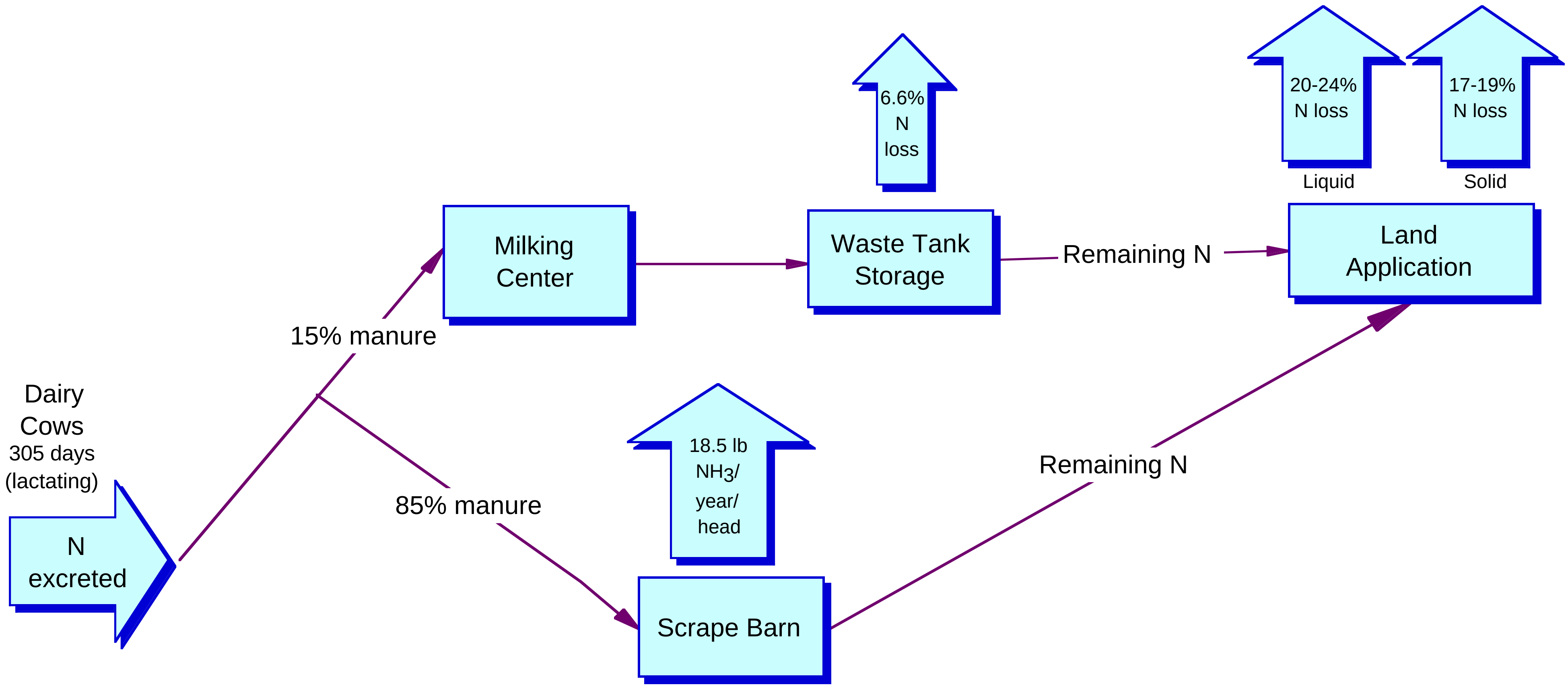
Dairy - Drylot



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 7

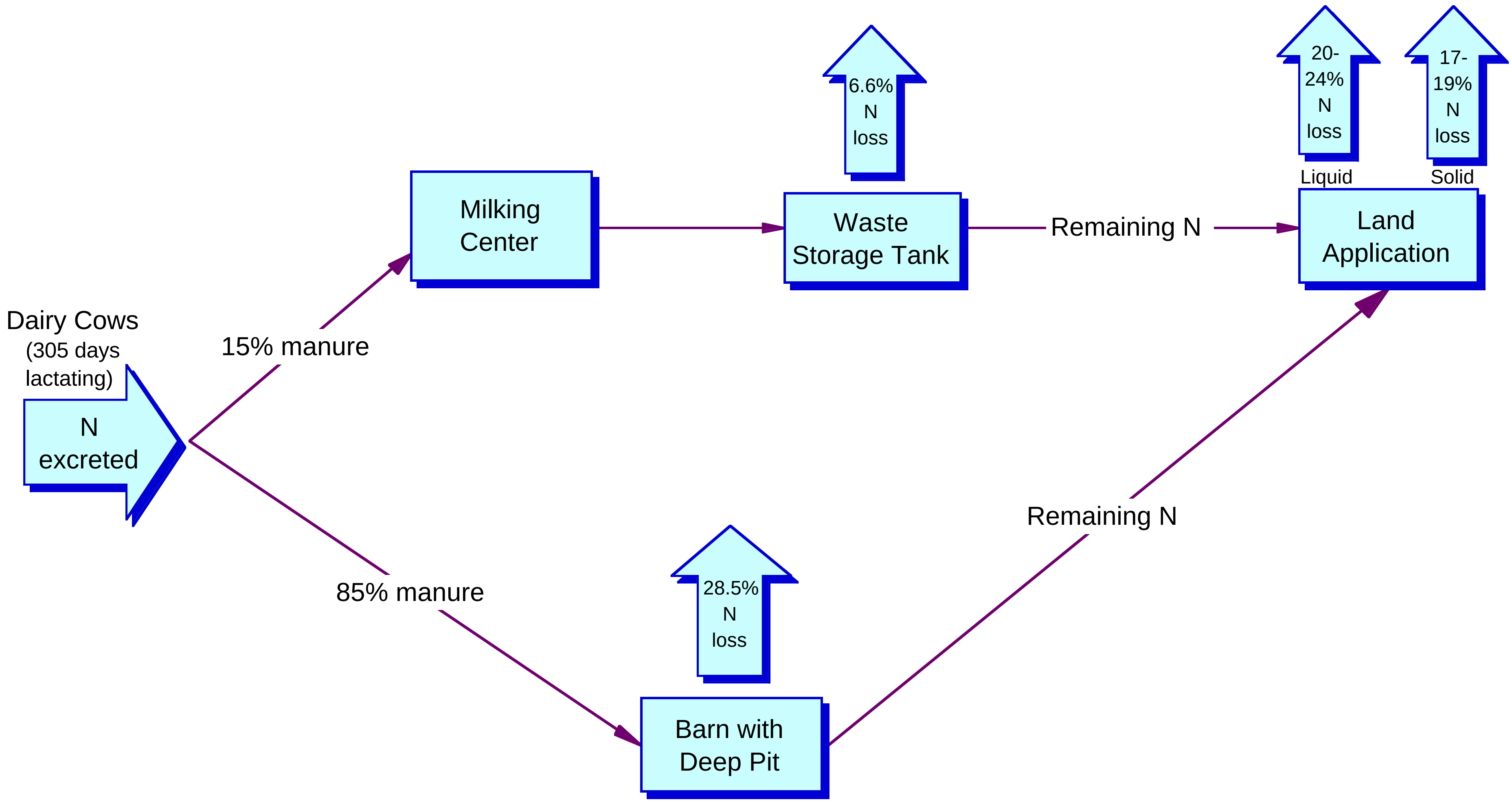
Dairy - Daily Spread (Scrape Barn)



