

Final Technical Work Paper for Air Quality and Odor Impacts

Prepared for the Generic Environmental Impact Statement on Animal Agriculture

Prepared for:



Environmental Quality Board

*658 Cedar Street, Room 300
Saint Paul, Minnesota 55155*

March 2001

Prepared by:



A **tyco** INTERNATIONAL LTD. COMPANY

3033 Campus Drive North
Suite 175
Minneapolis, Minnesota 55441
(763) 551-1001

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1.0 EXECUTIVE SUMMARY.....	1
1.1 PURPOSE.....	1
1.2 FINDINGS.....	1
2.0 ODOR COMPLAINT RECORDS.....	6
2.1 MPCA FEEDLOT ODOR DATABASE.....	6
2.1.1 Background Information	6
2.1.2 Evaluation of Database Systems	7
2.3 EQB ANIMAL FEEDLOT DEMOGRAPHIC DATABASE.....	9
2.4 EVALUATION OF TRENDS AND CORRELATIONS IN MPCA AND EQB FEEDLOT DATA	9
3.0 AIR QUALITY DATA.....	12
3.1 AIR CONTAMINANTS OF POTENTIAL INTEREST	12
3.2 AIR TOXICS MONITORING DATA.....	15
3.3 HYDROGEN SULFIDE DATA.....	19
3.4 OTHER SOURCES OF EXAMINED CONTAMINANTS.....	20
3.5 ENHANCEMENTS TO DATA ANALYSIS.....	20
4.0 ENVIRONMENTAL FATE.....	22
4.1 AMMONIA.....	22
4.1.1 Sources of Emissions	22
4.1.2 Environmental Significance.....	22
4.1.3 Atmospheric Concentrations.....	22
4.1.4 Atmospheric Reactions	23
4.1.5 Atmospheric Distribution And Transport.....	25
4.1.6 Atmospheric Deposition.....	26
4.2 HYDROGEN SULFIDE.....	28
4.2.1 Sources of Emissions	28
4.2.2 Environmental Significance.....	28
4.2.3 Atmospheric Concentrations.....	28
4.2.4 Atmospheric Reactions	28
4.2.5 Atmospheric Deposition.....	29
4.3 PARTICULATE MATTER.....	29
4.3.1 Sources of Emissions	30
4.3.2 Environmental Significance.....	30
4.3.3 Atmospheric Concentrations.....	30
4.3.4 Atmospheric Reactions	31
4.3.5 Atmospheric Transport and Deposition	31
4.4 SIGNIFICANCE TO MINNESOTA	32
5.0 EMISSION FACTOR AND DISPERSION MODEL EVALUATION.....	33
5.1 METHODOLOGY AND REFERENCES FOR SELECTING EMISSION FACTORS	33

5.2	COMPILATION OF EMISSIONS FACTORS	34
5.2.1	Swine	35
5.2.1.1	Ammonia Emission Factors.....	36
5.2.1.2	Hydrogen Sulfide Emission Factors	37
5.2.1.3	Methane Emission Factors.....	38
5.2.1.4	Volatile Organic Compound Emission Factors.....	39
5.2.1.5	Particulate Matter Emission Factors.....	40
5.2.1.6	Endotoxin Emission Factors	41
5.2.2	Cattle & Dairy.....	42
5.2.2.1	Ammonia Emission Factors.....	42
5.2.2.2	Hydrogen Sulfide Emission Factors	43
5.2.2.3	Methane Emission Factors.....	44
5.2.2.4	Volatile Organic Compound Emission Factors.....	45
5.2.2.5	Particulate Matter Emission Factors.....	46
5.2.2.6	Endotoxin Emission Factors	48
5.2.3	Poultry.....	49
5.2.3.1	Turkeys.....	49
5.2.3.2	Chickens	51
5.2.4	Sheep.....	57
5.2.4.1	Ammonia Emission Factors.....	57
5.2.5	Emission Reduction Strategies.....	58
5.2.5.1	Oil Sprinkling.....	58
5.2.5.2	Diet Manipulation.....	58
5.2.5.3	Air Filtration	59
5.2.5.4	Ozonation	59
5.2.5.5	Non-Thermal Plasma	59
5.2.5.6	Covers	59
5.2.5.7	Dilution of Liquid Waste.....	60
5.2.5.8	Reduction of Emitting Surfaces	60
5.2.5.9	Temperature Control.....	60
5.2.5.10	Manure Pit Additives	60
5.2.5.11	Lagoon Aeration.....	61
5.3	EVALUATION OF DISPERSION MODELS	63
5.3.1	Model Requirements.....	63
5.3.2	Candidate Models	64
5.3.3	Odor Modeling	66
5.4	RECOMMENDATIONS.....	67
6.0	PROGRAM APPROACHES.....	69
6.1	SELECTION OF PROGRAMS FOR EVALUATION	69
6.2	DISCUSSION OF PROGRAMS.....	70
6.2.1	Iowa.....	70
6.2.2	Wyoming.....	70
6.2.3	Missouri.....	70
6.2.4	North Carolina.....	71
6.2.5	Colorado.....	73
6.2.6	Minnesota	74
6.2.7	East Harris County Texas.....	75

6.3	COMPARISON OF REGULATORY PROGRAMS	75
6.3.1	Ambient Standards	76
6.3.2	Applicability	77
6.3.3	PREVENTION/MITIGATION REQUIREMENTS	78
6.3.4	COMPLIANCE MONITORING AND TRACKING	78
6.3.5	ENFORCEMENT/IMPLEMENTATION STATUS	79
6.4	LESSONS AND IMPLICATIONS FOR THE MINNESOTA PROGRAM	80
7.0	CONSEQUENCES OF TRENDS	82
7.1	IDENTIFICATION OF THE TRENDS	82
7.2	CONSEQUENCES OF THE TRENDS	82
8.0	REFERENCES	84
8.1	REFERENCES CITED	84
8.2	LITERATURE SUMMARY UPDATE	89

LIST OF TABLES

<u>Table</u>	<u>Page</u>	
2.1	Summary of the MPCA Feedlot Odor Complaint Database for All Logged Feedlot Complaints From June 1996 to September 2000	7
2.2	Minnesota Environmental Quality Board (EQB) County Animal Feedlot Demographic Information	12
3.1	List of Air Contaminants Emitted From Animal Agriculture	18
3.2	Mean Concentrations of Selected Air Toxics Associated With Animal Agriculture ($\mu\text{g}/\text{m}^3$)	20
4.1	Atmospheric Ammonia Reactions	26
4.2	Multiple Atmospheric Ammonia Reactions	27
4.3	Thermal Destruction of Ammonia	27
4.4	Photochemical Destruction of Ammonia	28
4.5	Atmospheric Hydrogen Sulfide Conversion to Sulfur Dioxide	32
4.6	Acid Rain Formation From Sulfur Dioxide	32
5.1	Ammonia (NH_3) Air Emission Factors for Swine Feedlots	39
5.2	Hydrogen Sulfide (H_2S) Air Emission Factors for Swine Feedlots	40
5.3	Methane Air Emission Factors for Swine Feedlots	41
5.4	Average Annual VOC Emission Rate Estimates	41
5.5	Particulate Matter (PM) Air Emission Factors for Swine Feedlots	42
5.6	Endotoxin (Total Microorganisms) Air Emission Factors for Swine Feedlots	43
5.7	Ammonia (NH_3) Air Emission Factors for Cattle and Dairy Feedlots	45
5.8	Hydrogen Sulfide (H_2S) Air Emission Factors for Cattle and Dairy Feedlots	46
5.9	Methane Air Emission Factors for Cattle and Dairy Feedlots	47
5.10	Average Annual VOC Emission Rate Estimates	48
5.11	Particulate Matter (PM) Air Emission Factors for Cattle and Dairy Feedlots	49
5.12	Endotoxin (Total Microorganisms) Air Emission Factors for Cattle and Dairy Feedlots	50
5.13	Ammonia (NH_3) Air Emission Factors for Poultry and Chicken Feedlots	52
5.14	Methane Air Emission Factors for Poultry and Chicken Feedlots	53
5.15	Hydrogen Sulfide (H_2S) Air Emission Factors for Poultry and Chicken Feedlots	54
5.16	Particulate Matter (PM) Air Emission Factors for Poultry and Chicken Feedlots	56

**LIST OF TABLES
(continued)**

<u>Table</u>		<u>Page</u>
5.17	Endotoxin (Total Microorganisms) Air Emission Factors for Poultry and Chicken Feedlots.	58
5.18	Ammonia (NH ₃) Air Emission Factors for Sheep Feedlots.....	59
5.19	Animal Agriculture Air Emission Control Efficiencies.....	63
6.1	Comparison of Ambient and Odor Standards Applicable to Animal Agriculture Operations	76
6.2	Comparison of Applicability Provisions of Odor and Air Quality Regulations Applicable to Animal Agriculture Operations.....	76
6.3	Comparison of Prevention/Mitigation Requirements Applicable to Animal Agriculture Operations.....	77
6.4	Comparison of Compliance Monitoring and Tracking Requirements Applicable to Animal Agriculture Operations.....	78
6.5	Comparison of Enforcement/Implementation Status of Regulations Applicable to Animal Agriculture Operations.....	79

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2.1	Comparison of County Total Feedlot Odor Complaints and County Animal Unit Density....	13
2.2	Comparison of County Total Feedlot Odor Complaints and County Population Density	14
2.3	Comparison of County Total Feedlot Odor Complaints and Average Feedlot Size	14
2.4	Comparison of County Total Feedlot Odor Complaints and Feedlots >500 Animal Units	15
2.5	Comparison of County Total Feedlot Odor Complaints and Feedlots >1000 Animal Units ..	15
3.2	Comparison of Air Toxics Data for Animal Agriculture Pollutants.....	21
3.3	Comparison of Air Toxics Data for Animal Agriculture Pollutants.....	22
4.1	Fate Analysis of Ammonia in the Atmosphere.....	29

LIST OF APPENDICES

Appendix

- A Emission Factors Used in Compilation of Air Pollutant Emission Factors
- B Odor Complaint Records and Feedlot Demographic Supporting Information

1.0 EXECUTIVE SUMMARY

The State of Minnesota has identified a need for a Generic Environmental Impact Statement (GEIS) on animal agriculture in Minnesota. The Legislature directed the Environmental Quality Board (EQB) to ‘examine the long-term effects of the livestock industry, as it exists and as it is changing, on the economy, environment and way of life of Minnesota and its citizens.’ This task will be partially accomplished through the generation of Technical Work Papers (TWPs) on twelve topical issues. This TWP addresses Topic H, Air Quality and Odor Impacts.

1.1 PURPOSE

With the increasing number and size of animal feedlot operations, odor and air toxics emissions from animal feedlots have become more of an environmental concern. In response, research efforts have recently begun to address many of the questions and concerns regarding animal feedlots and air quality. Earth Tech, Inc. performed the following analyses and evaluations to examine air quality and odor impacts from animal agriculture facilities in Minnesota:

- Reviewed the available literature to date on feedlot odor complaints, animal feedlot demographics, and ambient air quality monitoring data to seek out correlations, relationships, and patterns associated with odor and air quality and animal feedlot operations within the State of Minnesota.
- Evaluated the state of emissions data and the suitability of air emissions dispersion models to determine minimum setback or separation distances for various types and sizes of feedlot operations.
- Identified both regulatory and non-regulatory approaches being used nationally and internationally to address air quality and odor problems associated with animal feedlots and similar types of odor- and nuisance-causing facilities and evaluated the relative success of the programs in mitigating the problem and redressing neighbors concerns.
- Reviewed the information in the Literature Summary, identified the most promising sources of ongoing research, and added additional references to the Literature Summary for use in the GEIS to address Scoping Study Questions.
- Identified policy implications or potential long-range consequences of the current observed trends in facility design and management.

1.2 FINDINGS

Correlations with Ambient Air Quality Data

Earth Tech evaluated the ambient air contaminant monitoring data collected at MPCA stations as well as other MPCA monitoring data that were collected near animal feedlot operations to try to determine correlations, relationships, and patterns associated with animal feedlot characteristics and the results of air contaminant monitoring data. It appears that in general, ambient concentrations of air toxics are lower in agricultural areas than in urban areas, but are higher than the concentrations found in “background” areas. Additional air monitoring data would be needed to determine what portion of total ambient concentrations result from animal agriculture operations, and what portion is from other sources in these areas. No apparent correlations were seen in the hydrogen sulfide data collected by MPCA. However, there may be bias to these data based on the monitoring site selection criteria. Additional data would be necessary to

establish possible correlations with feedlot parameters. Also, ambient monitoring data would be helpful in establishing proper “background” levels of hydrogen sulfide.

Evaluation of Odor Complaint Records

Data from the MPCA odor database and the EQB county demographic feedlot database were reviewed and compared to seek out correlations, relationships, and patterns associated with the two data sets. Comparison of the two data sets yielded no apparent correlations or trends seen in the animal feedlot odor database and demographic feedlot data. It is likely that the public response to odor is related to a combination of a number of different factors including increasing feedlot sizes (and animal density), the species of animal housed, meteorological conditions, building configurations, manure management practices, public perception, and public odor sensitivity.

Feasibility of Air Dispersion Modeling

Emission factors are available for only a small subset of the toxic and odorous air contaminants emitted from animal agriculture activities. While it is likely that the emission factors for hydrogen sulfide and ammonia account for a large portion of the air toxics emissions on a mass basis, uncertainties about the emission rates of volatile organic compounds and other air toxics make it difficult at this time to assess what portion of the potential risk these compounds represent. Available emission factors are probably better suited for estimating long term average emission rates and evaluating chronic health impacts. There is a higher degree of uncertainty associated with estimating worst case short-term emission rates, which are used to evaluate acute health effects.

Air dispersion modeling has been recognized as a valuable tool in making predictive measurements of air pollutants from a variety of industrial and municipal emission sources, and has recently begun to receive attention as a potential tool in determining minimum setback and separation distances for animal feedlot operations.

From the limited amount of work that has been completed using air dispersion models to make predictive measurements of air emissions from animal feedlots, there appears to be strengths and weaknesses for each of the USEPA models, depending on intended use of the model (i.e., modeling of a single facility, or modeling of multiple facilities within a target area).

Rather than the selection of the appropriate model, the variability and uncertainty in characterizing emission rates appears to be the greatest limitation for utilizing an air dispersion model to make an accurate predictive measurement of air quality impacts. Each dispersion model is dependent on the quality of the emission factor for each pollutant used in the model to make an accurate predictive measurement of the air emissions. Determining accurate emission factors for animal feedlots is difficult since there are many variables that impact air emissions, including:

- The time and duration of the air sampling measurements used to derive emission factors.
- Facility design.
- Management practices.
- Meteorological conditions.

More detailed research efforts are needed to gain a better understanding of air emissions from animal feedlots and to develop a more reliable set of emission estimating tools for the various species of animal

feedlot operations. Reliable emission factors will add a significant amount of validity to any predictive measurements made using the available air dispersion models.

Environmental Fate of Air Pollutants

The potential exists for both localized impacts and long-range pollutant transport and transformation of ammonia, hydrogen sulfide and particulate emissions from animal agricultural operations.

While coarse particulate generated from feed, litter and manure handling may not routinely transport beyond facility boundaries in high concentrations, certain meteorological conditions can result in transport of particulates to off-site receptors. Additional study should be carried out to better define the factors affecting emissions from feedlots and the seasonal variation in the environmental transport and fate aspects of these pollutants.

The potential for impacts from long-range transport of hydrogen sulfide and ammonia is related to the persistence and reactivity of these pollutants in the atmosphere and their ability to contribute to the formation of fine particulate matter. The sulfate and nitrate particulate that can form from these processes can have impacts on a more regional scale. The extent of the contribution of animal agricultural operations on these processes is not fully understood.

These considerations point toward the need for a broad, national strategy for addressing these concerns. Any policies generated from this process should include a formal request to the federal government to increase its activities relative to animal operations and to fund additional studies of the impacts of these operations and to ultimately require national, or at least regional, control and reduction measures where required.

Evaluation of Program Approaches

Very little has been done to date by the federal government to address air quality and odor issues from animal agriculture facilities. Consequently, state and local governments have been essentially left on their own to develop programs addressing air quality. This has led to substantial variability in the extent and stringency of those states that have developed programs. Earth Tech did not attempt to survey the entire country to catalog the provisions of each state's program. Earth Tech instead identified a smaller number of state programs that span the range of programs in terms of their extent of coverage and their stringency. These programs were then evaluated in a more comprehensive evaluation. The goal of the evaluation was to identify the advantages and disadvantages of each approach in terms of its ability to cost effectively prevent or mitigate odor and air quality issues associated with animal agriculture facilities. The programs identified for this evaluation include Iowa, Colorado, North Carolina, Wyoming, Missouri, and Minnesota.

The Iowa state legislature established an advisory committee to evaluate any proposed regulatory programs affecting the agricultural industry in the state. This committee has very strong representation from the farming industry and does not look favorably on new regulatory programs. Consequently, despite having an estimated 3,000 large animal feeding operations that have the capacity for more than 1,000 animal units and receiving many odor complaints from neighbors, the State of Iowa has essentially no program in place for addressing odors or air emissions from animal agriculture facilities. There are no provisions in their air quality rules and the only provision in the water quality rules is a requirement for spray irrigation systems for manure to utilize low flow nozzles.

Wyoming promulgated new water quality rules for addressing animal feeding operations in 1999. The regulation states that water quality permits for animal feeding operations can be denied if a facility's management plan does not incorporate Best Available Technology for the control of odors, pathogens and vectors. Typical measures that have been proposed by facilities and approved by the state include ensuring adequate lagoon depth to provide for an aerobic layer, installation of aerators in lagoons and agreeing not to conduct spray irrigation during periods of high wind. The regulation in Wyoming is focused strictly on swine issues, even though Wyoming DEQ representatives indicated that complaints are received relative to beef operations as well as swine.