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 8

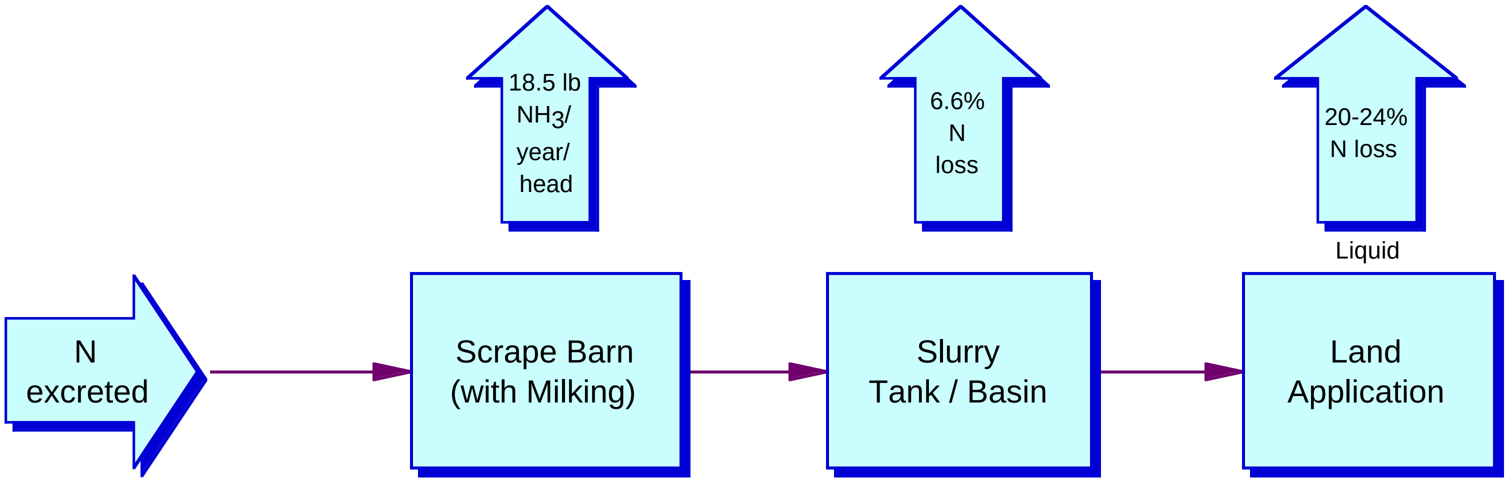
Dairy - Barn with Deep Pit



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 9

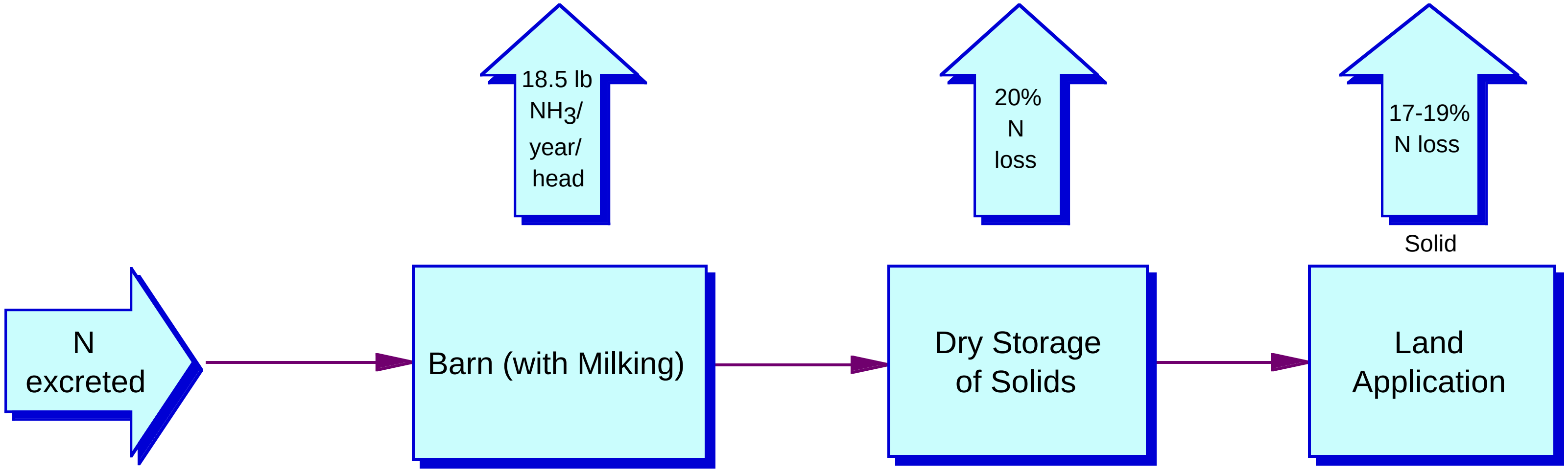
Dairy - Slurry



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 10

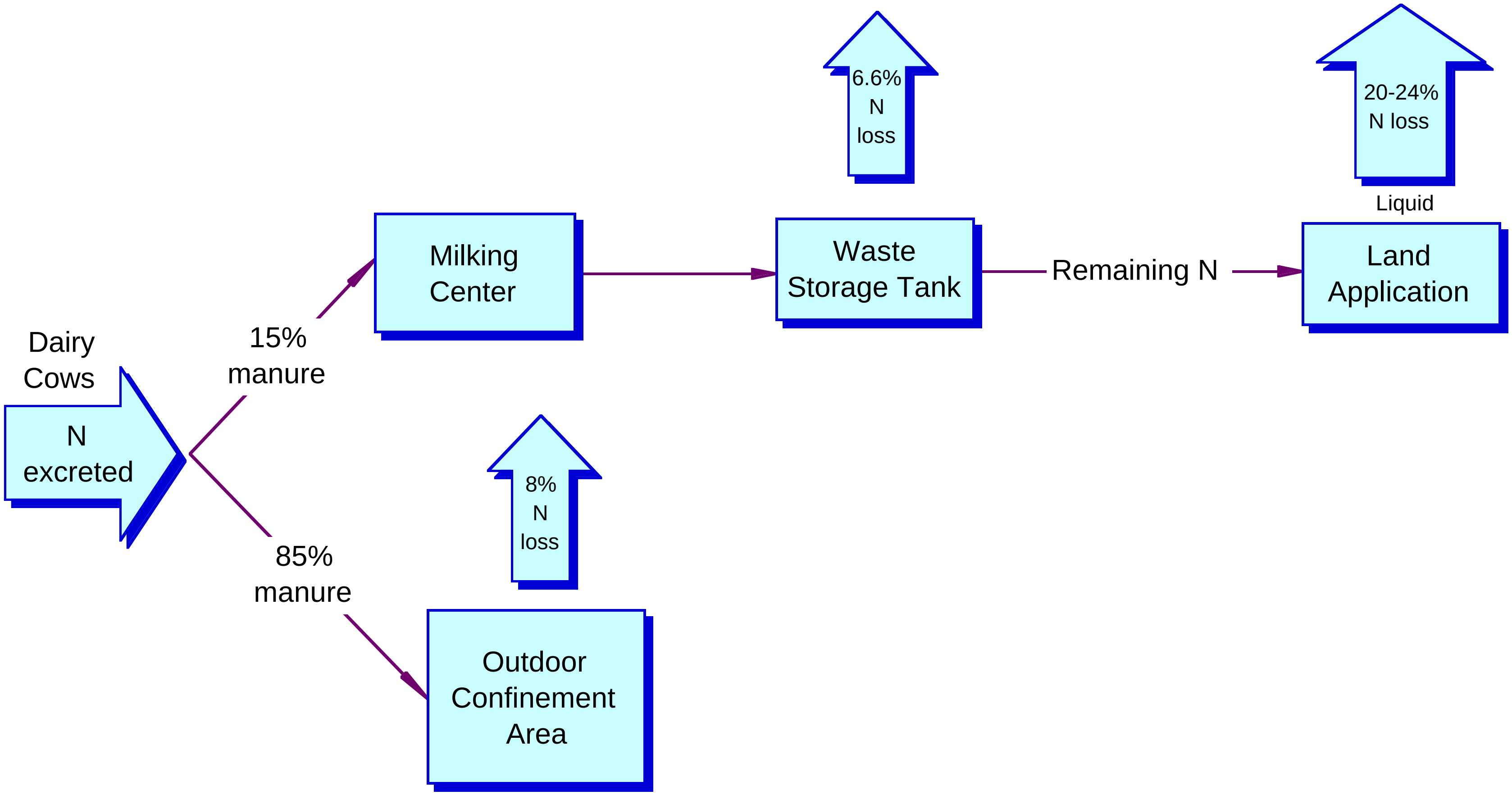
Dairy - Solid Storage



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 11

Dairy - Outdoor Confinement Area



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 12
Poultry - Dry Layers

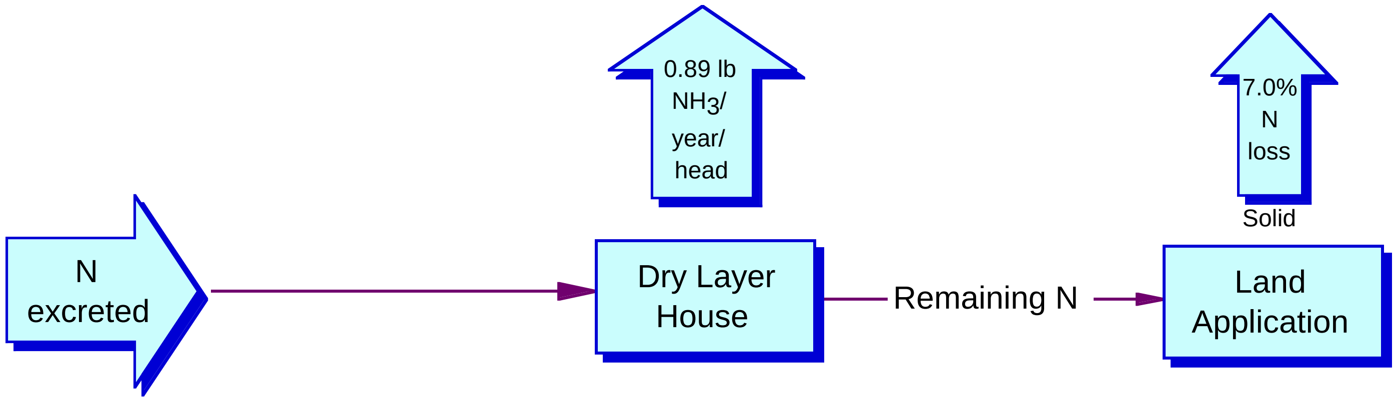
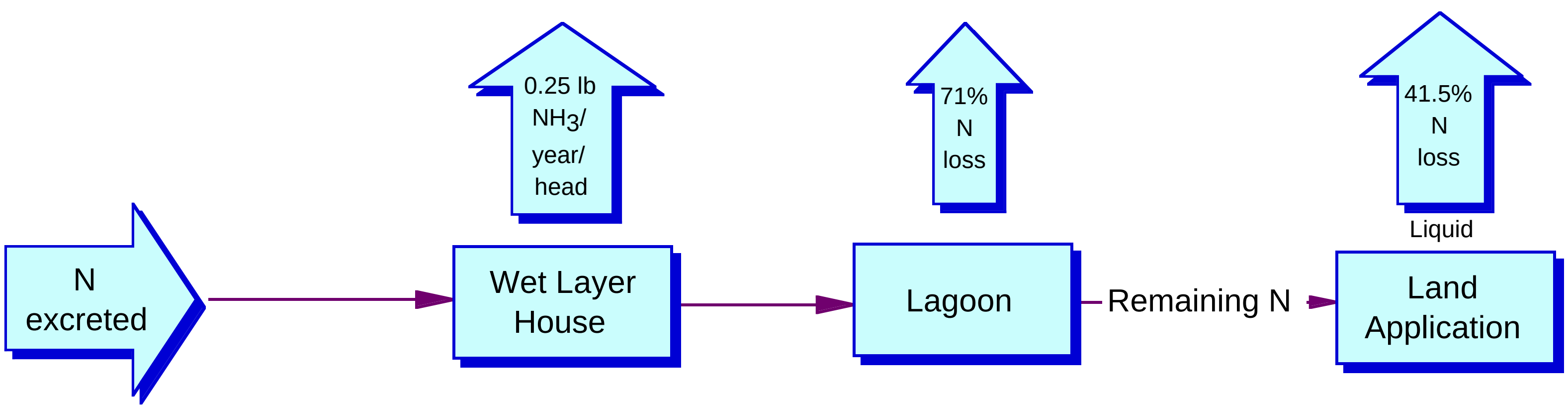