North Carolina, Colorado, and Missouri all have programs for addressing air and odor issues using dedicated air quality rules. Missouri and Colorado incorporate strategies that are typical of how a state would regulate industrial sources of pollution, such as a manufacturing plant or a utility boiler facility. Missouri's approach is similar to Minnesota's in that the main component of the odor management procedure is the development of a plan that each facility must develop on a case by case basis and utilize to minimize odor emissions. Missouri's program does go somewhat further than Minnesota's in prescribing that add-on control technology, in addition to management practices, should be utilized to reduce odors, if it has been shown to be feasible in a top down control technology analysis. Colorado goes even further than both Minnesota and Missouri in requiring that control technology and specified management practices be employed at animal agriculture facilities. North Carolina, takes a somewhat more unique strategy in designing a regulatory program that is driven largely by community complaints. The ultimate success of these and other recent program approaches in addressing concerns over odors and air quality has yet to be determined. They are either currently still in the initial stages of implementing new regulations or have only recently begun to evaluate the effect of new regulations on odor concerns. Follow up evaluation of these programs over the next several years should yield valuable information on their long-term effectiveness.

In addition to enforcing a state ambient air quality standard for hydrogen sulfide, Minnesota recently introduced new water quality regulations, which require animal agriculture facilities with a capacity to house more than 1,000 animal units to include an Air Emission Plan in their water quality permit application. While Minnesota's program for addressing air quality and odor concerns is not the most stringent, it shouldn't be concluded that it will not be as effective in minimizing odor and air quality concerns. It should provide the Minnesota Pollution Control Agency with sufficient flexibility to fit the specific control measures required at a particular facility to the specific aspects of the operation and the level of local concern and complaints regarding odors at the facility.

Consequences of Trends

As farm size and animal concentration increase, there is an increased potential for odor and air quality concerns to be raised by members of the local community. An increase in the size and concentration of an animal operations does not necessarily mean that an increase in odor and air quality concerns will result. More comprehensive management practices are essential to reducing odor and air quality problems regardless of facility size. Citizens are becoming more vocal about their concerns and in some cases are organizing grass-roots efforts to promote more stringent control of animal operations. These efforts, coupled with a lack of federal regulation or policy addressing air quality and odor impacts from animal agriculture facilities, have lead to increased regulation of animal agricultural operations by state governments. This trend toward increased regulation is occurring despite a lack of definitive information on the sources and quantities of air emissions from animal agricultural operations.

The farming industry has historically not been subjected to the kind of study and regulation that a traditional large industry has been. However, farms are getting bigger and more industrialized. A continued increase in size and concentration of animal operations is likely to lead to more and more public concern over their health and environmental impacts. To allay concerns, it will likely be necessary to treat these operations in the same manner as a manufacturing industry. Steps in developing a more comprehensive air program for addressing animal agriculture facilities would include the following:

- Fill data gaps in the demographic feedlot information for a number of heavily agricultural counties.
- Monitor research efforts nationally and internationally to gain a better understanding of air emissions from animal agriculture facilities in order to develop a more reliable set of emission estimating tools for the various species of animal agriculture operations.
- Develop a comprehensive state-wide emissions inventory of criteria air pollutants, toxic air contaminants, and odorous air pollutants; this inventory would help establish some perspective of the magnitude of emissions associated with the animal agriculture industry in relation to other regulated and non-regulated sources of air emissions in the state.
- Enhance the usefulness of the Minnesota Pollution Control Agency's Incident Management System database system by adding fields to prompt MPCA officials to gather more information on odor descriptors and weather conditions, which would yield a more effective odor management system that would focus on the odor 'episode' (location/citizen, duration, frequency) in addition to the odor 'source'.
- Conduct additional ambient air monitoring focused on defining the impact of animal agriculture facilities, especially to define concentrations of volatile organic compounds downwind of animal agriculture facilities as well as at appropriate "background" locations. Considerable effort has been devoted to measuring hydrogen sulfide concentrations downwind of animal agriculture facilities; however, collection of ambient hydrogen sulfide concentration data in a variety of locations would help to establish a 'background' level and help determine the contribution of feedlots to that background level.
- Evaluate new facility designs, management practices, and control equipment to determine their cost-effectiveness in preventing or reducing emissions from animal agriculture facilities.
- Monitor the effectiveness of regulatory and non-regulatory programs recently implemented in other states to determine their suitability as models for implementation in Minnesota.
- Implement flexible incentive programs to provide non-regulatory mechanisms to reduce air emissions and odors.

2.0 ODOR COMPLAINT RECORDS

Earth Tech reviewed the MPCA feedlot odor complaint database and other available information from the MPCA relevant to feedlot odor complaints. Earth Tech also reviewed information obtained from the EQB on the number, population, and species of animal feedlots by county in Minnesota. Although both of the data sets proved to have weaknesses and did not contain enough data to complete rigorous statistical analyses to seek out correlations; Earth Tech analyzed the available data for any general correlations and relationships associated with EQB feedlot demographic information and the MPCA odor complaint data.

2.1 MPCA FEEDLOT ODOR DATABASE

2.1.1 Background Information

The MPCA feedlot odor complaint database includes the non-confidential information that has been recorded by the MPCA from incoming odor complaints received from June of 1995 to September of 2000. Over this period of time the MPCA has compiled information on feedlot odor complaints using two separate database systems.

The initial database was a basic spreadsheet that was used to record information on all of the incoming feedlot odor complaints from June 1995 to January 2000. This database was kept and maintained by the MPCA staff at the St. Paul headquarters with dedicated individuals assigned to receive and process incoming odor complaints. The odor complaint interview questions were based on the database fields required to be completed by the MPCA staff. During this time period, the MPCA had no written protocol established for receiving and handling incoming odor complaints. There was also no protocol to ensure that odor complaints received by the MPCA regional offices or the county feedlot officers were referred to the MPCA headquarters.

Beginning in January of 2000, the MPCA initiated a new incident management system (IMS) to handle odor complaints. The IMS was designed to handle all incidents and citizen complaints that are reported to the MPCA, which includes animal feedlot odor complaints. This system is designed with the flexibility to provide a series of different screens to enter information specific to the type of odor complaint or incident (i.e., feedlot odor, chemical spills, improper waste disposal, etc.). This system was designed to decentralize the odor complaint system, with the MPCA regional offices now having more responsibility in receiving and handling incoming odor complaints. This IMS is a more complex database program that was designed to notify the appropriate regional MPCA official(s) once an odor complaint has been received. The IMS was designed with a written protocol, which provides consistency in answering, processing, and responding to feedlot odor complaints. This decentralized system also places the responsibility for each response with regional MPCA officers in close proximity to the odor episode.

The IMS as well as the initial odor complaint database systems provide somewhat similar fields to maintain a record of information relating to the odor complaint received including such fields as:

- Information of complainant (name, address).
- Time and date when complaint was received.
- Name of suspected offending facility.
- Location of facility (address, county, township, section).
- Meteorological data (estimates if available).

- Characterization of the odors (intensity, duration, etc.).
- Follow up information on MPCA action to odor complaint (monitoring, regulatory action, etc.).
- Additional comments.

A summary of all of the odor complaints logged by the MPCA from both database systems is contained in Appendix B. This table contains a tabulated breakdown of the odor complaints received per county as well as the species of the livestock.

2.1.2 Evaluation of Database Systems

The strengths and weaknesses of the original MPCA database system included:

Strengths:

- A relatively user-friendly database system.
- Flexibility in sorting and searching within the odor database.

Weaknesses:

- Not designed to collect essential ‘weather conditions’ (observations recorded by complainant or MPCA investigator), which are needed for a complete understanding of the odor incident.
- Lacked database fields that would prompt the MPCA staff to solicit odor descriptors. Both odor complaint database systems focus more on the source of emissions or the odor rather than the receptor (citizen), which provides an odor complaint database that is ‘incident’ (facility/responsible party) focused.
- No written protocol established for receiving and handling incoming odor complaints.
- No protocol established to ensure that odor complaints received by the MPCA regional offices or the county feedlot officers were referred to the MPCA headquarters.
- A centralized based odor reporting system and database, which made it difficult in some situations for odor episodes to receive immediate attention.

A summary of strengths and weaknesses of the IMS system include the following items:

Strengths:

- Established a standard statewide odor complaint system that provides consistency in answering, processing, and responding to feedlot odor complaints.
- Regionally based system with more immediate attention of the odor episode and provides a more local contact for the public to call.
- A database adaptable to the type of odor complaint or incident by providing a series of different screens to enter information specific to the type of odor complaint or incident.

Weaknesses:

- Not designed to collect essential ‘weather conditions’ (observations recorded by complainant or MPCA investigator), which are needed for a complete understanding of the odor incident.
- Lacks database fields that would prompt the MPCA staff to solicit odor descriptors. Both odor complaint database systems focus more on the source of emissions or the odor rather than the receptor (citizen), which provides an odor complaint database that is ‘incident’ (facility/responsible party) focused.
- Focuses on the immediate action needed rather than the building of a data base in a community that has episodes (i.e., cumulative episodes associated with a source or sources). The IMS is designed to ‘close out’ the incident rather than collect data for surveillance and possible future action.
- No protocol established to ensure that the appropriate officials receive the electronic response.

A number of other factors play a role in receiving and processing odors incidents. Odor sensitivity varies from one individual to the next. Two individuals can perceive the same odor generated from a facility quite differently, which results in difficulty assessing the severity of the immediate odor episode. In some instances an odor complaint regarding a feedlot may also go unreported due to fear of retribution. Other personal issues may also potentially come into play resulting in exaggerated or fabricated odor complaints.

The usefulness of the IMS database system could be enhanced by adding fields prompting MPCA officials to gather more information on odor descriptors and weather conditions, which would yield a more effective odor management system that would focus on the odor ‘episode’ (location/citizen, duration, frequency) in addition to the odor ‘source’. Weather conditions descriptors that ideally should be included for documenting odor episodes include:

- Weather conditions (sunny, partly cloudy, mostly cloudy, overcast, hazy, night).
- Precipitation (none, fog, rain, sleet, snow).
- Wind direction (N, NE, E, SE, S, SW, W, NW).
- Wind speed (calm, light breeze [1-5 mph], moderate wind [5-15mph] , and strong winds [15 or higher mph]).

A list of recommended improvements for the existing MPCA Incident Management System (IMS) include:

- Collecting more information on weather conditions for a more complete understanding of the odor incident.
- Addition of database fields that would prompt the MPCA staff to solicit odor descriptors. Current system focuses more on the source of emissions or the odor rather than the receptor (citizen), which provides an odor complaint database that is “incident” (facility/responsible party) focused.
- Modify database to focus on odor episodes within a community (i.e., cumulative episodes associated with a source or sources) for surveillance and possible future action rather than to “close out” the odor incident.
- Establish a protocol to ensure that the appropriate MPCA officials receive the electronic IMS notification.

- Possible consideration to establish protocol for dispatching feedlot odor complaint information to feedlot operators to help in developing methods to mitigate odors.
- Possible consideration to establish protocol for dispatching feedlot odor complaint information to local officials, so that the local or county government is aware of the complaints and any local activities resulting from those complaints.

2.3 EQB ANIMAL FEEDLOT DEMOGRAPHIC DATABASE

The EQB provided Earth Tech with feedlot demographic information for each county within Minnesota that has completed an animal feedlot inventory. County-specific data was only available for 38 out of 87 counties from within the State of Minnesota, and included permitted as well as non-permitted feedlots. A summary of this information is provided in Appendix B. Each county data set included information on the total number of feedlots and the animal units per feedlot. Although a number of county data sets included a breakdown of animal units based on species, there was not enough species-specific data available to make comparisons or confirm correlations and trends of demographic data to the MPCA feedlot odor database.

Without data available for a number of heavy agricultural counties, it is relatively difficult to seek out correlations and trends in the data on a statewide level. A statewide animal feedlot inventory containing more consistency in the type and amount of data collected from each individual county would be useful for making comparisons or seeking out trends in other feedlot-related data sets (e.g., MPCA feedlot odor complaint database). Recommended parameters from each feedlot operation that would be useful to collect during animal inventories include:

- Sub-classifications of each animal species based on age, size, and intended use of animal (e.g., broilers, layers, etc.).
- Size, type, and number of manure lagoon(s)/pit(s).
- Method(s) of manure spreading.
- Summary of facility design/configuration.
- Distance to nearby watersheds.
- Odor/Air toxics control technologies.

2.4 EVALUATION OF TRENDS AND CORRELATIONS IN MPCA AND EQB FEEDLOT DATA

The MPCA odor data base and the EQB feedlot demographic data both showed weaknesses and did not contain enough data from which statistically significant correlations could be drawn. Without demographic feedlot information for a number of heavily agricultural counties, it is difficult to make comparisons between the two data sets since there have been a significant number of feedlot odor complaints reported in counties without available feedlot demographic information. The initial MPCA odor complaint database may have also been compromised by a lack of a written protocol for receiving and processing odor complaints. The MPCA also reported a noticeable correlation between the number and location of feedlot odor complaints and the location and frequency of odor hotline advertising (Sullivan 2000).

Although the data does not lend itself to rigorous scientific analyses the following comparisons were evaluated to seek out any possible general trends in correlating odor complaints to animal and human demographic parameters:

- County total feedlot odor complaints vs. animal unit density.
- County total feedlot odor complaints vs. county human population density.
- County total feedlot odor complaints vs. average feedlot size.
- County total feedlot odor complaints vs. number of feedlots greater than 500 animal units.
- County total feedlot odor complaints vs. number of feedlots greater than 1,000 animal units.

The comparisons of the available EQB feedlot demographic data to the MPCA odor complaint log yielded no striking relationships or patterns in the data. Graphic illustrations of the comparisons between the animal feedlot odor complaints and a number of different demographic categories can be found in Appendix B.

Although no strong scientific correlations could be made from the data sets there were a few visible trends of significance within the MPCA odor complaint database which included;

- Nine separate facilities across the state of Minnesota (less than one percent of all of the total feedlot within Minnesota) were suspected to be responsible for 345 of the 911 feedlot odor complaints logged by the MPCA from 1996 to 2000. The average number of animal units (AU) housed in each of these feedlots was approximately 967 AU, which is greater than state average feedlot size of approximately 150 AU. Although these facilities are larger than average, there are approximately 500 other feedlots across the state of similar size with the same species of animals that operate without being suspected of a significant number of feedlot odor compliant incidents.
- 597 of the 911 odor complaints are suspected to have originated from swine facilities from across the state; approximately 50 percent of the total swine odor complaints were suspected to have originated from only six or seven swine feedlots. Comparatively, there are a large number of swine feedlot of similar size and type of operation across the state that have not been suspected of a significant number of feedlot odor compliant incidents. The MPCA commented that the only noteworthy similarity amongst all nine of these facilities is that they all operate using earthen manure storage basins (Sullivan 2001). A state-wide database was not available to determine significance of earthen storage basins in relation to feedlot odor complaints.

Although there is a lack of information to draw any strong scientific conclusions from the available data sets, it is likely that odor sensitivity and complaints are a function of several variables. These variables include:

- Increasing feedlot sizes (and animal unit density).
- Species and age of animal housed.
- Meteorological conditions.
- Building configurations.
- Manure management practices.
- Public perception, and public odor sensitivity.

With an increasing concern pertaining to animal feedlot odors, each of these factors should be evaluated on a feedlot-specific basis in order to develop a plan that will minimize public odor episodes, while still allowing for economic growth and stability within the animal agricultural industry.

3.0 AIR QUALITY DATA

Earth Tech evaluated the MPCA's ambient air contaminant monitoring data collected at MPCA stations established to measure concentrations of both criteria pollutants and toxic air contaminants. Earth Tech developed a list of specific air contaminants emitted from animal agriculture facilities for which ambient air monitoring data was evaluated. Earth Tech identified monitoring stations located in or near rural agricultural areas and selected a monitoring station to serve as a 'background' station, and evaluated data collected at these stations. Earth Tech also evaluated hydrogen sulfide data collected by MPCA near feedlot facilities. Additional sources of these air contaminants, other than feedlots that may contribute to ambient concentrations in agricultural areas, were identified. Possible enhancements to the data analysis were identified.

3.1 AIR CONTAMINANTS OF POTENTIAL INTEREST

Table 3.1 lists those contaminants recognized to be emitted into ambient air from animal agriculture and are known to have potential impacts on human health, including annoyance, discomfort, and non-specific symptoms (Jacobson 2000). This list contains not only contaminants that have determined inhalation toxicity values, but also includes many species that impact human health in other forms, such as by contributing to odor problems.