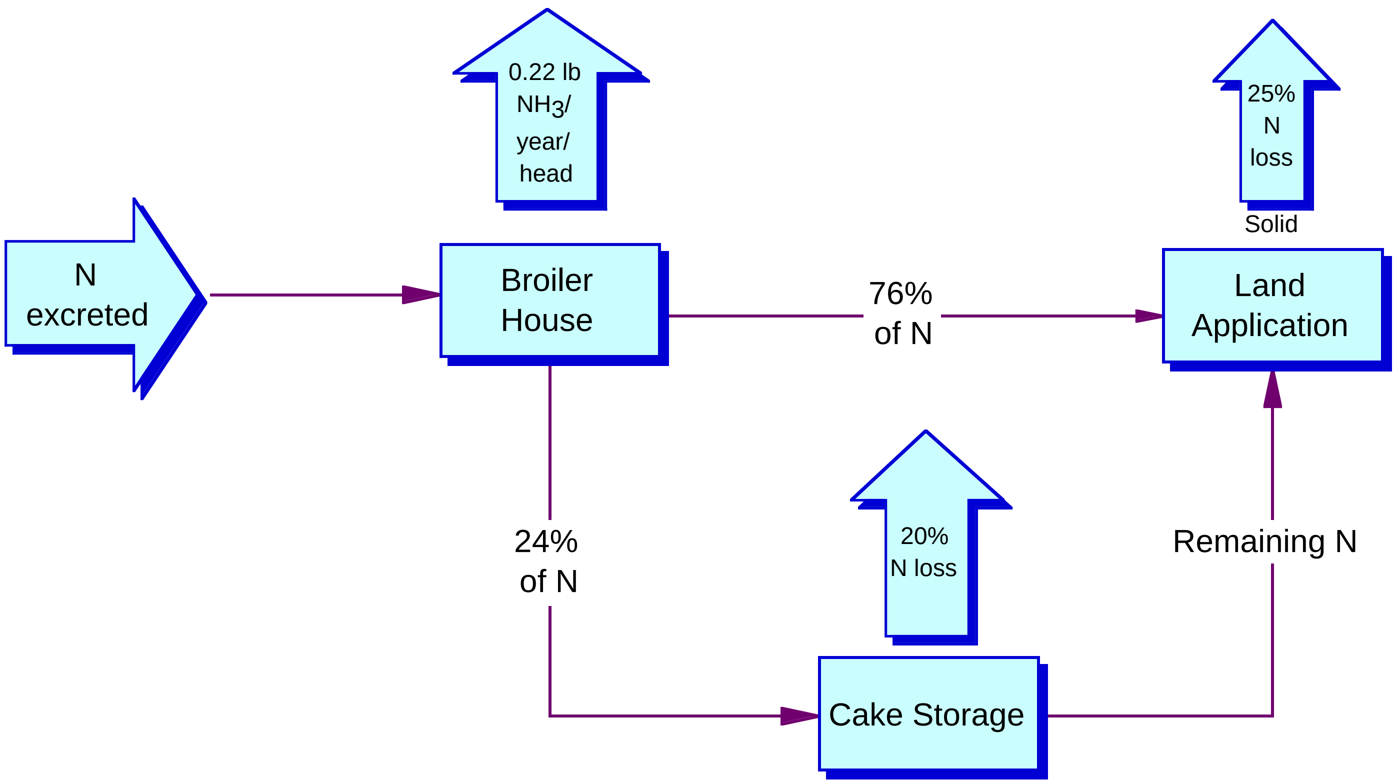
Figure 13
Poultry - Wet Layers



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 14

Poultry - Broiler House



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 15
Poultry - Turkey House

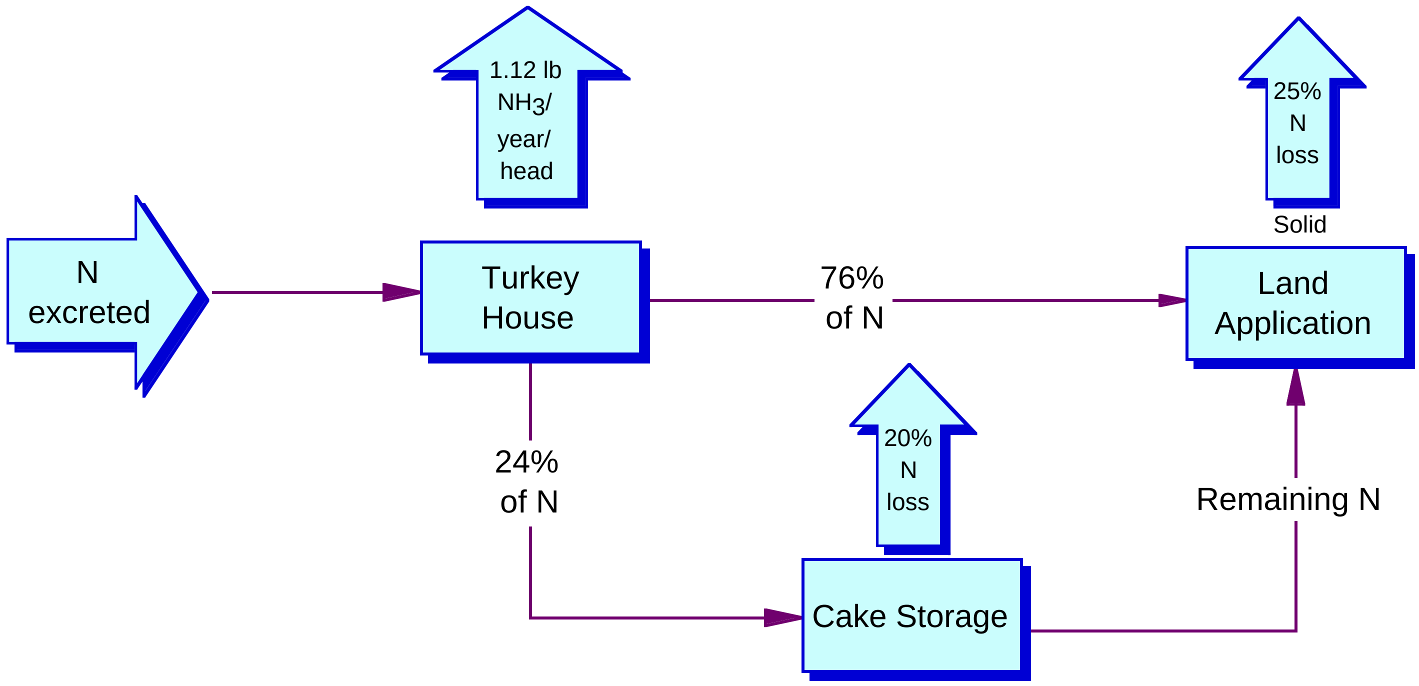
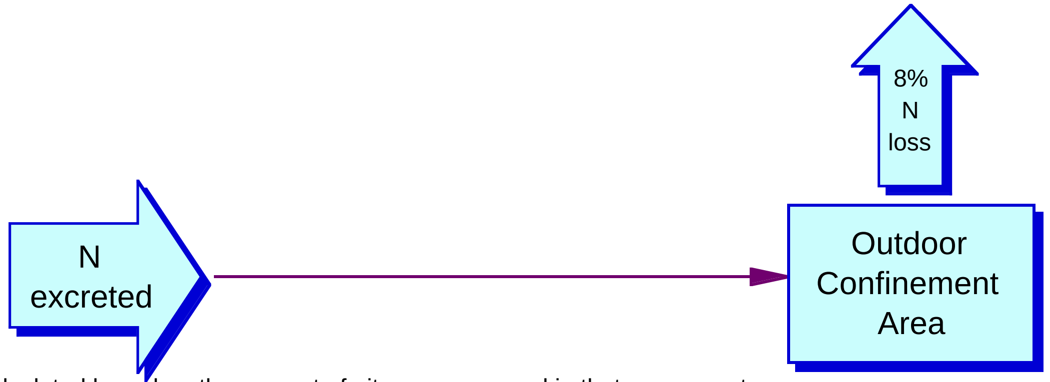


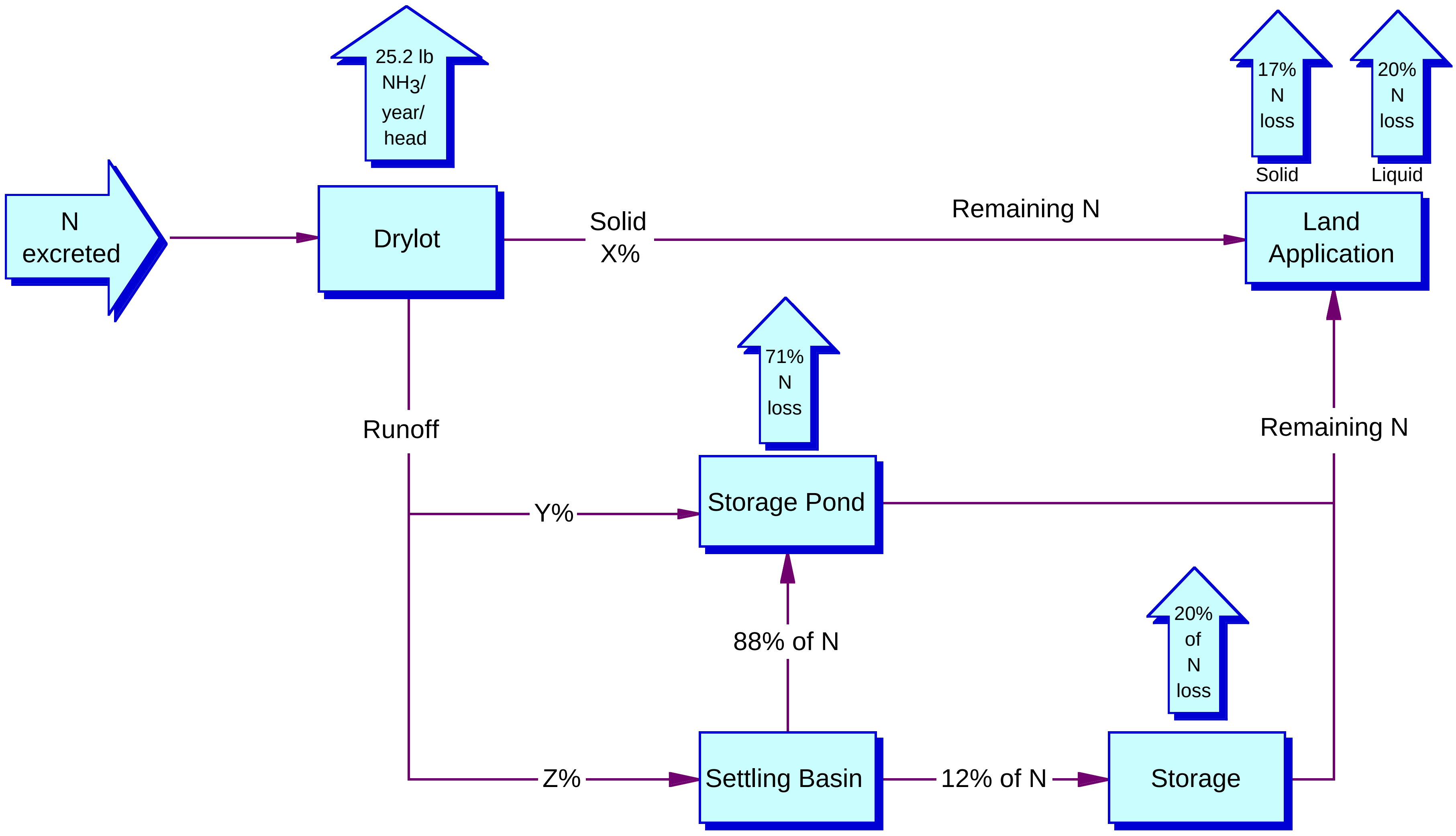
Figure 16
Poultry - Broiler/Turkey Outdoor Confinement Area



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

Figure 17

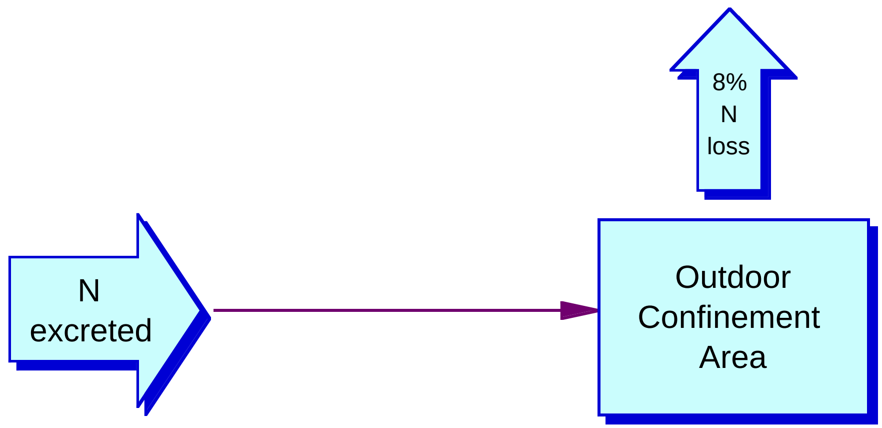
Beef - Feedlot



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.
The amount of nitrogen leaving the settling basin is based on the amount of nitrogen managed in the settling basin.
X%, Y% and Z% vary by size of operation, and represent the proportion of operations using each type of system.