TABLE 3.1

LIST OF AIR CONTAMINANTS EMITTED FROM ANIMAL AGRICULTURE

Air Contaminant	Inhalation Toxicity Information	Odorous	Monitoring Data
GASEOUS CONTAMINANTS			
• Ammonia	X		
• Hydrogen Sulfide	X	X	X
VOLATILE ORGANIC COMPOUNDS (VOCS)			
- Acetaldehyde	X	X	X
- Acetone			X
- Acetophenone			
- Acrolein (2-propenal)	X		
- Benzaldehyde		X	X
- Benzene	X		X
- Bis (2-ethylhexyl) phthalate			
- 2-Butanone	X		
- Carbon Disulfide	X	X	
- Carbonyl Sulfide		X	
- Chloroform	X		X
- Crotonaldehyde (2-butenal)		X	
- Ethyl Acetate			
- Formaldehyde		X	X
- Formic Acid			
- Hexane	X		
- Isobutyl Alcohol		X	
- Methanol	X	X	
- 2-Methoxyethanol (methyl cellosolve™)	X	X	
- Naphthalene	X		
- Phenol	X	X	
- Pyridine		X	
- Tetrachloroethylene (PERC)	X		X
- Toluene	X		
- Triethylamine	X	X	
- Xylene	X		X
OTHER GASES			
- Hydrazine	X		
- Sulfur Dioxide	X	X	
- Carbon Dioxide			
- Carbon Monoxide			
- Methane			
-VOCs produced by microbes			

Air Contaminant	Inhalation Toxicity Information	Odorous	Monitoring Data
ODORANTS			
• Volatile Fatty Acids (Such as Butyric Acid)		X	
• Phenolic Compounds		X	
• Aldehydes		X	
• Esters		X	
• Alcohols (May Overlap with VOCs Produced by Microbes)		X	
• Heterocyclic Nitrogen Compounds (Such as Pyridine and Indole Compounds)		X	
• Thiols		X	
• Amines		X	
• Ketones		X	
• Cresols		X	
• Alkanes		X	
• Aromatics		X	
• Sulfur gases		X	
PARTICULATE AND PARTICULATE-BOUND CONTAMINANTS			
• Allergenic particles			
- Skin flakes, hair, feathers, urinary proteins, dried fecal protein			
- Fungi			
- Bacterial allergens			
• Livestock feed particles			
• PM ₁₀			
• Respirable particles with irritants (such as ammonia) adsorbed onto them			
• Endotoxin			
• Mycotoxins			
• (1→3) – β-D-Glucan			
PATHOGENS			
- Spore-forming bacteria, such as <i>Bacillus anthracis</i>			
- Viruses			
- Fungi			
- <i>Histoplasma capsulatum</i>			
- <i>Cryptococcus neoformans</i>			

PM₁₀, ammonia, hydrogen sulfide, and methane have been the most extensively studied contaminants from this list.

Eight compounds on this list have been monitored for at MPCA air toxics monitoring sites. These compounds are acetaldehyde, acetone, benzaldehyde, benzene, chloroform, formaldehyde, tetrachloroethylene (PERC), and xylenes.

3.2 AIR TOXICS MONITORING DATA

Earth Tech evaluated ambient air contaminant monitoring data collected at MPCA stations to try and determine correlations, relationships, and patterns associated with animal feedlot characteristics. Ambient air concentrations are measured in the surrounding air (i.e., not directly from a source stack or vent). The information for this section was taken from the Minnesota Pollution Control Agency's "Staff Paper on Air Toxics" from November 1999. The study that generated the MPCA staff paper is being conducted to determine the impact of air toxics on the state of Minnesota. The ambient monitoring sites in the MPCA study were selected based on the proximity to sources of air toxics. While agricultural operations are a possible source of air toxics emissions, no special interest or consideration was given to these sources in the MPCA study. The concentrations measured at the monitoring sites are most likely due to a wide variety of sources, possibly including feedlot operations.

A list of the MPCA air toxics monitoring sites was evaluated to determine appropriate sites for analysis in this study (MPCA 1999). Since Minnesota's animal agriculture operations are located primarily in the southern half of the state, the analysis concentrated on those sites located south of I-94. From this subset of sites, those that are surrounded by rural agricultural areas were examined. Four air toxics monitoring sites were identified in areas that are primarily agricultural. The monitoring data from the agricultural sites was compared with data from two sites located in urban areas and one rural site located away from agricultural areas. This final site represents a 'background' concentration for purposes of comparison. The locations of the evaluated monitoring sites are shown on the feedlot density map in Figure 2.1.

The Pipestone, Granite Falls, Holloway, and Zumbrota monitoring sites are located in communities of less than 5,000 population surrounded by areas of high feedlot density. The Holman Field and Minneapolis Library sites are located in urban areas, in St. Paul and Minneapolis, respectively. The Warroad site is in a northern Minnesota community of 2,000 population. There is some industrial activity in the area, which probably contributes to the ambient concentrations. However, there is little agricultural activity in the vicinity, and is the closest representation to a 'background' site that is available in the MPCA study.

Air toxics monitoring data for the selected sites are shown in Table 3.2.

TABLE 3.2

**MEAN CONCENTRATIONS OF SELECTED AIR TOXICS
ASSOCIATED WITH ANIMAL AGRICULTURE (mg/m³)**

	AGRICULTURE ZONE				URBAN		BACKGROUND
	Pipestone	Granite Falls	Holloway	Zumbrota	Holman Field	Minneapolis Library	Warroad
Acetaldehyde	0.7465	1.0011	-	0.63	1.2669	1.6856	0.5697
Acetone	1.1301	1.568	-	0.9718	2.0094	2.0732	1.0795
Benzaldehyde	0.4074	0.1596	-	0.2908	0.2125	0.3215	0.1297
Benzene	0.8214	0.928	-	0.649	1.72	2.5332	0.6401
Chloroform	0.1264	0.084	-	0.1078	0.138	0.1432	0.1022
Formaldehyde	1.2568	1.9754	-	1.1647	1.5258	2.1787	1.2181
PERC	0.2847	0.214	-	0.2813	0.5428	1.2158	0.1776
Xylene	0.973	0.643	-	0.564	2.445	4.258	0.603

Note: Holloway reports only metals air toxics

These data are displayed graphically in Figure 2.2 by individual monitoring site, and in Figure 2.3 by category.

Figure 3.2
Comparison of Air Toxics Data for Animal Agriculture Pollutants

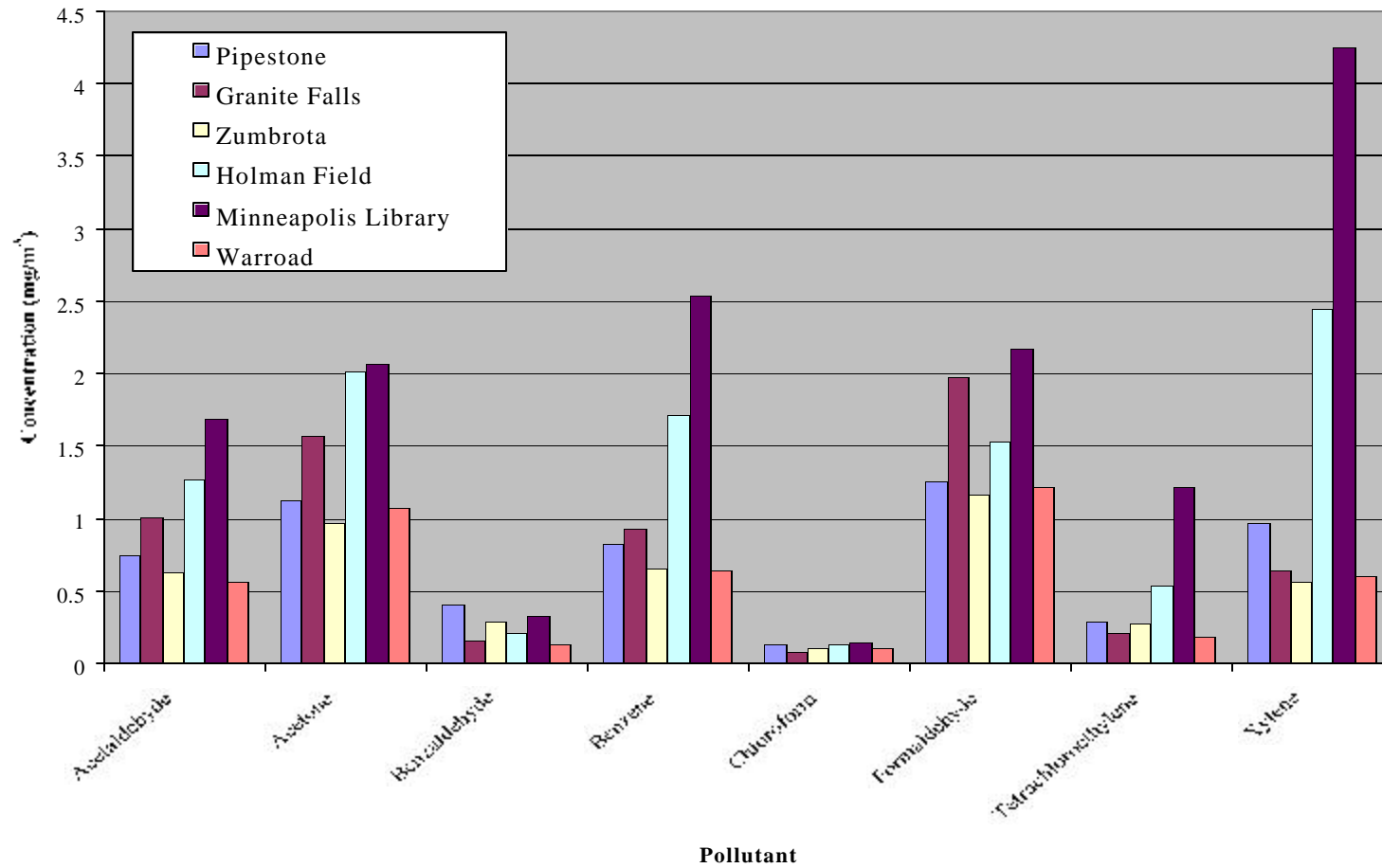
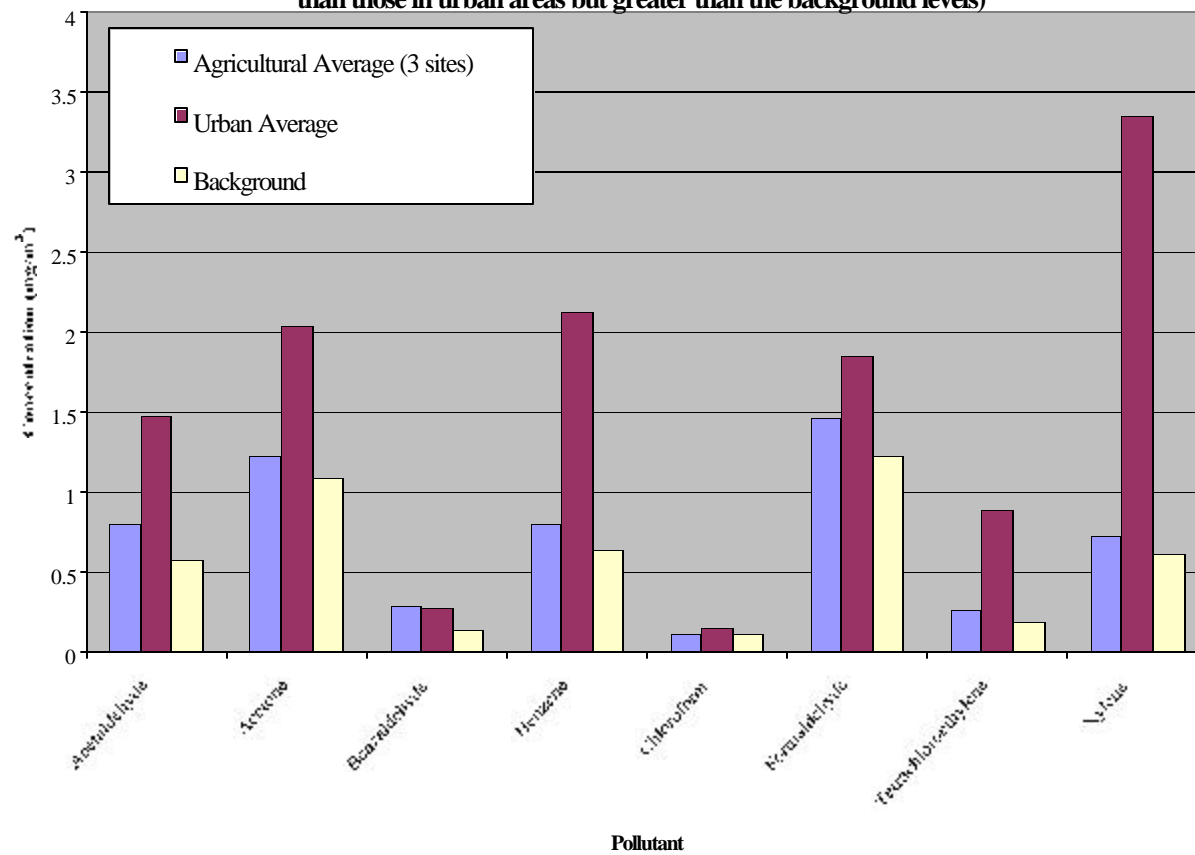


Figure 3.3
Comparison of Air Toxics Data for Animal Agriculture Pollutants
(concentrations in agricultural areas are generally less than those in urban areas but greater than the background levels)



As a general trend, the concentrations of these contaminants appear to be lower in agricultural areas than in heavily industrialized urban areas, but are higher than the concentrations that are found in 'background' areas. The one exception appears to be benzaldehyde, which was slightly higher in the agricultural areas than in both the urban and background areas.

Based on these air toxics data, it is not possible to identify what the contribution of animal feedlot emissions is to the ambient air concentrations. These compounds are also emitted from other sources, including motor vehicle emissions, equipment maintenance operations, and chemical fertilizer and pesticide application. Many of these activities support animal feedlot operations as well as crop production activities, which are often found in close proximity to animal feedlots.

3.3 HYDROGEN SULFIDE DATA

The MPCA Feedlot Air Quality Work Group has conducted screening-level sampling for hydrogen sulfide emissions around feedlot facilities to determine compliance with the state hydrogen sulfide ambient air standard (Sullivan 1999). Two methods were used for the sampling. Spot samples were taken using a Jerome Meter and continuous emissions information was taken using either a TRS monitor or a MDA Chemcastte. The continuous emissions monitors collect more information, but require a greater degree of effort to setup and analyze.

The bulk of the data were collected as non-continuous spot samples using a gold film H₂S monitor (or Jerome Meter). Sampling was performed near facilities that were selected primarily based on community odor complaints, and by pre-selection through a numeric modeling study. Therefore, the feedlots sampled may not represent a 'typical' group of feedlots found in the state of Minnesota. The sampling encompassed a large variety of feedlot sizes, animal types, and manure management systems. MPCA collected 435 data points from 137 individual facilities. Each data point collected represents a single site visit. The data ranged from 0 ppd to 497 ppd with a mean concentration of 11.5 ppd and a median concentration of 5.6 ppd.

The majority of Jerome Meter readings were taken at swine facilities, followed by dairy and beef facilities. The samples were taken in a variety of locations at varying distances from the sources, with the majority of samples collected within a distance of 1000 feet of the source. This was due to field logistics, such as property boundaries and location accessibility. Three types of confinement systems were studied. The majority of the samples were taken from total confinement type facility, with a small portion of the samples taken near partial confinement and open lot type facilities. Several manure management systems were represented at the examined facilities. Earthen basin and concrete pit manure storage facilities were the two most frequent manure storage types, with various other methods making up the remainder of the samples.

The majority of feedlots examined held 2,000 animal units or less, with a few holding up to 5,000 animal units. No discernible correlation was found between the number of animal units and H₂S concentrations. When the data were plotted with respect to animal species, the highest H₂S concentrations were found near swine and dairy facilities. However, since more complaints were received regarding swine operations, more extensive testing was conducted near swine operations. The data were also examined with respect to manure storage practice. The highest H₂S concentrations were observed from earthen storage basins. Again, there is some data bias based on the site selection criteria. The data were also examined with respect to type of animal confinement facility. The total confinement facilities showed the highest H₂S concentrations, but again, there is considerable bias based on the site selection criteria. Other

possible contributing factors (e.g., ventilation type, meteorological conditions, etc.) were not taken into account in trying to determine these correlations.

From this initial screening data, MPCA developed three recommendations for further research regarding hydrogen sulfide emissions from animal feedlots. These recommendations for continued research are: 1) to determine which factors contribute to the animal unit/ H₂S ambient concentration relationship, 2) to determine if there is a relationship between H₂S emissions and animal species, 3) to determine how animal housing and ventilation styles affect H₂S emissions.

The MPCA conducted continuous air monitoring for H₂S at four feedlot facilities found throughout the state of Minnesota. These facilities were selected for monitoring based on odor complaints directed at the facilities. Screening data were collected to determine the facilities' compliance with the state ambient H₂S standard. The screening data indicated the facilities had the potential to exceed the standard. In each case, the facility owners took action to reduce the hydrogen sulfide and odor emissions at the facility. These actions included enclosing manure flow channels, adjusting the animal feed ingredients, introducing biological additives to the waste storage system, covering the manure storage system, and constructing windbreaks. Not all corrective actions were taken at all the facilities. In many, but not all cases, the facilities were able to demonstrate compliance with the state ambient H₂S standard after the application of corrective actions.

During the hydrogen sulfide data collection, some preliminary sampling for ammonia concentrations was conducted. This sampling used a Draeger Tube colorimetric indicator. Air samples are drawn through a substrate inside a glass tube using a hand pump. The substrate will change color if ammonia is present. The lowest concentration of ammonia that can be detected using the Draeger Tube is 2 ppm. A total of 56 samples were taken using this method. All values appear to be less than the 2 ppm detection limit. The MPCA developed two conclusions from this information: 1) further research should be done to determine whether atmospheric emissions of ammonia should be regulated in Minnesota, and 2) field staff need a more effective field sampling method for ammonia.

3.4 OTHER SOURCES OF EXAMINED CONTAMINANTS

There are several other sources of these chemicals that may overwhelm the contribution to ambient concentrations from animal agriculture sources at the selected air toxics monitoring stations. Benzene, xylene, benzaldehyde, and formaldehyde are found as components in gasoline, and are emitted from motor vehicle exhaust. On-road motor vehicle emissions have been identified as the primary contributor to ambient concentrations of benzene and formaldehyde in the state of Minnesota. Benzaldehyde is also found in wood smoke. Acetone and xylene are commonly used as solvents and are often primary components of paints, including those that would be used in vehicle and farm machinery maintenance operations. PERC is used in metal degreasing, dry cleaning, and can be found in some pesticides. Hydrogen sulfide is emitted from wastewater treatment facilities, particularly from the primary treatment operations.

3.5 ENHANCEMENTS TO DATA ANALYSIS

There appears to be little benefit to be gained from more sophisticated analysis of the existing air toxics monitoring data. Most of the air toxics monitoring data that exist are from studies that were not targeted at defining ambient concentrations of the specific air contaminants emitted from animal agriculture

activities and monitoring station locations were not selected based on their proximity to feedlot operation. Therefore, additional analysis would reveal little new information from these data sets on their own.

More focused air monitoring would be helpful. There are several types of data collection that would improve the understanding of this issue. Collection of ambient hydrogen sulfide concentration data in a variety of locations would help to establish a 'background' level and help determine the contribution of feedlots to that background level, as well as provide information on the contribution of feedlots in areas of higher H₂S concentrations.

Emissions data exist for only a small number of pollutants emitted from feedlots. Hydrogen sulfide, ammonia, particulate matter (PM₁₀), and methane emissions have been studied extensively, and emissions data are available for these compounds. However, very little emissions information is available for other species. There is information on species that are potentially present, but little to support the direct determination of the contribution of animal feedlots to total ambient air toxics concentrations. In addition, many of the air toxics that are emitted from animal agriculture operations are also emitted from other sources, such as motor vehicles and pesticide application and their concentrations in air are the result of the cumulative impacts of all these sources. These sources are support activities for agriculture, both animal and crop-based, and often occur in close proximity to animal confinement facilities.

4.0 ENVIRONMENTAL FATE

Earth Tech compiled available information on the environmental fate of emissions of hydrogen sulfide, ammonia, and particulates released from animal agriculture facilities. This analysis included consideration of volatilization, redeposition, and chemical transformation of ammonia, hydrogen sulfide, and particulate matter. The findings of the evaluation and their significance in relation to animal agriculture emissions and air quality in Minnesota are discussed in this section.

4.1 AMMONIA

This section identifies sources, chemical reactions, distribution, transport, and deposition of ammonia in the atmosphere.

4.1.1 Sources of Emissions

A majority of the atmospheric ammonia (NH_3) emissions are produced and released into the atmosphere by natural processes, primarily through the decay and decomposition of organic matter. Animals used for agriculture purposes are considered to be one of the major contributors to global atmospheric ammonia emissions (Bouwman 1997). Protein contains amino acids, which are broken down to urea and uric acid and excreted from the bodies of mammals and poultry in feedlot operations. Depending upon the digestibility and nitrogen content of the animal feed, the retention of nitrogen in meat or milk, and the animal category, between 10 to 36 percent of the nitrogen in animal excreta is lost as NH_3 (Bouwman 1997). The use of ammonium compounds for sanitation purposes may also produce a small portion of the NH_3 detected from livestock buildings (Earth Tech 2000). The MPCA has reported that approximately 25 percent of the state-wide ammonia emissions are from animal husbandry. Other significant sources of atmospheric ammonia emissions include wastewater treatment facilities, undisturbed ecosystems, fossil fuel combustion, and other industrial processes (Bubenick 1984).

4.1.2 Environmental Significance

With increasing number and size animal feedlot operations the fate of atmospheric NH_3 emitted from animal feedlot operations is of growing importance because NH_3 is one of a number of air contaminants that is believed to contribute to water and soil acidification and eutrophication (European Environmental Agency 2000).

Despite a very short residence time NH_3 is the third most abundant nitrogen gas in the atmosphere. NH_3 is also considered to be the most abundant alkaline component in the troposphere and plays an important role in neutralizing atmospheric acids (Bouwman 1997). On the other hand, NH_3 and ammonium (NH_4^+) also contribute to acid deposition either directly as an acidifying component when it is deposited on the ground, or indirectly by promoting oxidation in clouds and rain droplets (Fekete 1993).

4.1.3 Atmospheric Concentrations

Atmospheric concentrations of ammonia have proven to be higher near intense agricultural activity than in non-industrialized rural settings. From a review of available literature, the range of atmospheric NH_3 concentrations measured near intense agricultural activity was 1.3 to 1,734 milligrams per cubic meter (mg/m^3), while the range of published concentrations measured in unpolluted rural areas ranged from 0.2 to 17 mg/m^3 (Environment Canada 2000). Concentrations of ammonia in the troposphere, the

upper layer of the atmosphere, are heavily influenced by temperature and exhibit strong seasonal variations. In a German study, the average winter concentration of ammonia ranged between 0.001 to 0.002 mg/ m³, while the average concentration was 0.005 mg/ m³ during the summer months (WHO 1986).

4.1.4 Atmospheric Reactions

NH₃ is mainly emitted from scattered low-level sources, and is not released into the atmosphere in significant concentrations until the animal waste dries. Once in the atmosphere, NH₃ typically undergoes four types of reactions; gas-phase, liquid-phase, thermal, and photochemical reaction. Gas-phase and liquid-phase are believed the most important types of reactions (Environment Canada 2000).

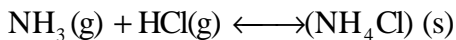
From a review of available literature, the main gas-phase and liquid-phase reactions of interest appear to be those associated with acids from industrial and municipal emissions, which typically include hydrochloric acid (HCl), nitric acid (HNO₃), sulfur dioxide (SO₂), and sulfuric acid (H₂SO₄) (Table 4.1). The result of ammonia reacting with an available acid is the formation of an ammonium salt. NH₃ has also demonstrated the potential to undergo reactions with more than just one pollutant (Table 4.2).

Under the right atmospheric conditions these atmosphere acid base reactions are expected to take place within milliseconds. Ammonium salts have been shown to account for 10 to 30 percent of the fine aerosols (solid or liquid particles suspended in a gas with a particle diameter less than 0.5 μm) in a polluted atmosphere (Environment Canada 2000).

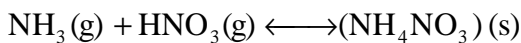
TABLE 4.1

ATMOSPHERIC AMMONIA REACTIONS

Ammonium Chloride



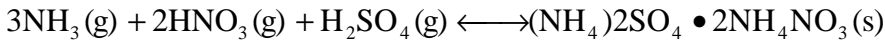
Ammonium Nitrate



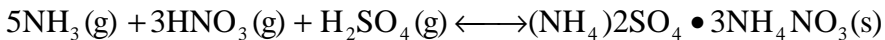
Source of information: Environment Canada (2000)

TABLE 4.2
MULTIPLE ATMOSPHERIC AMMONIA REACTIONS

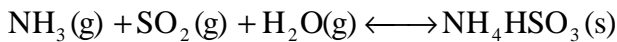
Ammonium Sulfate/Ammonium Nitrate



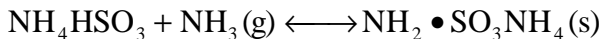
and



Ammonium Bisulfate/Ammonium Sulfamate



and

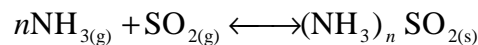


Source of information: Environment Canada (2000)

The most important atmospheric ammonia reactions appear to be those involving the conversion of NH_3 to NH_4^+ particulate. The conversion of NH_3 to NH_4^+ particulate is very dependent on a high concentration of NH_3 , temperature, relative humidity, and pH (Fangmeir et al., 1994). Daytime conversion rates are generally much faster than at night, and typically the conversion only occurs in the lowest 100 meters of the atmosphere (Environment Canada 2000).

Although ammonia does undergo thermal and photochemical reactions, these types of reactions are not believed to have as large of an impact as gas-phase and liquid-phase reaction on the atmospheric transformation of ammonia (Environment Canada 2000). The only thermal reaction involving ammonia is associated with the initial thermal anhydrous reaction between ammonia and sulfur dioxide (Table 4.3) ultimately resulting in the formation of ammonium sulfate particulates in the atmosphere.

TABLE 4.3
THERMAL DESTRUCTION OF AMMONIA

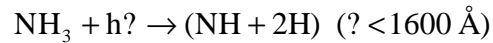
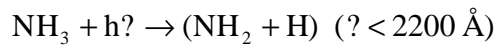


Source of Information: National Research Council 1979

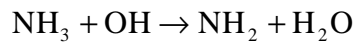
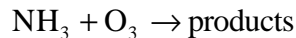
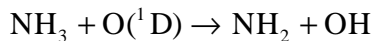
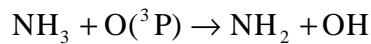
Photochemical reactions only degrade atmospheric ammonia. There is no known photochemical reaction that results in the production of ammonia in the atmosphere. A summary of the photochemical degradation reactions is shown in Table 4.4.

TABLE 4.4
PHOTOCHEMICAL DESTRUCTION OF AMMONIA

1. Photolytic dissociation at wavelengths $< 2200 \text{ \AA}$, resulting in the production of amino and amino radicals which further undergo other atmospheric reactions:



2. Reaction with ozone, atomic oxygen, and the hydroxyl radical, OH:



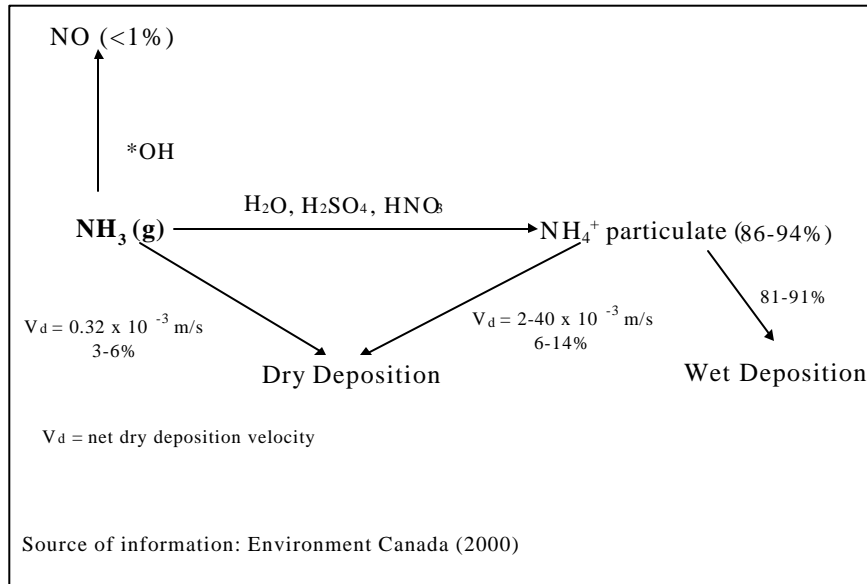
Source of Information: National Research Council 1979

4.1.5 Atmospheric Distribution And Transport

With the rapid reaction rate of ammonia in the atmosphere, anywhere from 56 to 94 percent of atmospheric ammonia emissions is typically converted to a form of ammonium particulate and less than one percent is converted to nitric oxide (NO). The remaining 6 to 44 percent remains present in the atmosphere as gaseous ammonia. The distribution, transport, and deposition of atmospheric ammonia is summarized in Figure 4.1.

FIGURE 4.1.

FATE ANALYSIS OF AMMONIA IN THE ATMOSPHERE.



Ammonium particulate in the atmosphere has a significantly longer residence time than that of gaseous ammonia. Over land the range of atmospheric residence time for ammonium particulate is 7 to 19 days (Moller 1985) and estimated at 22 hours over oceans (Quinn 1988). Comparatively, the range of atmospheric residence time for gaseous ammonia over land is 2.8 to 4 days (Fangmier et al., 1994) and an estimated 3.6 hours over oceans. These differences in residence times are due to the high dry deposition velocity of ammonia) and the rapid conversion to ammonium particulate (Asman 1998; Amsan et al., 1989).

Ammonia is only removed from the atmosphere via dry deposition, while NH_4^+ particulates are removed by both dry deposition and wet deposition (wash out during rainfall). Dry deposition occurs more predominantly in regions with high rates of ammonia emissions from low level emission sources and is indicative of short-range transport of typically less than 5 kilometers. In comparison, wet deposition is more significant in regions with lower rates of ammonia emissions and is indicative of long-range transport, ranging from tens to thousands of kilometers from the emission source (ECETOC 1994; Fangmeir et al. 1994).

With relatively low release height and relatively high emission rates, animal feedlot operations have an increased potential for a high dry deposition velocity of NH_3 . This high dry deposition velocity results in an increase in deposition of NH_3 near the facility and a decrease in long-range transport of NH_4^+ .

4.1.6 Atmospheric Deposition

A number of studies have demonstrated the increased deposition rates of ammonia within a short range of animal feedlot operations. Research of atmospheric dispersion and deposition of NH_3 in a large dairy area (142,000 dairy cows on 380 dairy farms) in California showed that atmospheric nitrogen concentrations were 23 times greater within the dairy area, with atmospheric nitrogen concentrations of 80 micrograms

per cubic meter ($\mu\text{g}/\text{m}^3$) found near the dairy site and 3 to 5 $\mu\text{g}/\text{m}^3$ found at the control site. Analysis of rainfall from both of the sites showed that the rain over the dairy area contained roughly three times more distillable nitrogen than the control area. The rainfall added 1.6 kilograms of nitrogen per hectare (kg N/ha) to soils in the dairy area compared to 0.5 kg N/ha in the control area (Luebs 1973).

In a study of a poultry house containing 8,000 to 12,000 chickens near Athens, Georgia, the soil deposition rate within 50 meters of the poultry facility was measured at 66 kg NH_3 /ha per year. The deposition rate decreased with distance, at 1.2 kilometers from the poultry facility the deposition of ammonia was equal to the background deposition rate of 15 kg/ha per year (Giddens, 1975). In a similar study, the soil deposition rate near a cattle feedlot was approximately 26.5 kg NH_3 /ha per year. The concentrations dropped to background levels at distances greater than 500 to 800 meters from the feedlot (Giddens, 1975).

In a two year study at nine sites in southern Alberta, Canada, the rate of NH_3 soil deposition was studied. Results of the study showed average concentrations of 4 to 6 kg N/ha per year at two background (control) sites. The highest average rates of approximately 66 kg N/ha per year were observed near a beef feedlot. Soil samples were collected at various distances downwind from the beef feedlot. The highest deposition rates were reported close to the feedlot and diminished with increased distance from the feedlot. At a distance of 1 kilometer from the facility, nitrogen levels were below the average background deposition rate (Environment Canada 2000).

The study of a lake located two kilometers from a large cattle feedlot (90,000 head) in the United States concluded that atmospheric NH_3 from the feedlots can deposit significant levels of NH_3 in the nearby lakes. The quantity of NH_3 received by the lake studied was enough to raise the total nitrogen content of the lake by 0.6 mg/L over a one-year period. The average difference in atmospheric concentrations of NH_3 between the cattle feedlot and the controls yielded a 20-fold difference. The average deposition of NH_3 in the soil closest to the feedlot was 145.6 kg NH_3 /ha per year, and the background site was only 7.8 kg/ha per year (Hutchinson and Viets, 1969).

Research suggests that deposition of NH_3 is to be of environmental and ecological significance and concern. Deposition of atmospheric NH_3 and chemical compounds resulting from atmospheric chemical reactions with NH_3 (e.g., ammonium aerosol) is believed to contribute to acidification and eutrophication of water and soil (European environmental Agency 2000). Acidification has shown potential to damage to freshwater systems, forest soils and natural ecosystems. Defoliation and reduced vitality of trees, declining fish stocks and decreased diversity in acid-sensitive lakes, rivers, and streams are all evidence of the effects of acidification. Eutrophication of sensitive bodies of water can potentially result in losses of fish diversity and amenity (European Environmental Agency 2000). Input of excessive nitrogen into the soil may result in the loss of plant species that require low nitrogen soil (Ellenberg 1988). NH_3 also deposits on buildings and promotes bacterial growth with enhances weathering and corrosions of buildings (Spiek et. al., 2990).

Although a limited number of studies have looked at transport and deposition of atmospheric NH_3 emitted from animal feedlots. More research is needed to study the environmental and ecological impacts of the deposition of NH_3 as well as the ammonium particulates both on a local and more distant scale.

4.2 HYDROGEN SULFIDE

This section identifies sources, chemical reactions, distribution, transport, and deposition of hydrogen sulfide in the atmosphere.

4.2.1 Sources of Emissions

Hydrogen sulfide (H₂S) is released to the atmosphere from natural and anthropogenic sources. Natural sources, including swamps, sea-spray, sulfur springs, and volcanoes, are responsible for about 90 percent of the H₂S in the atmosphere. Many petroleum deposits also contain large amounts of H₂S that are released when the deposits are developed (Sciences International 1997). Certain types of bacteria that are commonly found in animal and human wastes also produce H₂S through the decay of sulfur-containing organic compounds, such as proteins (National Research Council 1979). Other anthropogenic sources include petroleum refineries, kraft paper mills, rayon manufacturing plants, and iron smelters (Beauchamp 1984).

4.2.2 Environmental Significance

The growing number and size of animal feedlot operations, and subsequently the increasing H₂S emissions from these sources are of increasing significance to the environment. Atmospheric H₂S is primarily oxidized to form SO₂, either in the atmosphere itself or after being dissolved in water or sorbed onto soils (Sciences International 1997). SO₂ is then converted by various chemical or biological reactions into sulfate and eventually sulfuric acid. Sulfuric acid from the atmosphere returns to earth through “acid rain”. Increased acid concentrations in soils and freshwater ecosystems have been shown to have damaging impacts on plant and animal life (European Environmental Agency 2000).

4.2.3 Atmospheric Concentrations

Ambient air concentrations of H₂S vary based on the proximity to various sources. Concentrations that result from natural sources have been estimated to be between 0.15 and 0.46 µg/m³ (0.11 and 0.33 ppb). One study conducted in an unpolluted area of Colorado measured concentrations between 0.03 and 0.1 µg/m³ (0.02 and 0.07 ppb) (Sciences International 1997). H₂S concentrations in several urban areas were measured to range from about 1 to 6 µg/m³ (0.07 to 4 ppb). Concentrations as high as 200 to 300 µg/m³ (140 to 210 ppb) have been measured in industrial areas (Beauchamp 1984).