Figure 18

Beef - Outdoor Confinement Area



The percentage of nitrogen lost is calculated based on the amount of nitrogen managed in that component.

APPENDIX C
State-Level Population and MMT Data

Table C-1. Annual Average 2002 Animal Populations by State

State	Annual Average 2002 Animal Populations										
	Dairy	Other Cattle	Cattle Feedlots	Breeding Pigs	Marketing Pigs	Broilers	Layers	Turkeys	Sheep	Goats	Horses
AK	1,681	10,634	48	300	900	0	0	0	9,733	167	5,186
AL	26,732	1,474,533	3,789	10,000	155,000	191,146,000	15,256,000	0	9,733	27,578	92,889
AR	47,404	1,915,592	14,209	93,750	415,000	215,691,000	22,787,000	9,218,750	9,733	17,083	87,507
AZ	171,829	463,365	288,933	14,000	129,000	0	0	0	134,000	41,000	82,445
CA	2,359,240	2,736,777	454,714	21,000	114,000	36,813,500	26,323,000	5,531,250	800,000	40,191	246,978
CO	131,421	1,701,578	1,146,258	158,750	613,750	0	4,777,000	2,039,922	370,000	12,841	178,317
CT	35,040	29,693	139	800	3,000	0	3,793,000	2,188	7,833	1,460	14,841
DE	12,364	14,987	143	4,500	17,500	46,800,000	1,484,000	938	9,733	674	7,092
FL	190,544	1,741,123	1,985	7,000	28,000	20,854,000	13,012,000	0	9,733	24,209	119,827
GA	113,893	1,258,022	2,842	55,000	290,000	234,636,000	29,553,000	0	9,733	36,637	77,122
HI	9,882	154,999	596	5,000	19,000	160,000	625,000	0	9,733	3,305	10,749
IA	320,107	2,394,258	904,692	1,100,000	14,375,000	36,813,500	46,240,000	2,125,000	250,000	12,275	131,930
ID	545,027	1,183,193	317,353	3,000	19,000	0	1,245,000	0	260,000	6,269	130,048
IL	163,023	1,143,856	189,464	440,000	3,772,500	0	4,002,000	906,250	70,000	10,781	112,866
IN	217,395	616,298	108,942	332,500	2,867,500	36,813,500	29,098,000	4,062,500	57,000	11,664	128,015
KS	133,425	4,036,892	2,396,721	163,750	1,396,250	0	0	2,039,922	100,000	7,293	115,351
KY	163,488	2,304,848	14,210	40,000	330,000	49,073,000	6,195,000	0	9,733	13,877	209,469
LA	64,625	847,700	1,633	3,000	17,000	36,813,500	2,560,000	0	9,733	8,315	65,776
MA	29,645	24,382	120	2,500	14,000	0	336,000	21,250	7,833	2,490	20,547
MD	112,706	135,010	12,315	7,000	38,000	53,254,000	4,312,000	135,938	9,733	5,311	49,201

Table C-1. Annual Average 2002 Animal Populations by State (Cont.)

State	Annual Average 2002 Animal Populations										
	Dairy	Other Cattle	Cattle Feedlots	Breeding Pigs	Marketing Pigs	Broilers	Layers	Turkeys	Sheep	Goats	Horses
ME	57,192	46,122	201	1,300	4,700	0	5,790,000	0	7,833	2,214	12,555
MI	426,634	443,093	179,991	112,500	807,500	0	8,101,000	1,500,000	72,000	10,603	144,551
MN	782,964	1,679,246	255,777	577,500	5,372,500	8,036,000	14,685,000	13,750,000	160,000	7,871	121,989
MO	197,632	4,409,426	66,312	365,000	2,610,000	36,813,500	8,555,000	7,968,750	70,000	22,683	187,106
MS	48,406	1,147,124	3,279	29,000	246,000	139,909,000	10,814,000	0	9,733	18,389	68,979
MT	31,464	2,327,106	66,313	21,000	164,000	0	480,000	0	350,000	4,909	155,451
NC	94,808	949,070	4,737	1,000,000	8,900,000	133,673,000	17,042,000	14,218,750	9,733	36,892	89,911
ND	56,423	1,850,342	58,734	26,000	128,000	0	0	593,750	145,000	6,315	76,648
NE	92,034	3,950,250	2,245,150	377,500	2,572,500	673,000	13,679,000	2,039,922	101,000	5,185	100,088
NH	25,683	17,944	80	800	2,400	0	229,000	1,563	7,833	2,368	10,188
NJ	18,761	25,932	1,894	2,000	13,000	0	2,158,000	10,625	9,733	4,040	49,385
NM	347,945	1,213,573	102,311	400	2,600	0	0	0	230,000	45,294	84,755
NV	34,609	470,316	18,946	1,000	5,500	0	0	0	100,000	1,828	31,050
NY	963,107	480,241	23,683	9,000	77,000	436,000	4,892,000	162,500	60,000	14,322	104,274
OH	365,665	803,516	170,517	162,500	1,312,500	7,091,000	37,883,000	1,687,500	140,000	20,003	166,491
OK	106,294	5,060,923	345,772	327,500	2,060,000	42,327,000	5,590,000	2,039,922	60,000	31,967	204,622
OR	157,781	1,231,861	47,366	6,000	25,000	36,813,500	3,400,000	2,039,922	285,000	16,608	149,082
PA	861,591	819,129	71,049	127,500	950,000	24,218,000	29,257,000	3,093,750	86,000	20,403	142,086
RI	2,072	3,650	24	700	2,200	0	0	0	7,833	298	2,439
SC	27,687	442,120	3,789	30,000	270,000	35,073,000	6,598,000	3,093,750	9,733	27,153	50,179

Table C-1. Annual Average 2002 Animal Populations by State (Cont.)

State	Annual Average 2002 Animal Populations										
	Dairy	Other Cattle	Cattle Feedlots	Breeding Pigs	Marketing Pigs	Broilers	Layers	Turkeys	Sheep	Goats	Horses
SD	126,874	3,514,009	336,299	142,500	1,150,000	0	2,677,000	1,500,000	400,000	5,101	113,052
TN	128,415	2,283,681	9,473	30,000	190,000	33,891,000	2,200,000	0	9,733	49,755	194,370
TX	406,213	11,132,769	2,737,757	102,500	855,000	106,927,000	25,506,000	2,039,922	1,130,000	1,280,431	528,370
UT	135,243	795,499	23,683	90,000	580,000	0	3,853,000	2,039,922	365,000	5,974	107,182
VA	177,590	1,582,125	25,578	35,000	365,000	48,273,000	4,573,000	6,250,000	59,000	19,830	109,794
VT	209,750	92,092	277	500	2,000	0	201,000	14,375	7,833	2,617	19,368
WA	347,860	571,419	236,831	4,000	20,000	36,813,500	6,484,000	0	56,000	9,509	128,321
WI	1,903,851	1,454,836	151,572	60,000	447,500	6,146,000	5,600,000	2,039,922	80,000	20,071	114,521
WV	20,811	408,912	7,579	2,000	9,000	16,309,000	1,966,000	112,500	37,000	7,572	36,655
WY	5,966	1,405,001	75,785	20,000	95,000	0	17,000	0	480,000	6,174	110,383

Table C-2. Dairy MMT Distribution by State

State	Lactating Cow MMT Distribution (Percent)									Dry Cow MMT Distribution (Percent)	
	Flush Barn	Flush Barn with Solids Separation	Scrape Barn	Scrape Barn with Solids Separation	Outdoor Confinement Area	Dairy Slurry	Dairy Solid Storage	Daily Spread (Scrape Barn)	Barn with Deep Pit	Dry Lot	Outdoor Confinement Area
AK	7	2	23	2	10	12	22	17	6	90	10
AL	4	1	7	1	63	3	7	14	0	37	63
AR	0	0	6	0	63	5	12	14	1	37	63
AZ	45	22	16	7	0	0	0	10	0	100	0
CA	42	19	18	7	1	0	1	11	0	99	1
CO	23	10	39	13	1	3	6	2	2	99	1
CT	3	1	10	2	6	8	22	44	3	94	6
DE	4	1	6	1	8	8	25	45	3	92	8
FL	23	15	12	5	12	0	1	23	0	88	12
GA	7	2	9	1	53	3	8	16	0	47	53
HI	36	17	19	6	12	3	6	0	2	88	12
IA	2	0	7	1	10	12	47	17	4	90	10
ID	24	11	37	13	1	4	8	2	2	99	1
IL	1	0	8	1	7	14	51	12	5	93	7
IN	1	0	6	1	11	13	45	18	4	89	11
KS	1	0	6	1	8	14	51	14	5	92	8
KY	0	0	1	0	63	4	16	14	1	37	63
LA	2	1	8	1	58	4	11	15	1	42	58

Table C-2. Dairy MMT Distribution by State (Cont.)