H₂S concentrations have been measured near several animal feedlot operations in Minnesota (MPCA 1999). These measurements were recorded using a Jerome Meter, and were taken at animal feedlots with a variety of animal species, facility sizes, and manure management practices. The measured H₂S concentrations ranged from 0 to 497 ppb, with an average reading of 11.5 ppb and a median value of 5.6 ppb. These values are higher than those measured in unpolluted areas or urban areas, but are significantly less than concentrations reported in industrial areas.

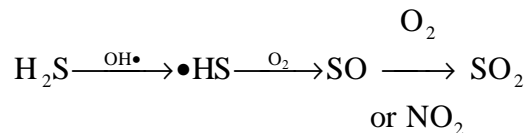
4.2.4 Atmospheric Reactions

Once released into the atmosphere, hydrogen sulfide is easily oxidized, and can undergo reactions with a large number of oxidizing agents. The primary oxidation reaction involves reaction with •OH radicals to form •HS radicals, which are further oxidized to SO and eventually SO₂ (Table 4.3). The rate-determining step in this reaction sequence is the first step, where the •OH radical extracts a hydrogen

atom from the H₂S to form the •HS radical and water. The residence time of H₂S in the atmosphere has been calculated to be 18 hours (Beauchamp 1984), but may be as high as 42 days in winter (Sciences International 1997). The SO₂ can then be converted into sulfuric acid by a reaction with oxygen, which is catalyzed by metal particles in raindrops (Table 4.4). Other oxidation reactions may occur, particularly reactions with oxides of nitrogen or ozone (WHO 1981). These reactions lead to a decreased atmospheric residence time for H₂S in polluted urban areas.

TABLE 4.5

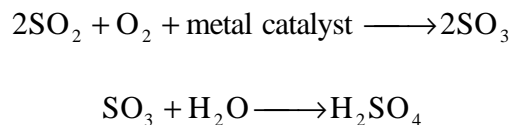
ATMOSPHERIC HYDROGEN SULFIDE CONVERSION TO SULFUR DIOXIDE



Source of information: Beauchamp (1984)

TABLE 4.6

ACID RAIN FORMATION FROM SULFUR DIOXIDE



Source of information: Heinsohn (1999)

4.2.5 Atmospheric Deposition

There are several pathways for H₂S to leave the atmosphere. It can react with •OH radicals or other oxidizing agents to form SO₂, which then further reacts to form sulfates and sulfuric acid. H₂S and its reaction products can all be flushed from the atmosphere by precipitation. H₂S is soluble in water, where it can oxidize readily (Sciences International 1997). Once in surface water, H₂S can be transported large distances from its source. H₂S can also be removed from the atmosphere by being absorbed onto soils, where bacterial activity will oxidize the H₂S to sulfates. Finally, H₂S and other sulfur compounds are readily absorbed by plant life. The effects on plant health and growth vary considerably, depending upon the particular plant species, the exposure concentration, and the duration of exposure. H₂S exposure tends to injure most plant species. However, exposure to low levels of H₂S has been shown to enhance growth in some species (lettuce and sugar beets) (Beauchamp 1984).

4.3 PARTICULATE MATTER

This section identifies sources, chemical reactions, distribution, transport, and deposition of particulate matter in the atmosphere.

4.3.1 Sources of Emissions

From a global perspective, particulate matter emissions result from both natural and anthropogenic sources. Natural sources include volcanoes, wind-blown soil, sea spray, and natural combustion sources, such as forest fires. There are many and varied anthropogenic sources of particulate matter. These include fossil-fuel combustion, material grinding and handling, petroleum refining, and agricultural activities. Unlike the hydrogen sulfide and ammonia discussed elsewhere in this report, particulate matter is not a distinct chemical entity. Its chemical make-up can vary considerably depending on the specific source of emissions. Size is also a very important factor in characterizing particulate matter. Small (or fine) particulate matter generally consists of sulfate, ammonium, and hydrogen ions; elemental carbon, secondary organic compounds and some primary organic compounds. Larger (or coarse) particulates generally consist of crustal materials, such as calcium, aluminum, silicon, magnesium and iron, as well as some organic materials such as pollen and plant and animal debris. Small particulates generally are more of a problem than large particulates because they are able to be transported through the atmosphere much longer distances and can pass deeper into human and animal respiratory systems than large particulates.

4.3.2 Environmental Significance

Particulate matter has significance due to its ability to produce adverse impacts strictly as particulate matter. From a regional perspective, the most significant effect of particulate matter (both natural and anthropogenic) is reduced visibility and sunlight penetration. On a local scale, these sources can result in adverse human health effects, such as reduced lung capacity and respiratory irritation. Beyond these “direct” effects of particulate matter, secondary effects can occur, depending on the chemical make-up of the particulate. One of the more well-known examples of this is acidification of lakes which can take place following deposition of sulfate and nitrate particulate matter. The sulfate and nitrate particulates form from the gas-phase reaction and subsequent condensation of constituent ions.

Among animal related operations, particulate matter emissions have not historically been considered a major problem. Of greater concern has been the indoor dust levels that can exist within animal confinement buildings. However, sources of outdoor emissions of particulates do occur at animal feeding operations. The most significant of these sources include wind-blown dusts from feed or dried manure and litter handling. In addition to their potential to produce direct effects as particulate matter, emissions from these sources could potentially contain endotoxins. Another source of particulate matter of environmental significance at animal operations is sulfate and nitrate particulate matter of which hydrogen sulfide and ammonia are precursors.

4.3.3 Atmospheric Concentrations

Atmospheric particulate matter can be broadly categorized into coarse and fine size fractions. Historically, coarse particulate has been considered those particulate greater than 10 μm in aerodynamic diameter. Particulate less than 10 μm , or PM_{10} , was considered fine particulate. The current National Ambient Air Quality Standard for Particulate matter is based on PM_{10} measurement. In 1997, however, U.S. EPA proposed a new ambient standard to be based on particulate less than 2.5 μm aerodynamic diameter. The rationale for this proposed standard is the greater human health significance of particulate of this size category.

Particulate concentrations across the United States range from 4-10 $\mu\text{g}/\text{m}^3$ in remote areas to 44.8 to 60.4 $\mu\text{g}/\text{m}^3$ in the urban areas with the highest concentrations. These values are annual average

concentrations of PM₁₀, based on the average of measurements taken every six days. Daily maximum concentrations can be considerably higher than these average values. Rural concentrations are in between these two extremes, and are variable depending on vegetation cover and land use patterns of a given area.

Annual-average PM₁₀ concentrations in Minnesota during the last 10 years have ranged from 18 µg/m³ to 27 µg/m³ in urban areas and 5 µg/m³ to 15 µg/m³ in rural areas. 24-hour average PM₁₀ concentrations in Minnesota during the last 10 years have ranged from 38 µg/m³ to 58 µg/m³ in urban areas and 10 µg/m³ to 15 µg/m³ in rural areas. None of the PM₁₀ monitoring conducted by the MPCA to date has been associated with animal agriculture facilities.

With regard to areas around animal agricultural facilities, particulate concentrations a majority of the particulate matter measured around them is coarse particulate, greater than 10 µm. In a study of cattle feedlots in Texas measured 24-hour upwind and downwind dust concentrations (total suspended particulate) and by subtracting the two values, determined the impact of the feedlots on ambient concentrations. The levels averaged 412 µg/m³, well above the ambient standard for PM₁₀ of 150 µg/m³. However, when strictly PM₁₀ was monitored were much lower, averaging only 19 to 40 percent of the total particulate concentrations, indicating that much of the particulate generated by feedlots is coarse particulate (Sweeten et al., 1988).

4.3.4 Atmospheric Reactions

In addition to being classified based upon its size, particulate matter can be classified as either primary or secondary depending on how it is formed. Primary particulate matter exists in the same form that it was originally emitted to the atmosphere. Secondary particulate matter is formed by chemical reactions in the atmosphere. In general, primary particulate matter is formed from mechanical processes. Examples are wind blown dust and fugitive emissions from unpaved road traffic. In the animal agricultural industry, primary particulate matter occurs through emissions from buildings, either fugitive or from ventilation equipment. Other sources include handling of dried manure and litter and vehicle traffic. Primary fine particulate matter can also be either emitted directly as particulates or be condensed from the vapor state, generally these particulates are formed from combustion processes.

Secondary particulate matter is formed from chemical reactions of gases. Most of this particulate matter is formed from condensable vapors that were formed from the reaction of gaseous precursors. The best example of this type of reaction is the formation of sulfate and nitrate particles in the atmosphere. As described in previous sections, hydrogen sulfide and ammonia from agricultural operations can play a significant role in these reactions.

4.3.5 Atmospheric Transport and Deposition

Transport of particulate matter is very dependent upon particle size. Coarse particulate tends to have short atmospheric residence times, on the order of minutes to hours and therefore travel relatively short distances (< 10 kilometers, or 6 miles). This occurs because large particles settle out relatively quickly. Although, under certain circumstances, large particles can undergo long range transport after being injected high into the atmosphere such as may occur during a dust storm.

Fine particulate matter has relatively low sedimentation velocities and its dispersion in the atmosphere is similar to that of a gas; therefore, it has much longer residence times than coarse particulates. The most

efficient removal mechanisms for fine particulates are generally through incorporation into cloud droplets and subsequent rainout.

4.4 SIGNIFICANCE TO MINNESOTA

The potential exists for both localized and long-range transport issues to arise relative to ammonia, hydrogen sulfide, and particulate from animal agricultural operations. The extent of their occurrence in Minnesota is dependent upon differing factors.

Relative to localized impacts, while coarse particulate generated from feed, litter and manure handling may not routinely transport beyond facility boundaries in high concentrations, certain conditions can result in transport of particulates to off-site receptors. Conditions of low relative humidity and strong winds can create an atmosphere where significant transport of particulate matter could occur. These conditions can occur with some frequency during late fall and winter in Minnesota. The conditions likely to lead to concerns for localized impacts from hydrogen sulfide and ammonia are the opposite of those for particulate matter. Warm, stagnant air with high relative humidity can result in less dispersion of these pollutants and potentially result in nuisance odors or respiratory irritation to neighbors of animal operations. These conditions occur during the summer months in Minnesota. Although there is much additional study that should be carried out to better define the factors affecting emissions from feedlots, the seasonal variation in the environmental transport and fate aspects of these pollutants points toward the need for detailed and targeted control measures which consider not just how emissions are generated but when they are generated as well.

The long-range transport issue is related to the persistence and reactivity of hydrogen sulfide and ammonia, and their ability to contribute to the formation of fine particulate matter. The sulfate and nitrate particulate that can form from hydrogen sulfide and ammonia emissions can have impacts on a more regional scale. Because air sheds, unlike watersheds, do not have well defined boundaries, emissions generated in one part of the state can result in ambient impacts in other regions, possibly even other states. Although the extent of the contribution of animal agricultural operations on regional air quality is not fully understood, it has been estimated that a significant percentage of atmospheric nitrate particulate is of animal agricultural origin.

These considerations point toward the need for a broad, national strategy for addressing these concerns. The long range issues are analogous to recent concerns with acid deposition, and the issue of long range transport of ozone precursors, which has led the U.S. EPA to recently require additional reduction measures on combustion sources in twenty Midwestern and Southeastern states known to generate pollution that impacts the Northeast. For this reason, it is recommended that any policies generated from this process should include a formal request to the federal government to increase its activities relative to animal operations and to fund additional studies of the impacts of these operations and to ultimately require national, or at least regional, control and reduction measures where required.

5.0 EMISSION FACTOR AND DISPERSION MODEL EVALUATION

Earth Tech evaluated the suitability of using air dispersion modeling as a tool for determining minimum setback or separation distances for various types and sizes of animal agriculture operations. As a tool for evaluating the air quality impacts from animal agriculture facilities, computerized air dispersion modeling offers the following advantages over ambient air quality monitoring:

- Dispersion modeling can be performed at lower cost than ambient monitoring.
- Dispersion modeling can be used as a predictive tool for evaluating impacts from facilities that are not yet in operation.

The reliability of air dispersion modeling for evaluating impacts from animal agriculture facilities is dependent upon two factors:

- Accuracy of emissions rate information input to the model.
- Selection of an air dispersion model best suited to simulating dispersion from the various types of emission sources found at animal agriculture facilities.

Both of these factors were evaluated to determine the suitability of air dispersion modeling for evaluating impacts from animal agriculture facilities.

5.1 METHODOLOGY AND REFERENCES FOR SELECTING EMISSION FACTORS

Earth Tech evaluated the available air emissions literature for animal feedlot operations to compile a list of emission factors for animal feedlot operations. An emission factor is utilized to make an accurate estimate of the average mass of a specific air pollutant that is emitted into the atmosphere per animal or amount of animal liveweight during a given period of time from an emission source (e.g., manure basins/pits, mechanically vented animal housing buildings). Emission factors provide information on the instantaneous emission rate of a pollutant from an emission source, which is an essential piece of information for air dispersion modeling analyses. Therefore, the availability and reliability of emission factors from the available literature are two factors that need to be taken into consideration when determining the feasibility of air dispersion modeling for an emission source.

Earth Tech reviewed emission factor information identified in the Summary of Literature Related to Air Quality and Odor prepared by the University of Minnesota (Jacobson, et al., 1999) for the Minnesota Environmental Quality Board, as well as additional information from other recently published peer reviewed journals, and State and Federal agency reports on air pollutants emitted from animal feedlot operations. The data was evaluated to determine the consistency or central tendency of the reported emission factors for each animal species, activity, and building ventilation configuration.

Earth Tech compiled a set of emission factors from the available data that appear to be most representative of typical feedlot operations. Air emissions from animal housing facilities are variable due to the various management practices and housing systems. The majority of the air quality work in the animal housing industry has been directed at measuring the ambient concentrations of pollutants. It is difficult to determine emission factors from ambient concentrations without detailed emission source parameters. Therefore, only studies that utilized these emission source parameters to quantify actual emission factors were included in this evaluation. The emission factors evaluated for animal housing

facilities were expressed in units of mass of pollutant per animal or animal liveweight per time. The emission factors presented in non-English units were converted to equivalent English units for uniform units of measurement throughout the emission factors presented. The terminology used to classify similar animals in the published literature varies greatly from one publication to another, therefore all emission factors evaluated within this section were re-classified using U.S. Agricultural Statistics Classifications. This re-classification provides a uniform classification of animals for emission factors for each individual air pollutant. It is important to note that evaluations of emission factors contained in this paper are somewhat subjective because not enough data could be found to provide meaningful quantitative statistics. Tables listing all the emissions data that were examined, the emission factors selected as most representative, and listing of other references that have corroborated the recommended emission factors are included in Appendix A.

The following criteria were used to select particular emission factors for presentation in the following section:

- Enough information was provided for the data to be expressed as emission factors, i.e., the amount of pollutant could be scaled based on animal numbers, a defined animal confinement area, or some other measurement of facility size or activity.
- An identifiable and consistent technical sampling and analysis protocol was used.
- Where available, the information with the larger pool of data was chosen (several emission sources versus singular emission source).

Earth Tech inspected a variety of animal agriculture confinement facilities that are representative of current trends in facility configurations and operational practices. The facilities represented a variety of animal species, housing designs, and manure management practices. Earth Tech used information gleaned from on-site inspections to help interpret emission factor data and to aid in selecting the most appropriate air emission dispersion models.

5.2 COMPILATION OF EMISSIONS FACTORS

Published emission factors are presented for a number of pollutants including; NH_3 , H_2S , CH_4 , PM, and endotoxins. The literature reviewed provides emission factor estimates for the major species of animal commonly housed within feedlot operations including swine, dairy and cattle, poultry, and sheep. A number of studies have also focused on developing emission factors for the different management practices and activities within a different species of feedlot operations. It should be noted that manure spreading is a periodic feedlot activity, and generally only takes place for a few days both in the spring and fall. Therefore, the emissions factors included within Section 5.2 for manure spreading represent more of a yearly inventory of air emissions rather than an estimate of the instantaneous emission rate.

Although there have been efforts from animal agricultural research to determine the presence of numerous volatile organic compounds (VOCs), Earth Tech found no published VOC emissions data suitable for deriving emission factors for VOCs. However, Gantzer Environmental Software and Services has adapted a USEPA wastewater treatment mass transfer models (USEPA 1994; WEF 1995) to estimate annual average emission rates for a number of VOCs as well NH_3 and H_2S from manure storage facilities based. This model is based on mass transfer rate correlations from the chemistry of manure basins/pits, and has been accepted by the MPCA for environmental review purposes. Although this mass transfer model provides a useful tool for estimating annual emission rates for a number of air pollutants from animal feedlot; there is great deal of uncertainty with using this model to estimate instantaneous

emissions rates from animal feedlot lagoons without instantaneous measurements of lagoon or pit chemistry parameters. Appendix A contains a listing of the algorithms and a description of how Gantzer utilized these algorithms to derive annual emission rate estimates.

With a number of variables having an impact on emission rates of air pollutants from feedlot operations, there is uncertainty in using the available emission factors for estimating air emission from a feedlot operation. For a number of the major air pollutants uncertainty is due a number factors including that:

- Many of the published emission factors come from small-scale studies with a limited amount of research conducted.
- There are very few emission factors published for a number of the major air pollutants emitted for animal feedlot operations.
- Facility design and ventilation, manure management practices, nutritional content of animal feed, and meteorological conditions can all have an impact on air emissions from a animal feedlot operation.

With only a limited amount of information available for estimating emissions for a number of the major air pollutants emitted, more extensive research is still needed in order to gain a stronger understanding of the rate of emissions for a number of the major air pollutants emitted from feedlot operations and for use of emission factors to make accurate estimates of emissions for determining the compliance status of feedlot operations with State and Federal air quality standards.

The limited amount of available emission factor data does not allow for rigorous scientific analysis to seek out correlations and trends in emission rates for various species of animal, type of housing confinement, and type of management practices. Although the data does not lend itself to detailed statistical analyses a number of general trends were seen in the data including:

- NH_3 and H_2S make a large percentage of the total amount of air pollutants emitted feedlot operations and are likely to be of most environmental significance.
- Poultry facilities demonstrate higher PM, PM_{10} and NH_3 emission rates per animal unit than other species of feedlot operations (This likely due in part to increased amount of dust and volatilization of compounds like NH_3 using dry manure management practices).
- Cattle/Dairy facilities in general have higher PM, PM_{10} , and NH_3 emission rates per animal unit than swine facilities.
- A large percentage of total facility emissions are emitted during the handling and spreading of manure.

5.2.1 Swine

The body of literature related to swine feedlot emissions is larger than for any other animal species. Swine were subdivided based on the age, size, and intended agricultural use of the animal. Emission factors for each classification were further subdivided by feedlot activities, which include the total of all activities, stable and storage, and manure spreading. There are a number of different configurations and practices used to handle and store swine manure. Swine are commonly housed on slatted floors with a liquid manure lagoon located beneath the floor to collect and store manure. A litter mat consisting of straw on a solid concrete or soil floor is an alternative method used to provide bedding for the animal and to collect manure. Outdoor open manure lagoons are used to store manure that has been scraped from floors within swine facilities. Open swine manure lagoons typically do not form a solid crust on the

surface as is common to dairy manure lagoons and therefore are more likely to be a source of air emissions. As with other animal species, air pollutants are typically emitted in high concentrations when the manure piles are removed and when manure lagoons are emptied once or twice a year for spreading.

Air contaminants for which emission factors for swine feedlots could be compiled include:

- Ammonia (NH₃)
- Hydrogen sulfide (H₂S)
- Methane (CH₄)
- Particulate matter (PM)
- Endotoxins

Emissions factors evaluated and compiled represent a limited amount of available research and further study is needed to strengthen the validity of the emission factors within this section.

5.2.1.1 Ammonia Emission Factors

The largest pool of available literature addresses research focusing on NH₃ emissions emitted from swine feedlot processes. NH₃ emission factors for swine were taken from the 1994 USEPA report by Battye, et al., (1994), which summarized the emission factors presented by Asman in 1992. Additional emission factors obtained from a review of literature were excluded from the evaluation since the studies either lacked adequate supporting information or summarized the emission factors presented by Asman in 1992. Battye (1994) sub-classified the emission factors presented by Asman (1992) into eight US agricultural classifications based on age, size, and intended agricultural use of animal. Emission factors for each classification were further subdivided by feedlot activities, which include the total of all activities, stable and storage, and manure spreading. The 1994 USEPA report (Battye 1994) assigned emission rating factor of B and C to the sub-categories of swine NH₃ emission factors. These emission factor ratings are based on the rating system used in the USEPA Compilation of Air Pollutant Emission Factors (AP-42), 5th Edition. The AP-42 uses an A through F scale to rate emission factors from highest to lowest based on the reliability of the data and sampling protocol used to derive each emission factor. An emission factor with a B-rating indicates that the emission factor was developed primarily from A or B rated test data from a moderate number of facilities. An emission factor rating of C indicates that the emission factor was developed primarily from A, B, and C rated test data from a reasonable number of facilities. Both ratings apply when it is not clear whether the facilities tested represent a random sample of the industry. These emission factors were based on a large literature summary, and the emission factor ratings were estimated conservatively by Battye to account for the many possible factors influencing NH₃ emissions from swine feedlots. It was unclear to Battye if the data set represented a good cross section of the U.S. agricultural practices, actual emission rate could vary since there are some possible differences between European and U.S feedlots include animal diet, housing configurations, and management practices.

TABLE 5.1

AMMONIA (NH₃) AIR EMISSION FACTORS FOR SWINE FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb NH ₃ /animal/yr)
Hogs and Pigs - Composite	28-05-025-000			20.30
Sows farrowing	28-05-025-011	Total	Breeding Sows >50 kg	35.46
		Stable and Storage		17.78
		Spreading		17.69
Other-kept for breeding	28-05-025-012	Total	Breeding Sows 20-50 kg	11.48
		Stable and Storage		5.32
		Spreading		6.16
Under 27.3 kg (60 lbs)	28-05-025-021	Total	Fattening Pigs	15.36
		Stable and Storage		7.00
		Spreading		8.36
27.2 to 54.0 kg (60 to 119 lbs)	28-05-025-022	Total	Fattening Pigs	15.36
		Stable and Storage		7.00
		Spreading		8.36
54.1 to 81.2 kg (120 to 179 lbs)	28-05-025-023	Total	Mature Boars	24.20
		Stable and Storage		12.14
		Spreading		12.06
81.3 kg (180 lbs) and over	28-05-025-024	Total	Mature Boars	24.20
		Stable and Storage		12.14
		Spreading		12.06

Source of Data:

Asman W. Ammonia Emissions in Europe: Updated Emission and Emission Variations. National Institute of Public Health and Environmental Protection. Bilthoven, The Netherlands. May 1992.

5.2.1.2 Hydrogen Sulfide Emission Factors

A number of relatively small recent research studies have been conducted to evaluate and compile H₂S emissions and emission factors from swine feedlots. The emission factors presented in this section were derived from evaluation of the emission factors presented in the limited amount of available literature. Zhu, et al., (1998) measured H₂S emissions from four mechanically ventilated swine facilities. H₂S emissions were measured during one 12-hour sampling period at four different swine facilities to determine emission factors for gestation, nursery, farrowing, and finishing facilities. An H₂S emission factor for naturally ventilated swine facilities was determined from a study conducted by Herber, et al., (1997). In another study Ni, et al., (1998) compiled research data over a three-month period to derive H₂S emission factors for underfloor liquid manure storage and deep-pitted liquid manure storage. Hobbs, et al., (1990) conducted a similar study and published an emission factor of 0.16 lb H₂S per day per pig place (one pig place is equal to approximately eight square feet for a finishing building). Hobb's (1997) emission factor was significantly higher than the Ni (1998) emission factor of 0.0015 lb H₂S per day per pig place, and was not included in the swine H₂S emission factors since it was well out the range of all other published swine H₂S emission factors. It is noteworthy that these emission factors were derived from a very limited amount of research data and are subject to great variability. Additional research is needed to gain a stronger understanding and to make more reliable estimates of H₂S from swine feedlots.

TABLE 5.2

HYDROGEN SULFIDE (H₂S) AIR EMISSION FACTORS FOR SWINE FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor ⁴
Not Identifiable	NA	Facility Total ¹	Swine nursery	45.7 µg/sec/m ²
Not Identifiable	NA	Facility Total ¹	Swine farrowing	5.5 µg/sec/m ²
Not Identifiable	NA	Facility Total ¹	Swine gestation	0.7 µg/sec/m ²
Not Identifiable	NA	Facility Total (Generic) ¹	Finishing facilities	7.4 µg/sec/m ²
Not Identifiable		Facility Total (Underfloor liquid manure storage) ²		6,300 µg/day/head
Not Identifiable		Facility Total (Naturally Ventilated) ³		0.00033 lb/day/pig place
Not Identifiable		Facility Total (Deep-pitted liquid manure storage) ²		0.00150 lb/day/pig place

Source of Data:

- ¹ Zhu, et al., 1998 Modeling the agricultural odor dispersion using atmospheric dispersion models. St. Joseph, MI: American Society of Agricultural Engineers. ASAE Paper No. 98-4056.
 - ² Ni, et al., 1998 Ammonia emission from a large mechanically-ventilated swine building during warm weather. St. Joseph, MI: American Society of Agricultural engineers. ASAE Paper No. 98-4051.
 - ³ Herber, et al., 1997 Manure treatment to reduce gas emissions from large swine houses. In: Voermans JAM, Monteny G, editors. Procs of the Intl. Symp on Ammonia and Odour Control from Animal Production Facilities Vinkelooord, The Netherlands. Rosmalen, 2:449-57.
 - ⁴ Emission factors are based on an annual average H₂S emission per square meter of a typical feedlot.
- ND = No Data Available

5.2.1.3 Methane Emission Factors

A very limited amount of research data exists on methane emission rates from feedlots. Safely and Casada (1992) provide the only publication found containing methane emission factors for swine facilities. This study estimated the total global emission rate for all sources of CH₄ at 540 billion kilograms per year. Approximately five percent of the total CH₄ emissions were a result of anaerobic decomposition of animal manure and 15 percent were the result decomposition in the gut of ruminant animals. The estimated contributions per animal were based on a global scale for swine feedlots. Since this emission factor is derived from a crude estimate, this emission factor should not be relied on to characterize the instantaneous emission rate from an individual facility.

TABLE 5.3
METHANE AIR EMISSION FACTORS FOR SWINE FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb methane/animal/yr)
Hogs and Pigs Composite	28-05-025-000	Total	Swine	44.0
Sows farrowing	28-05-025-011	Total	Breeding Sows >50 kg	ND
Other-kept for breeding	28-05-025-012	Total	Breeding Sows 20-50 kg	ND
Under 27.3 kg (60 lbs)	28-05-025-021	Total	Fattening Pigs	ND
27.2 to 54.0 kg (60 to 119 lbs)	28-05-025-022	Total	Fattening Pigs	ND
54.1 to 81.2 kg (120 to 179 lbs)	28-05-025-023	Total	Mature Boars	ND
81.3 kg (180 lbs) and over	28-05-025-024	Total	Mature Boars	ND

Source of Data:

Safley L., Casada M. 1992. Global Methane Emission from Livestock and Poultry Manure. United States Environmental Protection Agency. Document 400/1-91/048.

5.2.1.4 Volatile Organic Compound Emission Factors

Earth Tech found no published emission factor data for VOCs from swine facilities. As discussed in Section 5.2, Gantzer Environmental Software and Services has estimated annual average emission rates for a number of VOCs as well NH₃ and H₂S from deep-pitted swine barns and outdoor swine manure basins using a mass transfer model. This model provides a useful tool for estimating annual emission rates, but without instantaneous lagoon or pit chemistry parameters, there is a great deal of uncertainty with using this model to estimate instantaneous emissions rates from animal feedlot lagoons. A summary of Gantzer's annual emission rate estimates is found in Table 5.4.

TABLE 5.4
AVERAGE ANNUAL VOC EMISSION RATE ESTIMATES

Compound	Swine Deep- Pitted Barn (g/m ² /day)	Swine Outdoor Manure Basin (g/m ² /day)
Volatile Fatty Acids		
Acetic acid	2.65E-04	1.17E-02
n-Propanoic acid	1.36E-04	5.44E-03
iso-Butyric acid	8.89E-05	3.21E-03
n-Butyric acid	2.54E-04	9.41E-03
iso-Valeric acid	7.39E-05	2.50E-03
n-Valeric acid	1.25E-04	4.30E-03
iso-Caproic acid	8.44E-06	2.62E-04
n-Caproic acid	3.63E-05	1.13E-03
n-Heptanoic acid	8.96E-06	2.65E-04
n-Octanoic acid	3.78E-06	1.07E-04
Other Volatile Organic Compounds		
Phenol	7.06E-02	1.33E-01
meta-Cresol	3.73E-03	6.61E-03
para-Cresol	8.56E-02	1.51E-01
para-Ethyl phenol	1.93E-02	3.27E-02
Volatile Inorganic Compounds		
Hydrogen sulfide	4.06E-01	2.67E+00
Ammonia	2.34E+00	2.71E+00

5.2.1.5 Particulate Matter Emission Factors

Fugitive PM emissions from swine housing facilities consist of feed material, dried skin, dried feces, microorganisms, and other particulate. The agricultural housing industry has been concerned with fugitive particulate matter emissions because of indoor air quality and its impact on workers and animals inside the building. Therefore, most of the work has been designed to determine indoor particulate matter concentrations instead of quantifying PM emission rates. Takai, et al., (1998) compiled emission factors from a four-country study (England, Denmark, the Netherlands, and Germany), which measured both inhalable (>5 µm) and respirable (<5 µm) particulate emissions near the building air outlet using IOM (Institute of Occupational Medicine, Edinburgh) dust samplers. This study of fugitive particulate researched a number of feedlot variables including geographic location, housing practices, time of day and change of season. Emission factors were determined for housing practices for fatteners, sows, and weaners, with each emission factor based on an equally weighted average of the four-country emission factors presented by Takai (1998). Additional PM emission factor references for swine facilities collected during the review of literature were excluded from the evaluation since the studies lacked detailed supporting information and analysis of important variables that were considered in the emission factors compiled by Takai (1998).

TABLE 5.5

PARTICULATE MATTER (PM) AIR EMISSION FACTORS FOR SWINE FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor lb pm>5µm/hr/ (500lbs liveweight) ¹	Emission Factor lb pm<5µm/hr/ (500lbs liveweight) ¹
Sows farrowing	28-05-025-011	Litter Slats	Breeding Sows >50 kg	0.00045 0.00035	0.000048 0.000048
Other-kept for breeding	28-05-025-012	Litter Slats	Breeding Sows 20-50 kg	0.00045 0.00035	0.000048 0.000048
Under 27.3 kg (60 lbs)	28-05-025-021	Litter Slats	Fattening Pigs	0.0010 0.0010	0.000075 0.000075
27.2 to 54.0 kg (60 to 119 lbs)	28-05-025-022	Litter Slats	Fattening Pigs	0.00072 0.00061	0.000071 0.0000662
54.1 to 81.2 kg (120 to 179 lbs)	28-05-025-023	Litter Slats	Mature Boars	ND ND	ND ND
81.3 kg (180 lbs) and over	28-05-025-024	Litter Slats	Mature Boars	ND ND	ND ND

¹ Emission factors are based on an equally weighted average of four emission factors from studies in four different European countries.

Source of Data:

Takai H., et.al. 1998. Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. J. Agric. Engng Res. 70:59-77.

ND = No Data Available

5.2.1.6 Endotoxin Emission Factors

A very small amount of research and available literature exist on endotoxin emission factors from swine feedlots, which is due largely to the difficulty of making accurate measurements of endotoxins. Seedorf, et al., (1998) quantified average emission factors for inhalable (>5 µm) and respirable (<5 µm) endotoxins for total swine feedlot operations in four European countries, which included England, the Netherlands, Denmark, and Germany. The estimated endotoxin emission rates for total swine feedlot operations were based on 24-hour calculated averages of ventilation rates and measured indoor endotoxin concentrations (Seedorf, et al., 1998). Taking into consideration that this was the only available estimate of emission factors and the difficulty and variability associated with quantifying endotoxins, a great deal of weight should not be placed on this emission factor.

TABLE 5.6

ENDOTOXIN (TOTAL MICRORGANISMS) AIR EMISSION FACTORS FOR SWINE FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor mg >5µm/hr/ (500lbs liveweight)*	Emission Factor mg <5µm/hr/ (500lbs liveweight)*
Sows farrowing	28-05-025-011	Total	Breeding Sows >50 kg	0.017	0.0017
Other-kept for breeding	28-05-025-012	Total	Breeding Sows 20-50 kg	0.017	0.0017
Under 27.3 kg (60 lbs)	28-05-025-021	Total	Fattening Pigs	0.030	0.0024
27.2 to 54.0 kg (60 to 119 lbs)	28-05-025-022	Total	Fattening Pigs	0.023	0.0024
54.1 to 81.2 kg (120 to 179 lbs)	28-05-025-023	Total	Mature Boars	ND	ND
81.3 kg (180 lbs) and over	28-05-025-024	Total	Mature Boars	ND	ND

Source of Data:

Seedorf J, et.al. 1998. Concentrations and emissions of airborne Endotoxins and microorganisms in livestock buildings in Northern Europe. Journal of Agricultural Engineering Research 70:97-109.

ND = No Data Available

5.2.2 Cattle & Dairy

Air pollutant emission factors for cattle and dairy facilities were compiled and evaluated from the available literature. Emission factors for cattle and dairy were subdivided based on age, size, and intended agricultural use of the animal. Emission rates from cattle and dairy facilities are subject to great variability based on differences in housing systems and management systems. Therefore, emission factors were then further subdivided where published literature provided adequate information.

There are several different methods of housing cattle and dairy and handling and storing manure, which typically involves piling the manure in a solid form, or storage in a liquid manure lagoon. In some operations, a combination of the two practices is utilized where the solids are separated and stored or composted and the liquid portion of the manure is stored in a liquid lagoon. Manure stored as liquid in lagoons from dairy facilities tends to form a crust from the solid portion of the manure separating out of the liquid and rising to the surface of the lagoon. This crust acts as a natural cover and has a significant impact on suppressing the volatilization and dispersion of odor and other chemicals. Generally, solid manure and liquid manure lagoons are emptied for spreading one to two times per year.

Air contaminants for which adequate data exists to compile and evaluate emission factors for cattle and dairy feedlots include:

- Ammonia (NH₃)
- Hydrogen sulfide (H₂S)
- Methane (CH₄)
- Particulate matter (PM)
- Endotoxins

It should be noted that the emission factors contained within this section are estimates of air emissions from cattle and dairy facilities, and that not all of the emission factors listed should be treated with equal weight. A number of the emission factors are from limited pools of research and additional research is needed to strengthen the validity of the available emission factors and to gain a stronger understanding of the air emissions emitted from various cattle and dairy feedlot operations.

5.2.2.1 Ammonia Emission Factors

From the review of literature, NH₃ has been the most extensively studied pollutant from cattle and dairy feedlots. NH₃ emission factors for cattle and dairy were obtained from the 1994 USEPA report by Battye, et al., (1994), which summarized the emission factors presented by Asman in 1992. Battye (1994) concluded that the work of Asman (1992) presents the most extensive and accurate set of ammonia emission factors for cattle and dairy. The 1994 USEPA report assigned emission factor ratings of B and C to the sub-categories of cattle and dairy NH₃ emission factors. These emission factors were based on a large literature summary, and the emission factor ratings were estimated conservatively by Battye to account for the many possible factors influencing NH₃ emissions from swine feedlots. It was unclear to Battye if the data set represented a good cross section of the U.S. agricultural practices, actual emission rate could vary since there are some possible differences between European and U.S. feedlots include animal diet, housing configurations, and management practices. Battye sub-classified the emission factors presented by Asman (1992) into eight U.S. agricultural classifications based on age, size, and intended agricultural use of animal. Emission factors for each classification were further subdivided by feedlot activities, which include the total of all activities, stable and storage, grazing, and manure

spreading. Other emission factors obtained from a review of literature were excluded from the evaluation since the studies either lacked adequate supporting information or summarized the emission factors presented by Asman in 1992.