State	Lactating Cow MMT Distribution (Percent)									Dry Cow MMT Distribution (Percent)	
	Flush Barn	Flush Barn with Solids Separation	Scrape Barn	Scrape Barn with Solids Separation	Outdoor Confinement Area	Dairy Slurry	Dairy Solid Storage	Daily Spread (Scrape Barn)	Barn with Deep Pit	Dry Lot	Outdoor Confinement Area
MA	1	0	7	1	8	8	26	46	3	92	8
MD	2	1	7	1	8	8	25	46	3	92	8
ME	1	0	6	1	9	7	26	47	3	91	9
MI	5	2	15	3	6	14	41	10	5	94	6
MN	3	1	5	1	11	12	45	19	4	89	11
MO	1	0	5	0	10	14	49	16	5	90	10
MS	1	0	8	1	63	4	9	14	0	37	63
MT	3	1	31	2	3	17	31	4	9	97	3
NC	1	0	5	1	63	4	10	14	2	37	63
ND	0	0	3	0	12	12	48	20	4	88	12
NE	2	0	5	0	9	14	48	16	5	91	9
NH	1	0	7	1	7	9	26	45	3	93	7
NJ	3	1	5	1	8	9	26	46	3	92	8
NM	30	15	30	15	0	0	0	10	0	100	0
NV	30	15	32	15	2	1	2	3	0	98	2
NY	3	1	9	2	8	7	22	46	2	92	8
OH	2	1	6	1	10	13	46	17	5	90	10
OK	4	1	28	1	0	19	33	5	9	100	0

Table C-2. Dairy MMT Distribution by State (Cont.)

State	Lactating Cow MMT Distribution (Percent)									Dry Cow MMT Distribution (Percent)	
	Flush Barn	Flush Barn with Solids Separation	Scrape Barn	Scrape Barn with Solids Separation	Outdoor Confinement Area	Dairy Slurry	Dairy Solid Storage	Daily Spread (Scrape Barn)	Barn with Deep Pit	Dry Lot	Outdoor Confinement Area
OR	11	4	29	7	31	5	9	0	3	69	31
PA	1	0	4	1	10	7	27	48	2	90	10
RI	0	0	2	0	12	6	28	51	2	88	12
SC	2	1	9	2	63	3	7	14	0	37	63
SD	1	0	6	1	10	13	47	17	4	90	10
TN	2	0	3	0	63	4	13	14	2	37	63
TX	30	12	25	6	0	6	10	7	3	100	0
UT	11	4	39	7	2	10	19	3	5	98	2
VA	2	0	3	0	63	4	12	14	2	37	63
VT	3	1	8	2	8	7	23	46	3	92	8
WA	17	7	32	10	23	3	6	0	2	77	23
WI	4	1	6	1	10	12	46	17	4	90	10
WV	1	0	5	1	9	8	27	47	3	91	9
WY	4	1	29	3	8	12	22	14	6	92	8

Table C-3. Swine MMT Distribution by State

State	Swine MMT Distribution (Percent)			
	Swine Houses with Lagoon Systems	Swine Houses with Lagoon Systems and Solid Separation	Swine Houses with Deep Pit Systems	Outdoor Confinement Area
AK	52	8	23	16
AL	81	0	18	1
AR	85	0	14	0
AZ	62	3	29	6
CA	64	2	31	4
CO	66	1	32	1
CT	14	3	82	1
DE	26	4	69	1
FL	70	0	28	2
GA	81	0	18	1
HI	52	8	23	16
IA	25	4	70	1
ID	16	2	81	1
IL	25	4	70	1
IN	25	4	70	1
KS	62	3	30	6
KY	80	0	19	1
LA	70	0	28	2
MA	14	3	82	1
MD	21	5	73	1

Table C-3. Swine MMT Distribution by State (Cont.)

State	Swine MMT Distribution (Percent)			
	Swine Houses with Lagoon Systems	Swine Houses with Lagoon Systems and Solid Separation	Swine Houses with Deep Pit Systems	Outdoor Confinement Area
ME	14	3	82	1
MI	20	1	79	0
MN	19	1	79	0
MO	83	0	16	1
MS	86	0	13	0
MT	21	1	78	0
NC	89	0	11	0
ND	18	2	80	0
NE	23	4	71	1
NH	14	3	82	1
NJ	16	5	78	2
NM	52	8	23	16
NV	52	8	23	16
NY	18	2	80	0
OH	22	5	73	1
OK	66	1	32	1
OR	14	3	82	1
PA	26	4	69	1
RI	14	3	82	1
SC	83	0	17	1

Table C-3. Swine MMT Distribution by State (Cont.)

State	Swine MMT Distribution (Percent)			
	Swine Houses with Lagoon Systems	Swine Houses with Lagoon Systems and Solid Separation	Swine Houses with Deep Pit Systems	Outdoor Confinement Area
SD	19	2	79	0
TN	78	0	21	1
TX	63	2	30	5
UT	66	1	32	1
VA	30	4	66	0
VT	14	3	82	1
WA	17	2	81	1
WI	16	2	81	1
WV	16	5	78	2
WY	23	0	77	0

Table C-4. Poultry MMT Distribution by State

State	Poultry MMT Distribution (Percent)					
	Layers		Broilers		Turkeys	
	Dry Layers	Wet Layers	House	Outdoor Confinement Area	House	Outdoor Confinement Area
AK	75	25	99	1	99	1
AL	58	42	99	1	99	1
AR	100	0	99	1	99	1
AZ	40	60	99	1	99	1
CA	88	12	99	1	99	1
CO	40	60	99	1	99	1
CT	95	5	99	1	99	1
DE	95	5	99	1	99	1
FL	58	42	99	1	99	1
GA	58	42	99	1	99	1
HI	75	25	99	1	99	1
IA	100	0	99	1	99	1
ID	40	60	99	1	99	1
IL	98	2	99	1	99	1
IN	100	0	99	1	99	1
KS	98	2	99	1	99	1
KY	95	5	99	1	99	1
LA	40	60	99	1	99	1
MA	95	5	99	1	99	1

Table C-4. Poultry MMT Distribution by State (Cont.)

State	Poultry MMT Distribution (Percent)					
	Layers		Broilers		Turkeys	
	Dry Layers	Wet Layers	House	Outdoor Confinement Area	House	Outdoor Confinement Area
MD	95	5	99	1	99	1
ME	95	5	99	1	99	1
MI	98	2	99	1	99	1
MN	100	0	99	1	99	1
MO	100	0	99	1	99	1
MS	40	60	99	1	99	1
MT	40	60	99	1	99	1
NC	58	42	99	1	99	1
ND	98	2	99	1	99	1
NE	100	0	99	1	99	1
NH	95	5	99	1	99	1
NJ	95	5	99	1	99	1
NM	40	60	99	1	99	1
NV	40	60	99	1	99	1
NY	95	5	99	1	99	1
OH	100	0	99	1	99	1
OK	40	60	99	1	99	1
OR	75	25	99	1	99	1
PA	100	0	99	1	99	1

Table C-4. Poultry MMT Distribution by State (Cont.)

State	Poultry MMT Distribution (Percent)					
	Layers		Broilers		Turkeys	
	Dry Layers	Wet Layers	House	Outdoor Confinement Area	House	Outdoor Confinement Area
RI	95	5	99	1	99	1
SC	40	60	99	1	99	1
SD	98	2	99	1	99	1
TN	95	5	99	1	99	1
TX	88	12	99	1	99	1
UT	40	60	99	1	99	1
VA	95	5	99	1	99	1
VT	95	5	99	1	99	1
WA	88	12	99	1	99	1
WI	98	2	99	1	99	1
WV	95	5	99	1	99	1
WY	40	60	99	1	99	1

Table C-5. Beef MMT Distribution by State

State	Beef MMT Distribution (Percent)	
	Feedlot	Outdoor Confinement Area
AK	99.6	0.4
AL	99.7	0.3
AR	99.3	0.7
AZ	61.6	38.4
CA	85.8	14.2
CO	59.7	40.3
CT	99.5	0.5
DE	99.1	0.9
FL	99.9	0.1
GA	99.8	0.2
HI	99.6	0.4
IA	72.6	27.4
ID	78.9	21.1
IL	85.8	14.2
IN	85.0	15.0
KS	62.7	37.3
KY	99.4	0.6
LA	99.8	0.2
MA	99.5	0.5
MD	91.6	8.4

Table C-5. Beef MMT Distribution by State (Cont.)

State	Beef MMT Distribution (Percent)	
	Feedlot	Outdoor Confinement Area
ME	99.6	0.4
MI	71.1	28.9
MN	86.8	13.2
MO	98.5	1.5
MS	99.7	0.3
MT	97.2	2.8
NC	99.5	0.5
ND	96.9	3.1
NE	63.8	36.2
NH	99.6	0.4
NJ	93.2	6.8
NM	92.2	7.8
NV	96.1	3.9
NY	95.3	4.7
OH	82.5	17.5
OK	93.6	6.4
OR	96.3	3.7
PA	92.0	8.0
RI	99.3	0.7
SC	99.2	0.8

Table C-5. Beef MMT Distribution by State (Cont.)

State	Beef MMT Distribution (Percent)	
	Feedlot	Outdoor Confinement Area
SD	91.3	8.7
TN	99.6	0.4
TX	80.3	19.7
UT	97.1	2.9
VA	98.4	1.6
VT	99.7	0.3
WA	70.7	29.3
WI	90.6	9.4
WV	98.2	1.8
WY	94.9	5.1

APPENDIX D
Emission Factor Development

APPENDIX D: EMISSION FACTOR DEVELOPMENT

This appendix presents the development of annual average emission factors for swine, dairy, poultry, and beef operations. These emission factors were developed following a review of existing data and are presented in units of ammonia per head per year, or percent of nitrogen lost as ammonia.

D.1 SWINE EMISSION FACTOR DEVELOPMENT

EPA estimated ammonia emission factors for three separate types of swine operations. These operations are swine houses with lagoons, deep pit houses, and outdoor confinement areas. Figures 1 through 3 in Appendix B present these operations graphically. The development of emission factors for the components of these operations is discussed below.

D.1.1 Swine Houses with Lagoon Systems

The ammonia emission factor for swine houses with lagoon systems is based on five data sources identified in the literature review. These data include flush houses, pit recharge systems, and pull plug systems. Table D-1 presents the data points and calculations used to estimate this emission factor.

Table D-1. Ammonia Emission Factor for Swine Houses with Lagoon Systems

Reference	Emission Factor (EF)	EF Units	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Andersson, M., 1998	229.1	mg/head/hour	229.1	24 hours/day 119 days/cycle 2.8 cycles/yr 1000 mg/g 1 lb/453.6 g	4.0
Oosthoek et al., 1991	3.1	kg/animal/yr	3.1	2.2046 lb/kg	6.8
Oosthoek et al., 1991	3	kg/head/yr	3	2.2046 lb/kg	6.6
Harris and Thompson, 1998	3.7	kg/finish pig/yr	3.7	2.2046 lb/kg	8.2
Heber, 1997	13	lb/1,000 pigs/day	13	119 days/cycle 2.8 cycles/yr	4.3
AVERAGE					**6.0**

D.1.2 Swine Houses with Deep Pit Systems

The literature search identified nine applicable data points for swine houses with deep pit systems. Table D-2 presents these data points and the calculations used to estimate the emission factor.

Table D-2. Ammonia Emission Factor for Swine Houses with Deep-Pit Systems

Reference	Emission Factor (EF)	EF Units	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Asman, 1992	3.18	kg/fattening pig/yr	3.18	2.2046 lb/kg	7.0
Hoeksma et al., 1993	10.0-12.0	g NH_3/animal/day	11.0	119 days/cycle 2.8 cycles/yr 1 lb/453.6 g	8.1
Hoeksma et al., 1993	8.0-9.0	g NH_3/animal/day	8.5	119 days/cycle 2.8 cycles/yr 1 lb/453.6 g	6.2
Ni et al., 2000	255	g/hour/858 pigs	255	24 hours/day 119 days/cycle 2.8 cycles/yr 1 lb/453.6 g	5.2
Ni et al., 2000	186	g/hour/870 pigs	186	24 hours/day 119 days/cycle 2.8 cycles/yr 1 lb/453.6 g	3.8
Ni et al., 2000	145	g NH_3/500 kg LW-day	145	1 lb/453.6 g 0.4536 kg/lb 135 lb/head 119 days/cycle 2.8 cycles/yr	12.5
Oosthoek et al., 1988	3	kg/animal/yr	3	2.2046 lb/kg	6.6
Secrest, 1999	34.9-44.6	lb/day/2,000 finishing hogs	39.75	119 days/cycle 2.8 cycles/yr	6.6
USDA, 2000	13	g/hd/day	13.0	119 days/cycle 2.8 cycles/yr 1 lb/453.6 g	9.5
AVERAGE					**7.3**

D.1.3 Outdoor Confinement Area

EPA did not identify any applicable data points for swine on outdoor confinement areas. A swine outdoor confinement area is most likely a dirt lot and therefore is expected to resemble a cattle drylot. Although some swine may be on pastures, data are not available to quantity the number of animals on pasture. The percentage of swine on pastures is expected to be low. Therefore, EPA used cattle drylot emission factors to establish an emission factor for swine outdoor confinement areas. To address the variability of swine outdoor confinement areas, EPA averaged the cattle drylot emission factors to represent the swine on outdoor confinement areas.

EPA calculated the average nitrogen excreted by cattle on drylots using the typical animal mass (TAM) and the nitrogen excretion rate (Nex).

Table D-3. Ammonia Emission Factors for Cattle Drylots

Animal	TAM (kg animal mass/ hd)	Nex Rate (kg N/ 1000 kg animal mass/ day)	Nex (lbN/hd/yr)	Emission Factor	
				lb NH_3/hd	%
Feedlot Cattle	420	0.30	101	25.2	20.5
Dairy Drylot Cattle - Dry Cows - Heifers	 604 476	 0.36 0.31	 175 119	18.58[1]	12.6[1]
AVERAGE DRYLOT					**16.6**

[1] These values represent averages.

The ammonia emission factor from beef drylots is 25.2 lbs NH_3/head/year (Section D.4.2) and from dairy drylots is 18.58 lbs NH_3/head/year (Section D.2.3). To express this emission factor as a percentage of the nitrogen excreted by the animal, Equation D-1 was used.

$$\% \, Loss \, of \;\; N = \frac{Ammonia \; Emission \; Factor \times CF}{Manure \; Nitrogen_{excreted}} \times 100\% \qquad [D\text{-}1]$$

where:

% Loss of N	=	Percent of nitrogen lost as ammonia
Ammonia Emission Factor	=	Ammonia emission factor (lb/yr/head)
CF	=	Conversion factor (14 N/17 NH_3)
Manure $Nitrogen_{excreted}$	=	Nitrogen excreted (lb/yr/head)

Using Equation D-1 and the data presented in Table D-3 , EPA estimated the percent loss of nitrogen from swine confinement areas to be 16.6 percent nitrogen loss.

D.1.4 Lagoons at Swine Operations

The literature search identified six applicable data points for lagoons at swine operations. Table D-4 presents these data points and the calculations used to estimate the emission factor.

Table D-4. Ammonia Emission Factor for Lagoons at Swine Operations

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF (lb NH_3/yr/head)
Aneja et al., 2000	2.2	kg N/yr/head	2.2046 lb/kg 17 NH_3/14 N	5.9
Fulhage, 1998	64.7	Percentage of excreted nitrogen	56 lb N/yr-AU 17 NH_3/14 N 1 AU/2.5 head	17.6
Koelliker and Miner, 1971	6.53	kg NH_3/yr/head	2.2046 lb/kg	14.4
Fulhage, 1998	77.2	Percentage of excreted nitrogen	56 lb N/yr-AU 17 NH_3/14 N 1 AU/2.5 head	21.0
Martin, 2000	8,210	kg/yr/500 AU	2.2046 lb/kg 1 AU/2.5 head	14.5
Martin, 2000	5,602	kg/yr/500 AU	2.2046 lb/kg 1 AU/2.5 head	9.9
AVERAGE				**13.9**

This average emission factor is based on data mainly from swine finishing operations. In order to better represent all swine operations, including farrowing operations, this emission factor was converted to a percentage of nitrogen loss using Equation D-2.

$$\%\ \text{Loss of N}_{\text{lagoon}} = \frac{\text{Ammonia Lagoon Emission Rate}_{\text{swine}} \times \text{CF}}{\text{Nitrogen}_{\text{input}}} \times 100\% \qquad \text{[D-2]}$$

where:

% Loss of N_{lagoon}	=	Percentage of nitrogen entering the swine lagoon lost as ammonia
Ammonia Lagoon Emission $Rate_{swine}$	=	Ammonia emission factor for the swine lagoon (lb NH_3/yr/head)
CF	=	Conversion factor (14 N/17 NH_3).
$Nitrogen_{input}$	=	Nitrogen input to the lagoon (lbs N/yr/head)

EPA estimated that 21.1 lb N/yr/head is excreted at swine operations and 6.0 lb

NH_3/yr/head is lost at the swine house. As shown in Table D-4, the swine lagoon emission factor is 13.9 lb NH_3/yr/head; therefore, using Equation D-2, the percentage of nitrogen lost from the lagoon as ammonia is:

$$\text{Emission Factor}_{lagoon} = \frac{13.9 \text{ lb } NH_3 / \text{yr} / \text{head} \times \frac{14 \text{ N}}{17 \text{ NH}_3}}{21.1 \text{ lb N} / \text{yr} / \text{head} - (6.0 \text{ lb } NH_3 / \text{yr} / \text{head} \times \frac{14 \text{ N}}{17 \text{ NH}_3})} \times 100\%$$

$$= 71\% \text{ N loss}$$

D.1.5 Land Application of Swine Manure

Limited data were available for emission factors associated with the land application of swine manure. Therefore, EPA developed emission factors using general ammonia volatilization information for the land application of animal manure.

Table D-5 presents nitrogen volatilization rates for six different land application methods obtained from the *Midwest Plan Service: Livestock Waste Facilities Handbook* (MWPS, 1983).

Table D-5. Percentage of Nitrogen Volatilizing as Ammonia from Land Application

Application Method	Percent Loss[a]	Avg Percent Loss
Broadcast (solid)	15-30	22.5
Broadcast (liquid)	10-25	17.5
Broadcast (solid, immediate incorporation)	1-5	3
Broadcast (liquid, immediate incorporation)	1-5	3
Knifing (liquid)	0-2	1
Sprinkler irrigation (liquid)	15-40	27.5

[a]MWPS, 1983. Percentage of nitrogen applied that is lost within 4 days of application.

The percentage of nitrogen lost as ammonia as a result of land application activities depends on both the application method used and the rate of incorporation. Both the application method and the rate of incorporation vary by animal operation; therefore, ERG calculated the percent nitrogen losses separately for each animal type using Equation D-3.

% N Lost During and After Application =
(% Applied with Incorporation x Average % Loss) + (% Applied without Incorporation x Average % Loss)
[D-3]

where:

% Applied with Incorporation	=	The percentage of land-applied manure that is incorporated into the soil immediately after application.
Average % Loss	=	The average percentage of the ammonia lost from the land application method used, from Table D-5. (This value is calculated by averaging the minimum and maximum percent loss for each application method.)
% Applied without Incorporation	=	The percentage of land-applied manure that is surface applied.

EPA used data from the United States Department of Agriculture (USDA)'s National Animal Health Monitoring System (NAHMS) to estimate land application methods for swine farms. For large (greater than 2000 head) swine operations, EPA estimated that 30 percent of the manure being land applied is incorporated and 70 percent of the manure is surface-applied, using a sprinkler irrigation system for liquid manure. For small (less than 2,000 head) swine operations, EPA estimated that 20 percent of the manure being land applied is incorporated and 80 percent of the manure is surface applied, using a sprinkler irrigation system for liquid manure.

EPA calculated the expected nitrogen losses as follows, using the emission factors from Table D-5:

% N lost from liquid manure application (Large) = (30% × 3%) + (70% × 27.5%) = 20%

% N lost from solid manure application (Large) = (30% × 3%) + (70% × 22.5%) = 17%

% N lost from liquid manure application (Small) = (20% × 3%) + (80% × 27.5%) = 23%

% N lost from solid manure application (Small) = (20% × 3%) + (80% × 22.5%) = 19%

D.2 DAIRY EMISSION FACTOR DEVELOPMENT

EPA developed ammonia emission factors for five separate types of dairy operations: flush, scrape, barns with deep pits, daily spread (scrape barn), and outdoor confinement area operations. All dairies have milking parlors; 15 percent of milking cow's manure is deposited in the milking parlor and 85 percent is deposited in the barn (USDA 1996). However, milking parlors emit negligible amounts of ammonia because typically they are flushed frequently and, therefore, do not have an emission factor. The estimation of emission factors for the components of these operations is presented below. Figures 4 through 11 in Appendix B present these operations graphically.

D.2.1 Flush Barns with Lagoon Systems

EPA's August 2001 report does not contain data points for dairy flush barns with lagoon systems. Swine confinement houses with lagoon systems and dairy flush houses have similar manure management practices; therefore, EPA transferred the ammonia emission factor for swine houses with lagoon systems to dairy flush barns.

The ammonia emission factor for flush barns at dairies is based on the percent loss of nitrogen from swine confinement houses with lagoon systems. EPA calculated the percent loss of nitrogen represented by the swine house with lagoon system emission factor using Equation D-1.