TABLE 5.7

AMMONIA (NH₃) AIR EMISSION FACTORS FOR CATTLE AND DAIRY FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb NH ₃ /animal/yr)
Cattle and Calves - Composite	28-05-020-000	Composite		50.50
Cows and heifers that have calved (Beef cows)	28-05-020-001	Total	Dairy and calf cows	87.38
		Stable and Storage		28.31
		Spreading		46.40
		Grazing		12.67
Cows and heifers that have calved (Milk cows)	28-05-020-002	Total	Dairy and calf cows	87.38
		Stable and Storage		28.31
		Spreading		46.40
		Grazing		12.67
Heifers - Beef cow replacements: 500 lbs and over	28-05-020-003	Total	Young cattle for fattening	33.42
		Stable and Storage		12.67
		Spreading		20.75
		Grazing		0.00
Heifers Milk cow replacements: 500 lbs and over	28-05-020-004	Total	Young cattle	28.69
		Stable and Storage		8.51
		Spreading		13.95
		Grazing		6.23
Heifers (Others): 500 lbs and over	28-05-020-005	Total	Young cattle	28.69
		Stable and Storage		8.51
		Spreading		13.95
		Grazing		6.23
Steers: 500 lbs and over	28-05-020-006	Total	Fattening/grazing cattle > 2 yr	18.08
		Stable and Storage		0.00
		Spreading		0.00
		Grazing		18.08
Bulls: 500 lbs and over	28-05-020-007	Total	Breeding Bulls > 2yr	61.40
		Stable and Storage		23.28
		Spreading		38.13
		Grazing		0.00
Calves: Under 500 lbs	28-05-020-008	Total	Fattening calves	11.51
		Stable and Storage		3.52
		Spreading		7.99
		Grazing		0.00

Source of Data:

Asman W. Ammonia Emissions in Europe: Updated Emission and emission Variations. National Institute of Public Health and Environmental Protection. Bilthoven, The Netherlands. May 1992.

5.2.2.2 Hydrogen Sulfide Emission Factors

From the review of published literature, the research of Zhu, et al., (1998) provided the only available source of H₂S emission factors for dairy feedlot operations. Zhu derived H₂S emission factors from measurements obtained during one 12-hour sampling period at one mechanically vented freestall dairy facility. No H₂S emission factors were available for cattle from the available literature. The

H₂S emission factor for dairy should not be relied on very heavily, since this was the only available emission factor available, and was derived from a limited amount of research.

TABLE 5.8
HYDROGEN SULFIDE (H₂S) AIR EMISSION FACTORS
FOR CATTLE AND DAIRY FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb H₂S/m²/hr)¹
Cattle and Calves - Composite	28-05-020-000	Composite		ND
Cows and heifers that have calved (Beef cows)	28-05-020-001	Total	Dairy and calf cows	ND
Cows and heifers that have calved (Milk cows)	28-05-020-002	Total	Dairy and calf cows	0.4 ND
Heifers - Beef cow replacements: 500 lbs and over	28-05-020-003	Total	Young cattle for fattening	ND ND
Heifers Milk cow replacements: 500 lbs and over	28-05-020-004	Total	Young cattle	0.4 ND
Heifers (Others): 500 lbs and over	28-05-020-005	Total	Young cattle	0.4
Steers: 500 lbs and over	28-05-020-006	Total	Fattening/grazing cattle > 2 yr	ND
Bulls: 500 lbs and over	28-05-020-007	Total	Breeding Bulls > 2yr	ND
Calves: Under 500 lbs	28-05-020-008	Total	Fattening calves	ND

¹ Emission factors are expressed as an annual average H₂S emission per square meter of a typical feedlot.

Source of Data:

Zhu, et.al. 1998. Modeling the agricultural odor dispersions using atmospheric dispersion models. St. Joseph, MI: American Society of Agricultural Engineers. ASAE Paper No. 98-4056.

ND = No Data Available

5.2.2.3 Methane Emission Factors

With a very limited amount of research studying actual emission rates of methane (CH₄) from feedlots, the work of Safely and Casada (1992) was the only available source emission factors for methane emissions from cattle and dairy feedlots. This publication presented very crude CH₄ estimates for cattle and dairy based on global estimates of CH₄ emissions from animal feedlot operations. These CH₄ emission factors should not be relied on heavily since they are crude estimates, and there are a number of factors that potentially impact the effect of CH₄ emission rates.

TABLE 5.9

METHANE AIR EMISSION FACTORS FOR CATTLE AND DAIRY FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb methane/animal/yr)
Cattle and Calves - Composite	28-05-020-000	Composite		50.60
Cows and heifers that have calved (Beef cows)	28-05-020-001	Total	Dairy and calf cows	ND
Cows and heifers that have calved (Milk cows)	28-05-020-002	Total	Dairy and calf cows	155.40 ND
Heifers - Beef cow replacements: 500 lbs and over	28-05-020-003	Total	Young cattle for fattening	ND
Heifers Milk cow replacements: 500 lbs and over	28-05-020-004	Total	Young cattle	155.40
Heifers (Others): 500 lbs and over	28-05-020-005	Total	Young cattle	ND
Steers: 500 lbs and over	28-05-020-006	Total	Fattening/grazing cattle > 2 yr	ND
Bulls: 500 lbs and over	28-05-020-007	Total	Breeding Bulls > 2yr	ND
Calves: Under 500 lbs	28-05-020-008	Total	Fattening calves	ND

¹ Emission factors are expressed as an annual average H₂S emission per square meter of a typical feedlot.

Source of Data:

Safley L., Casada M. 1992. Global Methane Emission from Livestock and Poultry Manure. United States Environmental Protection Agency. Document 400/1-91/048.

ND = No Data Available

5.2.2.4 Volatile Organic Compound Emission Factors

Although there have been efforts from animal agricultural research to determine the presence of numerous volatile organic compounds (VOCs), Earth Tech found no published emissions data for VOCs from which to develop emission factors. As discussed in Section 5.2, Gantzer Environmental Software and Services has estimated annual average emission rates for a number of VOCs as well NH₃ and H₂S from outdoor dairy manure basins using a mass transfer model that is based on a USEPA wastewater treatment mass transfer model. This model provides a useful tool for estimating annual emission rates, but without instantaneous lagoon or pit chemistry parameters, there is a great deal of variability associated with using this model to estimate instantaneous emissions rates from outdoor dairy manure basins. A summary of Gantzer's annual emission rate estimates is found in Table 5.10.

TABLE 5.10
AVERAGE ANNUAL VOC EMISSION RATE ESTIMATES

Compound	Dairy Outdoor Manure Basin (g/m²/day)
Volatile Fatty Acids	
Acetic acid	1.87E-03
n-Propanoic acid	8.69E-04
iso-Butyric acid	5.13E-04
n-Butyric acid	1.50E-03
iso-Valeric acid	4.00E-04
n-Valeric acid	6.87E-04
iso-Caproic acid	4.19E-05
n-Caproic acid	1.81E-04
n-Heptanoic acid	4.23E-05
n-Octanoic acid	1.71E-05
Other Volatile Organic Compounds	
Phenol	1.99E-02
meta-Cresol	9.91E-04
para-Cresol	2.27E-02
para-Ethyl phenol	4.90E-03
Volatile Inorganic Compounds	
Hydrogen sulfide	3.75E-01
Ammonia	3.58E+00

5.2.2.5 Particulate Matter Emission Factors

There has been a growing concern in the agricultural industry with the impact of fugitive PM emissions on indoor air quality with connection with human and animal health. Therefore, most of the current PM research has focused on quantifying indoor PM concentrations, and only a limited amount of research has focused on quantifying PM emission rates. Takai, et al., (1998) published the most extensive study of fugitive particulate emission factors from animal feedlots, which researched a number of feedlot variables including geographic location, housing practices, time of day and change of season. This four-country study (England, Denmark, the Netherlands, and Germany) measured both inhalable (>5 µm) and respirable (<5 µm) PM emissions near the building air outlet using IOM dust samplers to derive emission factors for dairy, beef, and calves. The PM emission factors for cattle and dairy presented in this section are based on an equally weighted average of the four-country emission factors presented by Takai (1998). With a number of important variables considered in the evaluation of compilation of the emission factors in four different countries, Takai presents the most representative PM emission factors for cattle and dairy feedlots.

**TABLE 5.11
PARTICULATE MATTER (PM) AIR EMISSION FACTORS
FOR CATTLE AND DAIRY FEEDLOTS**

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor lb pm>5um/hr/ (500lbs liveweight) ¹	Emission Factor lb pm<5um/hr/ (500lbs liveweight) ¹
Cows and heifers that have calved (Beef cows)	28-05-020-001	Litter Slats	Dairy and calf cows	0.000086 0.00011	0.000016 0.00001
Cows and heifers that have calved (Milk cows)	28-05-020-002	Litter Cublies	Dairy and calf cows	0.000089 0.00017	0.000029 0.00003
Heifers - Beef cow replacements: 500 lbs and over	28-05-020-003	Litter Slats	Young cattle for fattening	0.000086 0.00011	0.000016 0.00001
Heifers Milk cow replacements: 500 lbs and over	28-05-020-004	Litter Cublies	Young cattle	0.000089 0.00017	0.000029 0.00003
Heifers (Others): 500 lbs and over	28-05-020-005	Litter Cublies	Young cattle	0.000089 0.00017	0.000029 0.00003
Steers: 500 lbs and over	28-05-020-006		Fattening/grazing cattle > 2 yr	ND	ND
Bulls: 500 lbs and over	28-05-020-007		Breeding Bulls > 2yr	ND	ND
Calves: Under 500 lbs	28-05-020-008	Litter Slats	Fattening calves	0.000132 0.000128	0.000027 0.000019

¹ Emission factors are based on an equally weighted average of four emission factors from studies in four different European countries.

Source of Data:

Takai H., et.al. 1998. Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. J. Agric. Engng Res. 70:59-77.
ND = No Data Available

5.2.2.6 Endotoxin Emission Factors

Due to the difficulty of making quantitative measurements of airborne endotoxins, only a limited amount of published literature on endotoxin emissions from animal feedlots exists to date. Seedorf, et al., (1998) provides the only source of endotoxin emission factors from the available literature. Seedorf, et al., (1998) estimated emission factors based on ventilation rates using the carbon dioxide balance method and the measured indoor endotoxin concentrations. Endotoxin emissions were calculated as an average over 24 hours (Seedorf, et al., 1998), and emission factors were subdivided into cows, beef, and calves. Since this was the only available source of emission factors and measurement of airborne endotoxins is subject to great variability, these emission factors should be used with caution.

TABLE 5.12

ENDOTOXIN (TOTAL MICRORGANISMS) AIR EMISSION FACTORS FOR CATTLE AND DAIRY FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor mg >5um/hr/ (500lbs liveweight)	Emission Factor mg <5um/hr/ (500lbs liveweight)
Cows and heifers that have calved (Beef cows)	28-05-020-001	Total	Dairy and calf cows	0.0017	0.00027
Cows and heifers that have calved (Milk cows)	28-05-020-002	Total	Dairy and calf cows	0.0013	0.00014
Heifers - Beef cow replacements: 500 lbs and over	28-05-020-003	Total	Young cattle for fattening	0.0017	0.00027
Heifers Milk cow replacements: 500 lbs and over	28-05-020-004	Total	Young cattle	0.001318	0.00014
Heifers (Others): 500 lbs and over	28-05-020-005	Total	Young cattle	ND	ND
Steers: 500 lbs and over	28-05-020-006	Total	Fattening/grazing cattle > 2 yr	ND	ND
Bulls: 500 lbs and over	28-05-020-007	Total	Breeding Bulls > 2yr	ND	ND
Calves: Under 500 lbs	28-05-020-008	Total	Fattening calves	0.0097	0.00123

Source of Data:

Seedorf J, et.al. 1998. Concentrations and emissions of airborne Endotoxins and microorganisms in livestock buildings in Northern Europe. Journal of Agricultural Engineering Research 70:97-109.

ND = No Data Available

5.2.3 Poultry

The classifications of poultry included in the compilation and evaluation of emission factors included chickens and turkeys. There have been a few studies documenting emission factors for ducks. The emission factors for ducks were not evaluated because raising ducks is not a large industry within the state of Minnesota and the few emission factors referenced lacked supporting documentation. Within the chicken classification subcategories include broilers, pullets, and hens. A distinction between the data sets for different classifications of broilers, pullets, and hens could not be completely determined. It appears that the classification of hens and pullets are used interchangeably. However, to be consistent with the emission factor references, the classifications were not combined.

The poultry emission factors that were compiled and evaluated include:

- Ammonia (NH₃)
- Hydrogen sulfide (H₂S)
- Methane (CH₄)
- Particulate matter (PM)
- Endotoxins

The emission factors contained within this section represent a limited survey of research and further study is needed to strengthen the validity of the emission factors.

5.2.3.1 Turkeys

The emission factors evaluated for turkeys were differentiated by age and the intended agricultural use of the animal. Turkey feedlots typically use litter floor housing. The majority of emissions occur while cleaning out the housing facility, which is typically done between shipping old turkeys and receiving new turkeys. There were no H₂S, PM, or endotoxin emission factors found for turkey operations.

5.2.3.1.1 Ammonia Emission Factors

The NH₃ emission factors for turkeys were obtained from the 1994 USEPA report by Battye, et al., which summarizes the emission factors presented by Asman in 1992. Based on the 1994 USEPA report, the Asman emission factors appear to be the most representative for turkeys.

The other NH₃ emission factors for turkeys were excluded from evaluation because the studies lacked supporting information or referenced the Asman (1992) study. The 1994 USEPA report (Battye 1994) assigned emission factor ratings of B and C to the sub-categories of turkey NH₃ emission factors. These emission factors were based on a large literature summary, and the emission factor ratings were estimated conservatively by Battye to account for the many possible factors influencing NH₃ emissions from swine feedlots. It was unclear if the data set represented a good cross section of the U.S. agricultural practices, actual emission rate could vary since there are some possible differences between European and U.S. feedlots include animal diet, housing configurations, and management practices.

Emission factors for NH₃ emissions from turkey feedlots were broken down by activities, which include the total of all activities, stable and storage, and manure spreading. Linking the emission factors to an activity is helpful, but additional uncertainty is introduced (Battye 1994). The fryer-roasted

turkey-for-slaughter NH₃ emission factor was given an emission factor rating of C to reflect the uncertainty associated with the activity link (Battye 1994).

TABLE 5.13

**AMMONIA (NH₃) AIR EMISSION FACTORS
FOR POULTRY AND CHICKEN FEEDLOTS**

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb NH₃/animal/yr)
Poultry - Chickens - Composite	28-05-030-000	Composite		0.393
Hens	28-05-030-001	Total	Mother animals > 6 mo.	1.316
		Stable and Storage		0.693
		Spreading		0.623
Pullets - Of laying age	28-05-030-002	Total	Laying hens > 18 wk.	0.671
		Stable and Storage		0.220
		Spreading		0.451
Pullets - 3 months old and older not of laying age	28-05-030-003	Total	Mother animals < 6 mo.	0.592
		Stable and Storage		0.310
		Spreading		0.282
Pullets - Under 3 months old 500 lbs and over	28-05-030-004	Total	Laying hens < 18 wk.	0.374
		Stable and Storage		0.110
		Spreading		0.264
Other chickens	28-05-030-005	Total		0.394
		Stable and Storage		ND
		Spreading		ND
Broilers	28-05-030-006	Total	Broilers	0.367
		Stable and Storage		0.143
		Spreading		0.224
Turkeys	28-05-035-002	Total	Turkeys for slaughter	1.888
		Stable and Storage		0.944
		Spreading		0.944
Young Turkeys	28-05-035-003	Total	Turkeys < 7 mo.	1.958
		Stable and Storage		0.979
		Spreading		0.979
Old Turkeys	28-05-035-004	Total	Turkeys > 7 mo.	2.812
		Stable and Storage		1.406
		Spreading		1.406
Fryer-roasted turkey	28-05-035-005	Total	Turkeys for slaughter	1.888
		Stable and Storage		0.944
		Spreading		0.944

Source of Data:

Asman W. Ammonia Emissions in Europe: Updated Emission and emission Variations. National Institute of Public Health and Environmental Protection. Bilthoven, The Netherlands. May 1992.

5.2.3.1.2 Methane Emission Factors

There has been limited research done to quantify CH₄ emission rates from turkey feedlots. Only one CH₄ emission factor for turkeys was found during the literature search. This work of Safely and Casada (1992) estimated the total global emission rate for all sources of CH₄ at 540 billion kilograms per

year. Approximately five percent of the total CH₄ emissions resulted from anaerobic decomposition of animal manure and 15 percent resulted from decomposition in the gut of ruminant animals. The estimated contributions per animal were based on a global scale. Safley (Safley and Casada 1992) grouped turkeys and ducks together to determine a total CH₄ emission factor. It is not possible to differentiate between turkey and duck CH₄ emissions. This CH₄ emission factor should not be heavily relied on to estimate emissions because there was a high uncertainty related to linking global emissions to individual emission sources. More work is needed to determine CH₄ emission factors for turkey feedlots.