Assuming an average weight of 125 pounds, market pigs excrete 19.2 lb N/head/year, while breeding pigs excrete 38.2 lb N/head/year. Using national population estimates, approximately 10 percent of swine are breeding pigs. Therefore, EPA estimated that 21.1 lb N/head/year is excreted at the swine confinement houses. As shown in Table D-1, the swine house with lagoon system emission factor is 6.0 lb NH_3/yr/head; therefore, using Equation D-1, EPA calculated the percentage of nitrogen lost from the house as ammonia as:

$$\text{Emission Factor}_{\text{flush dairy barn}} = \frac{6.0 \text{ lb NH}_3\text{/yr/head} \times \dfrac{14 \text{ N}}{17 \text{ NH}_3}}{21.1 \text{ lb N/yr/head}} \times 100\%$$

$$= 23.5\% \text{ N loss}$$

D.2.2 Scrape Barns at Dairies

The ammonia emission factor for scrape barns at dairies is based on data identified from the literature review. Table D-6 presents the four data points and calculations used to estimate this emission factor. Daily spread operations are also represented with this emission factor.

Table D-6. Ammonia Emission Factor for Scrape Barns at Dairy Operations

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Demmers et.al., 2001	8.9	kg/500 kg/yr	8.9	2.2046 lb/kg 604 kg/head	23.7
Jungbluth, 1997	7-13	g/LU/day	10	1 LU/500 kg LW 1 lb/ 453.6 g 604 kg/head 365 days in barn/yr	9.7
Misselbrook et al., 1998	8.3	g N/cow/day	8.3	365 days in barn/yr, 1lb/453.6 g 17 NH_3/14 N	8.1
Van Der Hoek, 1998	14.5	kg /animal/year	14.5	2.2046 lb/kg	32.0
AVERAGE					**18.5**

D.2.3 Drylots at Dairies

The ammonia emission factor for drylots at dairies is based on data identified from the literature review. Table D-7 presents the three data points and calculation used to estimate this emission factor.

Table D-7. Ammonia Emission Factor for Drylots at Dairy Operations

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Misselbrook et al., 1998	8.3	g N/cow/day	8.3	1,000 g/kg, 2.2046 lb/kg 365 days/yr 17 NH_3/14 N	8.1
USDA, 2000	8	kg/cow/yr	8	2.2046 lb/kg	17.6
USDA, 2000	30	lb/head/yr	30	NA	30.0
AVERAGE					**18.58**

NA - Not Applicable

D.2.4 Dairy Outdoor Confinement Areas

The recommended ammonia emission factor for outdoor confinement areas at dairies is based on a single reference identified from the literature review. Table D-8 presents the data.

Table D-8. Ammonia Emission Factor for Dairy Outdoor Confinement Areas

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF
Bouwman et al., 1997	8	Percent of N	NA	8 percent of N

D.2.5 Dairy Barns with Deep Pits

The literature search did not yield applicable data points for dairy barns with deep pit systems. Swine houses with deep pit systems and dairies with deep pits have similar manure management practices; therefore, the ammonia emission factor for deep pits at dairies is based on the percent loss of nitrogen from swine confinement houses with deep pits. EPA calculated the percent loss of nitrogen represented by the swine house with deep pit system emission factor using Equation D-1.

EPA estimated that 21.1 lb N/yr/head is excreted at the swine confinement houses. As shown in Table D-2, the swine house with deep pit system emission factor is 7.3 lb NH_3/yr/head; therefore, using Equation D-1, the percentage of nitrogen lost from the house as ammonia is:

$$\text{Emission Factor}_{\text{dairy deep pit}} = \frac{7.3 \text{ lb } NH_3/\text{yr/head} \times \frac{14 \text{ N}}{17 \text{ } NH_3}}{21.1 \text{ lb N/yr/head}} \times 100\%$$

$$= 28.5\% \text{ N loss}$$

D.2.6 Dairy Lagoons

EPA did not identify any emission data for anaerobic lagoons at dairies. The ammonia emission factors for dairy lagoons at dairies is based on the percent loss of nitrogen from lagoons at swine operations. EPA calculated the percent loss of nitrogen represented by the swine lagoon emission factor in Section D.1.4. The percent nitrogen loss from swine lagoons is 71 percent.

Dairies with and without settling basins have differing lagoon emissions. At dairies with settling basins, the nitrogen flushed from the confinement house first flows through the settling basins before entering the lagoon, which EPA estimated removes 12 percent of the nitrogen. EPA calculated the amount of ammonia lost from the lagoon was calculated based on the estimated nitrogen entering the lagoon.

In addition, the ammonia emission from the lagoon depends on whether the dairy flushes or scrapes manure. Flush dairies transport the wastewater from both the milking parlor and the free-stall barn to the lagoon. Scrape dairies transport only the wastewater from flushing the milking parlor to the lagoon.

D.2.7 Dairy Manure Storage Tanks

The ammonia emission factor for manure storage tanks at dairies is based on a single data point identified from the literature review. Table D-9 presents this data point.

Table D-9. Ammonia Emission Factor for Dairy Manure Storage Tanks

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF
Safley, 1980	6.6	Percentage of N	NA	6.6 percent of N

NA - Not applicable

D.2.8 Solid Storage (Stockpile)

The stockpile ammonia emission rate recommended for use in the inventory is based on information from a literature review (Sutton et al., 2001), which indicated that 20 to 40 percent of nitrogen is lost from solid manure storage. The nitrogen loss is related to the amount of time the material is stored. For this analysis, EPA used an emission factor of 20 percent.

EPA calculated the stockpile ammonia emission factors using Equation D-4:

$$Stockpile\,Emissions = Nitrogen_{Stockpile}(lb/yr) \times 0.20 \times \frac{17\,NH_3}{14\,N} \qquad [D-4]$$

where:

$Nitrogen_{Stockpile}$	=	Amount of nitrogen entering the stockpile
0.20	=	Fraction of ammonia emitted from the stockpile.

For flush dairies, the amount of nitrogen entering the stockpile is equal to the sum of the nitrogen entering the solids separator (N excreted in barn - N emitted from the barn as NH_3 + N excreted in milking parlor) and nitrogen scraped from drylot.

For scrape dairies, the amount of nitrogen entering the stockpile is equal to the sum of the nitrogen entering the solids separator (N excreted in milking parlor), the nitrogen scraped from the drylot, and the nitrogen scraped from the barn (N excreted in barn - N emitted from the barn as NH_3).

D.2.9 Land Application of Dairy Manure

For dairy operations, EPA used data from USDA NAHMS to estimate land application practices. For dairies with more than 200 head, 30 percent of the manure being land applied was estimated to be incorporated and 70 percent of the manure was estimated to be surface applied, assuming sprinkler irrigation for liquid manure. Dairies with 100-200 head were estimated to incorporate 23 percent of their manure and surface apply 77 percent. For dairies with less than 100 head it was estimated that 16 percent of the manure was incorporated and 84 percent of the manure was surface applied. Therefore, EPA calculated the expected nitrogen losses as follows, using Equation D-3 and the emission factors from Table D-5:

For dairies with greater than 200 head:

$$\% \text{ N lost from liquid manure application} = (30\% \times 3\%) + (70\% \times 27.5\%) = 20\%$$

$$\% \text{ N lost from solid manure application} = (30\% \times 3\%) + (70\% \times 22.5\%) = 17\%$$

For dairies with 100-200 head:

$$\% \text{ N lost from liquid manure application} = (23\% \times 3\%) + (77\% \times 27.5\%) = 22\%$$

$$\% \text{ N lost from solid manure application} = (23\% \times 3\%) + (77\% \times 22.5\%) = 18\%$$

For dairies with less than 100 head:

$$\% \text{ N lost from liquid manure application} = (16\% \times 3\%) + (84\% \times 27.5\%) = 24\%$$

$$\% \text{ N lost from solid manure application} = (16\% \times 3\%) + (84\% \times 22.5\%) = 19\%$$

D.3 POULTRY EMISSION FACTOR DEVELOPMENT

EPA estimated ammonia emissions for five types of poultry operations: wet layer houses, dry layer houses, broiler houses, turkey houses, and outdoor confinement operations. The estimation of emission factors for the components of these systems is described below. Figures 12 through 16 in Appendix B present the operations graphically.

D.3.1 Dry Layer Houses

The literature search identified two applicable data points for dry layer houses. Table D-10 presents these data points and the calculations used to estimate the emission factor.

Table D-10. Ammonia Emission Factor for Dry Layer Houses

Reference	Emission Factor (EF)	Units of EF	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Valli et al., 1991	87	lb NH_3/AU-yr	87	1 AU/100 head	0.87
Yang et al., 2000	41.6-74.8	Percentage of N	64.1	% N loss = 1.3488 x moisture content + 12.167 38.5% Average moisture content 1.162 N excreted per bird 4 lbs LW/bird 50-week laying cycle	0.90
AVERAGE					**0.89**

D.3.2 Wet Layer Houses

The literature search identified three applicable data points for wet layer houses. Table D-11 presents these data points and the calculations used to estimate the emission factor.

Table D-11. Ammonia Emission Factor for Wet Layer Houses

Reference	Emission Factor (EF)	Units of EF	Conversion Factors	EF (lb NH_3/yr/head)
Kroodsma et al., 1988	110	g/hen/yr	1 lb/453.6 g	0.24
Hartung and Phillips, 1994	83	g/hen/yr	1 lb/453.6 g	0.18
Hartung and Phillips, 1994	38.8	kg/500 kg LW (lb/500 lb LW)	3.98 lb/hd	0.31
AVERAGE				**0.25**

D.3.3 Broiler Houses

The literature search identified eight applicable data points for broiler houses. Table D-12 presents these data points and the calculations which were used to estimate the emission factor.

Table D-12. Ammonia Emission Factor for Broiler Houses

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF (lb NH_3/yr/head)
Asman, 1992	0.065	kg/animal/yr	2.2046 lb/kg	0.14
Groot Koerkamp et al., 1998	18.5	mg/hr/broilers housed in litter	24 hrs/day, 49 days/cycle, 5.5 cycles/yr, 1g/1,000 mg, 1 lb/453.6 g	0.26
Groot Koerkamp et al., 1998	8.9	mg/hr/broilers housed in litter	24 hrs/day, 49 days/cycle, 5.5 cycles/yr, 1g/1,000 mg, 1 lb/453.6 g	0.13
Groot Koerkamp et al., 1998	19.8	mg/hr/broilers housed in litter	24 hrs/day, 49 days/cycle, 5.5 cycles/yr, 1g/1,000 mg, 1 lb/453.6 g	0.28
Groot Koerkamp et al., 1998	11.2	mg/hr/broilers housed in litter	24 hrs/day, 49 days/cycle, 5.5 cycles/yr, 1g/1,000 mg, 1 lb/453.6 g	0.16
Kroodsma et al., 1988	21.9	g/animal/fattening period	1 lb/453.6 g, 5.5 cycles/yr	0.27
Tamminga, 1992	0.1	kg/broiler/yr	2.2046 lb/kg	0.22
Van Der Hoek, 1998	0.15	kg/animal/yr	2.2046 lb/kg	0.33
AVERAGE				**0.22**

D.3.4 Turkey Houses

The literature search identified two applicable data points for turkey houses. Table D-13 presents these data points and the calculations used to estimate the emission factor.

Table D-13. Ammonia Emission Factor for Turkey Houses

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Asman, 1992	0.429 - 0.639	kg/animal/yr	0.534	2.2046 lb/kg	1.18
Van Der Hoek, 1998	0.48	kg/animal/yr	0.48	2.2046 lb/kg	1.06
AVERAGE					**1.12**

D.3.5 Poultry Outdoor Confinement Area

The literature review has not produced any emission factors for poultry in outdoor confinement areas. EPA used the emission factor from cattle in outdoor confinement areas (8 percent of nitrogen lost) to estimate ammonia emissions from poultry managed in outdoor confinement areas.

D.3.6 Wet Layers Lagoon

At poultry operations using a wet layer system, manure is flushed out of the layer house and stored in a lagoon. EPA assumes that wet layer poultry operations do not have settling basins. The literature review has not produced any emission factors for wet layer lagoons. EPA used the emission factor from swine lagoons to model the emissions from wet layer lagoons (calculated in Section D.2.6). Using the emission factor from swine lagoons, 71 percent of the nitrogen entering the poultry lagoon is lost as ammonia.

D.3.7 Poultry Cake Storage

No data were identified for broiler and turkey cake storage during the literature review. EPA used the emission factor from manure stockpiles (20 percent of nitrogen lost, presented in Section D.2.8).

D.3.8 Poultry Land Application

Table D-14 presents the data for poultry manure land application identified during the literature review.

Table D-14. Ammonia Emission Factors for Poultry Manure Land Application

Reference	Animal Type	Emission Factor (EF) % of N applied	Average Emission Factor % of N applied
Lockyer and Pain, 1989	Dry Layers	7	7
Lockyer and Pain, 1989	Wet Layers	38-45	41.5
Cabera et al., 1994	Broilers	22.5-27.6	25.1

EPA found no applicable data points for turkey manure land application. The agency used the broiler land application emission factor (25 percent of N applied) for turkeys.

D.4 BEEF AND HEIFERS EMISSION FACTOR DEVELOPMENT

EPA estimate ammonia emissions for two types of beef and heifer operations: drylots and outdoor confinement areas. The emission factor development for the components of these systems is described below. Figures 17 and 18 in Appendix B present diagrams of the operations.

D.4.1 Beef and Heifer Drylots

The literature search identified three applicable data points for beef and heifer drylots. Table D-15 presents these data points and the calculations used to estimate the emission factor.

Table D-15. Ammonia Emission Factor for Cattle Drylots

Reference	Emission Factor (EF)	Units of Emission Factor	Avg EF	Conversion Factors	EF (lb NH_3/yr/head)
Grelinger, 1997	35 - 50	lb/day/1000 head	42.5	365 days/yr	15.5
Hutchinson et al., 1982	0.76 - 2.82	g N/head/hour	1.79	24 hours/day, 365 days/yr, 1 lb/ 453.6 g, 17 NH_3/14 N	42.0
USDA, 2000	18	lb/head/year	18	NA	18.0
AVERAGE					**25.2**

NA - Not applicable.

D.4.2 Beef and Heifer Outdoor Confinement Areas

The literature search identified one data point for beef and heifers on outdoor confinement areas (pasture). Table D-16 presents this emission factor.

Table D-16. Ammonia Emission Factor for Beef and Heifers on Outdoor Confinement Areas

Reference	Emission Factor (EF)	Units of Emission Factor	Conversion Factors	EF
Bouwman et al., 1997	8	Percent of N	NA	Percent of N
AVERAGE				**8 percent of N**

NA - Not applicable

D.4.3 Beef and Heifer Storage Ponds

A portion of the nitrogen excreted at beef and heifer drylots is carried away in the runoff, which collects in the storage pond. At operations without settling basins, EPA assumes that all of the nitrogen in the runoff enters the pond. At operations with settling basins, EPA assumes the runoff first enters the settling basin, which removes 12 percent of the nitrogen. The remaining 88 percent of the nitrogen then enters the pond. Based on these assumptions, EPA estimated the pond ammonia emission factor to be 71 percent of the nitrogen entering the pond (using the emission factor for swine lagoons calculated in Section D.1.4).

D.4.4 Beef and Heifer Solid Storage (Stockpiles)

For beef and heifer drylots, EPA assumes the amount of nitrogen being stored in stockpiles is equal to the sum of N entering the solids separator from runoff and nitrogen scraped from drylot. The stockpile ammonia emissions were calculated similarly to dairy stockpile ammonia emissions, using Equation D-4 and an emission factor of 20 percent of nitrogen.

D.4.5 Beef and Heifer Land Application

No data were identified in the literature search for beef and heifer manure land application. EPA assumes that the majority of beef and heifer storage ponds are evaporative and only a small portion land applied manure is liquid. For liquid land application, EPA assumes that 30 percent of the solid manure being land applied is incorporated and 70 percent of the solid manure is surface applied. The Agency calculated the expected nitrogen losses as follows, using Equation D-3 and the emission factors from Table D-5:

$$\% \text{ N lost from liquid manure application} = (30\% \times 3\%) + (70\% \times 27.5\%) = 20\%$$

$$\% \text{ N lost from solid manure application} = (30\% \times 3\%) + (70\% \times 22.5\%) = 17\%$$

APPENDIX E
SCC Tables

Table E-1. New SCC's and Source Descriptions Recommended for Agricultural Production - Livestock

SCC	Description
Beef	
28-05-002-000	Beef cattle production composite; Total
28-05-001-100	Beef cattle - finishing operations on feedlots (drylots); Confinement
28-05-001-200	Beef cattle - finishing operations on feedlots (drylots); Manure handling and storage
28-05-001-300	Beef cattle - finishing operations on feedlots (drylots); Land application of manure
28-05-003-100	Beef cattle - finishing operations on pasture/range; Confinement
Poultry	
28-05-030-000	Poultry production composite; Total
28-05-007-100	Poultry production - layers with dry manure management systems; Confinement
28-05-007-300	Poultry production - layers with dry manure management systems; Land application of manure
28-05-008-100	Poultry production - layers with wet manure management systems; Confinement
28-05-008-200	Poultry production - layers with wet manure management systems; Manure handling and storage
28-05-008-300	Poultry production - layers with wet manure management systems; Land application of manure
28-05-009-100	Poultry production - broilers; Confinement
28-05-009-200	Poultry production - broilers; Manure handling and storage
28-05-009-300	Poultry production - broilers; Land application of manure
28-05-010-100	Poultry production - turkeys; Confinement
28-05-010-200	Poultry production - turkeys; Manure handling and storage
28-05-010-300	Poultry production - turkeys; Land application of manure
Dairy	
28-05-018-000	Dairy cattle composite; Total
28-05-019-100	Dairy cattle - flush dairy; Confinement
28-05-019-200	Dairy cattle - flush dairy; Manure handling and storage
28-05-019-300	Dairy cattle - flush dairy; Land application of manure
28-05-021-100	Dairy cattle - scrape dairy; Confinement
28-05-021-200	Dairy cattle - scrape dairy; Manure handling and storage
28-05-021-300	Dairy cattle - scrape dairy; Land application of manure
28-05-022-100	Dairy cattle - deep pit dairy; Confinement
28-05-022-200	Dairy cattle - deep pit dairy; Manure handling and storage
28-05-022-300	Dairy cattle - deep pit dairy; Land application of manure

Table E-1. New SCC's and Source Descriptions Recommended for Agricultural Production - Livestock (Cont.)

SCC	Description
28-05-023-100	Dairy cattle - drylot/pasture dairy; Confinement
28-05-023-200	Dairy cattle - drylot/pasture dairy; Manure handling and storage
28-05-023-300	Dairy cattle - drylot/pasture dairy; Land application of manure
28-05-024-100	Dairy cattle - daily spread dairy; Confinement
28-05-024-200	Dairy cattle - daily spread dairy; Manure handling and storage
28-05-024-300	Dairy cattle - daily spread dairy; Land application of manure
28-05-026-100	Dairy cattle - slurry dairy; Confinement
28-05-026-200	Dairy cattle - slurry dairy; Manure handling and storage
28-05-026-300	Dairy cattle - slurry dairy; Land application of manure
28-05-027-100	Dairy cattle - solid dairy; Confinement
28-05-027-200	Dairy cattle - solid dairy; Manure handling and storage
28-05-027-300	Dairy cattle - solid dairy; Land application of manure
28-05-028-100	Dairy cattle - outdoor confinement dairy; Confinement
28-05-028-200	Dairy cattle - outdoor confinement dairy; Manure handling and storage
28-05-028-300	Dairy cattle - outdoor confinement dairy; Land application of manure
Swine	
28-05-025-000	Swine production composite; Total
28-05-039-100	Swine production - operations with lagoons (unspecified animal age); Confinement
28-05-039-200	Swine production - operations with lagoons (unspecified animal age); Manure handling and storage
28-05-039-300	Swine production - operations with lagoons (unspecified animal age); Land application of manure
28-05-047-100	Swine production - deep-pit house operations (unspecified animal age); Confinement
28-05-047-300	Swine production - deep-pit house operations (unspecified animal age); Land application of manure
28-05-053-100	Swine production - outdoor operations (unspecified animal age); Confinement
Goats	
28-05-045-000	Goat production composite; Total
Horses	
28-05-035-000	Horse and pony production composite; Total
Sheep	
28-05-040-000	Sheep and lamb production composite; Total

Table E-2. Current Source Classification Codes and Source Level Descriptions

SCC	SCC2	SCC4	SCC7	SCC10
28-05-000-000	Miscellaneous area sources	Agriculture production - livestock	Agriculture - livestock	Total
28-05-001-000			Beef cattle feedlots	Total
28-05-001-001			Beef cattle feedlots	Feed preparation
28-05-005-000			Poultry operations	Total
28-05-005-001			Poultry operations	Feed preparation
28-05-010-000			Dairy operations	Total
28-05-010-001			Dairy operations	Feed preparation
28-05-015-000			Hog operations	Total
28-05-015-001			Hog operations	Feed preparation
28-05-020-000			Cattle and calves composite	Total
28-05-025-000			Hogs and pigs composite	Total
28-05-030-000			Poultry and chickens composite	Total