TABLE 5.14

METHANE AIR EMISSION FACTORS FOR POULTRY AND CHICKEN FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb methane/animal/yr)
Hens	28-05-030-001	Total	Mother animals > 6 mo.	ND
Pullets - Of laying age	28-05-030-002	Total	Laying hens > 18 wk.	0.660
Pullets - 3 months old and older Not of laying age	28-05-030-003	Total	Mother animals < 6 mo.	ND
Pullets - Under 3 months old 500 lbs and over	28-05-030-004	Total	Laying hens < 18 wk.	ND
Other chickens	28-05-030-005	Total		ND
Broilers	28-05-030-006	Total	Broilers	0.198
Turkeys	28-05-035-002	Total	Turkeys for slaughter	0.352
Young Turkeys	28-05-035-003	Total	Turkeys < 7 mo.	ND
Old Turkeys	28-05-035-004	Total	Turkeys > 7 mo.	ND
Fryer-roasted turkey	28-05-035-005	Total	Turkeys for slaughter	ND

¹ Emission factors are based on an annual average H₂S emission per square meter of a typical feedlot.

Source of Data:

Sfley L., Casada M. 1992. Global Methane Emission from Livestock and Poultry Manure. United States Environmental Protection Agency. Document 400/1-91/048.

ND = No Data Available

5.2.3.2 Chickens

Most of the emissions quantification work for poultry has been focused on chicken facility emissions. The emission factors for chickens were differentiated by age and chicken classification. Chickens were divided into two main groups, which include egg laying and broilers. Chickens raised for egg laying were divided into subcategories of pullets and hens of different ages. Emissions factors were evaluated for NH₃, H₂S, PM, and endotoxins.

5.2.3.2.1 Ammonia Emission Factors

The NH₃ emission factors for chickens were obtained from the 1994 USEPA report by R. Battye, et al., which summarizes the emission factors presented by Asman in 1992. All other NH₃ emission factors for chickens were excluded from evaluation because the studies lacked supporting information or referenced the Asman (1992) study. The 1994 USEPA report established emission factor ratings ranging from B to C for the chicken NH₃ emission factors. Asman presented emission factors based on a large literature summary. However, the emission factor ratings were lowered to account for the many possible factors

influencing NH₃ emissions from animals (Battye 1994). It was unclear to Battye if the data set represented a good cross section of the U.S. agricultural practices.

Emission factors for NH₃ emissions from chicken feedlots were broken down by activities, which include the total of all activities, stable and storage, and manure spreading. Linking the emission factors to an activity is helpful, but additional uncertainty is introduced (Battye 1994). The NH₃ emission factors for pullets greater than three months old not of laying age and other chickens were given an emission factor rating of C to reflect the uncertainty associated with the activity link (Battye 1994). Based on the 1994 USEPA report (Battye 1994), the Asman (1992) NH₃ emission factors appear to be the most representative for chickens. Emission factors for NH₃ from chicken facilities are presented in Table 5.13.

5.2.3.2 Hydrogen Sulfide Emission Factors

Only one H₂S emission factor for chicken feedlots was found from the literature search. The research by Zhu, et al., (1998) measured H₂S emissions from a mechanically ventilated broiler facility. H₂S emissions were measured during one 12-hour sampling period to determine an average emission rate. This H₂S emission factor should not be heavily relied on to estimate emissions because the factor was based on only one sampling event and there are many possible factors influencing H₂S emissions. Further study should be done to determine H₂S emission factors for chicken feedlots.

TABLE 5.15

HYDROGEN SULFIDE (H₂S) AIR EMISSION FACTORS FOR POULTRY AND CHICKEN FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb H ₂ S/m ² /hr) ¹
Hens	28-05-030-001	Total	Mother animals > 6 mo.	ND
Pullets - Of laying age	28-05-030-002	Total	Laying hens > 18 wk.	ND
Pullets - 3 months old and older not of laying age	28-05-030-003	Total	Mother animals < 6 mo.	ND
Pullets - Under 3 months old 500 lbs and over	28-05-030-004	Total	Laying hens < 18 wk.	ND
Other chickens	28-05-030-005	Total		ND
Broilers	28-05-030-006	Total	Broilers	0.2
Turkeys	28-05-035-002	Total	Turkeys for slaughter	ND
Young Turkeys	28-05-035-003	Total	Turkeys < 7 mo.	ND
Old Turkeys	28-05-035-004	Total	Turkeys > 7 mo.	ND
Fryer-roasted turkey	28-05-035-005	Total	Turkeys for slaughter	ND

¹ Emission factors are based on an annual average H₂S emission per square meter of a typical feedlot.

Source of Data:

Zhu, et.al. 1998. Modeling the agricultural odor dispersions using atmospheric dispersion models. St. Joseph, MI: American Society of Agricultural Engineers. ASAE Paper No. 98-4056.

ND = No Data Available

5.2.3.2.3 Methane Emission Factors

There has been limited research done to quantify CH₄ emission rates from chicken feedlots. Only one CH₄ emission factor study for chickens was found during the literature search. Safley (Safley and Casada 1992) presented a crude estimate of CH₄ emissions from chicken facilities based on global estimates of CH₄ emissions from animal feedlot operations. Safley (Safley and Casada 1992) differentiated chicken CH₄ emission factors between caged layers and broilers. These CH₄ emission factors should not be heavily relied on to estimate emissions because there was a high uncertainty related to linking global emissions to individual emission sources. Further research is required to determine CH₄ emission factors for chicken feedlots. Emission factors for CH₄ from chicken facilities are presented in Table 5.14.

5.2.3.2.4 Particulate Matter Emission Factors

The poultry industry has been concerned with fugitive particulate matter emissions because of indoor air quality and its impact on workers and animals inside the building. Most of the work to date has been conducted to determine particulate matter concentrations instead of quantifying PM emission rates. Takai, et al., (1998) published the most extensive study of fugitive PM emission factors from animal feedlots. This research compiled emission factors from a four-country study which measured inhalable (>5 µm) and respirable (<5 µm) particulate emissions for subcategories of layers, broilers, and poultry in general. The four countries evaluated in the study included England, the Netherlands, Denmark, and Germany. Each PM measurement was performed near the building air outlet using IOM dust samplers. The daily mean ventilation rate was used to determine an emission rate per animal liveweight. Emission factors for layers were classified into perchery and cage housing practices. Broiler emission factors were for litter housing facilities and general poultry emission factors were for the total housing facility. Each emission factor presented in this document is based on the equally weighted average of the four countries. The Takai, et al., (1998) particulate matter emission factors are based on test data from a moderate number of facilities. Testing was performed while varying a number of factors including location, housing practices, time of day, and change in season; therefore the Takai, et al., (1998) PM emission factors appear to be the most representative for chickens.

TABLE 5.16
PARTICULATE MATTER (PM) AIR EMISSION FACTORS
FOR POULTRY AND CHICKEN FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor lb pm>5um/hr/ (500lbs liveweight)*	Emission Factor lb pm<5um/hr/ (500lbs liveweight) ¹
Poultry		Total Housing Facility		0.003	0.00049
Hens	28-05-030-001		Mother animals > 6 mo.	ND	ND
Pullets - Of laying age	28-05-030-002	Perchy Cage	Laying hens > 18 wk.	0.0025 0.00072	0.00059 0.111179
Pullets - 3 months old and older not of laying age	28-05-030-003		Mother animals < 6 mo.	ND ND	ND ND
Pullets - Under 3 months old 500 lbs and over	28-05-030-004		Laying hens < 18 wk.	ND ND	ND ND
Other chickens	28-05-030-005			ND	ND
Broilers	28-05-030-006	Litter	Broilers	0.0036	0.00052
Turkeys	28-05-035-002		Turkeys for slaughter	ND	ND
Young Turkeys	28-05-035-003		Turkeys < 7 mo.	ND	ND
Old Turkeys	28-05-035-004		Turkeys > 7 mo.	ND	ND
Fryer-roasted turkey	28-05-035-005		Turkeys for slaughter	ND	ND

¹ Emission factors are based on an equally weighted average of four emission factors from studies in four different European countries.

Source of Data:

Takai H., et.al. 1998. Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. J. Agric. Engng Res. 70:59-77.
ND = No Data Available

5.2.3.2.5 Endotoxin Emission Factors

Endotoxin emissions from chicken housing facilities are highly variable and difficult to quantify. Only a limited amount of research has been published quantifying endotoxin emissions from feedlot facilities. The study published by Seedorf, et al., (1998) quantified average emission factors for inhalable ($>5 \mu\text{m}$) and respirable ($<5 \mu\text{m}$) endotoxins for total chicken facility operations in four European countries which included England, the Netherlands, Denmark, and Germany. Emission rates were calculated by estimating ventilation rates using the carbon dioxide balance method and indoor endotoxin concentrations. Endotoxin emissions were calculated as an average over 24 hours (Seedorf, et al., 1998). The emission factors were subdivided into layers and broilers. Seedorf, et al., (1998) showed that poultry had higher endotoxin emission rates than cattle and pigs. Seedorf, et al., (1998) indicated that it was unclear if outdoor human exposure to endotoxin emissions was hazardous to human health. The Seedorf, et al., (1998) research represented a reasonable number of facilities. However, due to the high variability in measuring endotoxin emissions, the Seedorf, et al., (1998) endotoxin emission factors should not be heavily relied on to estimate endotoxin emissions from chicken housing facilities. Further study should be done to determine endotoxin emission factors from chicken housing facilities.

TABLE 5.17

**ENDOTOXIN (TOTAL MICRORGANISMS) AIR EMISSION FACTORS
FOR POULTRY AND CHICKEN FEEDLOTS**

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor mg >5um/hr/ (500lbs liveweight)	Emission Factor mg <5um/hr/ (500lbs liveweight)
Hens	28-05-030-001		Mother animals > 6 mo.	ND	ND
Pullets - Of laying age	28-05-030-002		Laying hens > 18 wk.	0.00026	0.000017
Pullets - 3 months old and older not of laying age	28-05-030-003		Mother animals < 6 mo.	ND	ND
Pullets - Under 3 months old 500 lbs and over	28-05-030-004		Laying hens < 18 wk.	ND	ND
Other chickens	28-05-030-005			ND	ND
Broilers	28-05-030-006		Broilers	0.00037	0.000022
Turkeys	28-05-035-002		Turkeys for slaughter	ND	ND
Young Turkeys	28-05-035-003		Turkeys < 7 mo.	ND	ND
Old Turkeys	28-05-035-004		Turkeys > 7 mo.	ND	ND
Fryer-roasted turkey	28-05-035-005		Turkeys for slaughter	ND	ND

Source of Data:

Seedorf J, et.al. 1998. Concentrations and emissions of airborne Endotoxins and microorganisms in livestock buildings in Northern Europe. Journal of Agricultural Engineering Research 70:97-109.

ND = No Data Available

5.2.4 Sheep

Although in 1991 there was an estimated 10.5 million sheep with the U.S. (Asman 1992), sheep have not received as much environmental attention as many of the other animal species. Therefore, only a very limited amount of emissions research has been conducted at sheep feedlots. From a survey of available literature, NH₃ is the only air contaminant for which an emission factor has been derived for emissions from sheep housing facilities.

5.2.4.1 Ammonia Emission Factors

The 1994 USEPA report by Battye, et al., (1994 summarizes the emission factors presented by Asman in 1992 and provides an emission estimate for total NH₃ emissions from ewe facilities. Battye (1994) concluded that there was a large discrepancy between the factor that was provided for sheep and lambs presented by Asman (1992) and the NH₃ emission factor that was presented by Denmead (1990) in Australia. Due to a large discrepancy, Battye (1994) applied a D emission factor rating to the Asman NH₃ emission factor. According to the 5th Edition of AP-42, an emission factor rating of D indicates that the emission factor was below average and was developed from A-, B-, and/or C-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source population. More research is needed for a better understanding of NH₃ and other chemical emission rates from sheep feedlots.

TABLE 5.18

AMMONIA (NH₃) AIR EMISSION FACTORS FOR SHEEP FEEDLOTS

Animal Source (U.S. Agricultural Statistics Classifications)	AMS Classification Code	Feedlot Process	Emission Factor Classifications	Emission Factor (lb NH ₃ /animal/yr)
Sheep and lambs on feed	28-05-040-001	Total	Ewes	7.414
		Stable and Storage		1.540
		Spreading		2.816
		Grazing		3.058
Stock sheep-lambs-ewes	28-05-040-002	Total	Ewes	7.414
		Stable and Storage		1.540
		Spreading		2.816
		Grazing		3.058
Stock sheep-lambs-wethers and rams	28-05-040-003	Total	Ewes	7.414
		Stable and Storage		1.540
		Spreading		2.816
		Grazing		3.058
Stock sheep- 1yr. and over	28-05-030-004	Total	Ewes	7.414
		Stable and Storage		1.540
		Spreading		2.816
		Grazing		3.058

Source of Data:

Asman W. Ammonia Emissions in Europe: Updated Emission and emission Variations. National Institute of Public Health and Environmental Protection. Bilthoven, The Netherlands. May 1992.

5.2.5 Emission Reduction Strategies

A large body of the animal feedlot emission factor literature is based on research conducted from five to twenty years ago. Therefore, the emission factors represent emissions from animal feedlot operations that utilized more traditional management practices and facility designs. With the current changes and environmental concerns within the animal industry, there are a number of relatively new control/suppression technologies and management practices designed to reduce air pollutant emissions from animal feedlot operations. The emission factors presented in Section 2.2 of this document present emission factors that were compiled from more traditional feedlot facilities that have not incorporated these emerging technologies or practices. Therefore, the estimated reduction efficiencies for emerging control technologies and management practices should be applied to the traditional ‘uncontrolled’ emission factors to account for the emission reduction achieved by the control technology or best management practice.

There are a number of management practices and emerging control technologies that can be applied to animal housing operations to reduce emissions of air pollutants. Table 4.1 lists a number of control technologies and management practices with an estimated range of control efficiencies for applicable pollutants. The control efficiency ranges are based on published research. Some technologies are relatively new and are still in experimental stages. Most of the control technology research to date has been conducted using optimum conditions, control efficiencies in actual applications may not meet the calculated control efficiencies established under the optimum experimental conditions. The selection of best management practices and control technologies should be tailored to facility-specific conditions including facility design, management, climate, topography, and potential receptors. With a limited amount of published information and with the variability in reported control efficiencies for animal housing facilities, further work is needed to quantify the effectiveness of a number of these control technologies.

5.2.5.1 Oil Sprinkling

Emission reduction from oil sprinkling is highly dependent on the application rate and frequency. A current study of Canola oil sprinkling by Godbout, et al., (2000) reported fugitive dust reductions of up to 90 percent. The lowest published fugitive dust reduction was 40 percent in an Iowa pig finishing barn (Kiryuchuk, et al., 1999). Research by Zhang, et al., (1996) showed a reduction of H₂S and NH₃ emissions by up to 20 and 30 percent respectively. Based on the literature review, oil sprinkling has been applied only to pig housing facilities, but appears to be an emerging control technology with potential for suppressing a number of air pollutants.

5.2.5.2 Diet Manipulation

Diet manipulation has been researched to reduce in order to reduce emissions of pollutants. A study by Rom, et al., (2000) showed a 40 to 50 percent reduction in NH₃ emissions by using a food additive (juice extract from the Yucca Schidigera plant). Ammonia reductions have been recorded as 28 to 79 percent through lower protein diets (Sutton, et al., 1999). A reduction in dust emissions has been shown to be 35 to 70 percent by adding fat and oil to coat the feed in swine facilities (Chiba and others 1987; Heber and Martin 1988; Takai and others 1996). Although there is believed to be somewhat of a tradeoff in animal productivity for odor reduction through diet manipulation, further research on diet manipulation may provide the agricultural industry with an efficient and economic method for reducing air emissions.

5.2.5.3 Air Filtration

Most of the sources of dust emissions are inside the animal housing facilities. An effective way to reduce dust emissions is by filtering the air during recirculation. Reductions of dust emissions have been shown between 50 and 60 percent by using a dual-phase filter (Carpenter and Fryer 1990). Other filtering systems include biomass filters, biofilters, wet scrubbers, bioscrubbers, and electrostatic precipitators. A study by Hoff and others (1997) showed that a biomass filter using chopped cornstalks and corncobs as filter substrate can achieve between 62 and 67 percent reduction of dust emissions.

Air emissions from agricultural facilities are considered to very biodegradable, and in general, biofilters have demonstrated higher removal efficiencies of air pollutants from agricultural feedlot emissions. Removal efficiencies of air pollutants from animal feedlot emissions for biofilters have been reported from 9 to 99 percent for NH_3 , 50 to 90 percent for H_2S , up to 46 percent for other organics, and up to 86 percent for PM. Wet scrubbers have been shown to reduce animal feedlot emissions by 8 to 94 percent for NH_3 , 44 to 90 percent for PM (Chiumenti and others 1994; Pearson 1989). NH_3 reductions of 22 to 54 percent have been documented for bioscrubbers (Dong and others 1997; Lais and others 1997). Electrostatic precipitators were shown to achieve PM reductions of 40 to 60 percent (Moller F.). Higher removal efficiencies are commonly achieved with biofilters, scrubbers, and electrostatic precipitators in carefully engineered systems used to control air emissions from other industrial processes.

Typically these systems have not been applied to animal housing facilities, but with the increasing awareness and concern with air emissions from animal feedlots, these alternative technologies will receive more attention within the feedlot industry for controlling air emissions.

5.2.5.4 Ozonation

Only limited research has been published evaluating the use of ozone to control emissions from animal housing facilities. Ozone is a highly reactive oxidizing agent. In a 16-month experiment, Priem (1977) found that ozone at concentrations up to 0.2 ppm reduced NH_3 concentrations in a swine barn by 15 percent under summer ventilation conditions and 50 percent under winter ventilation conditions. Ozonation has not been thoroughly tested. Additional research is needed to determine the efficiency and economic feasibility of this technology

5.2.5.5 Non-Thermal Plasma

Non-thermal plasma is a relatively new technology that is being researched further by the University of Minnesota's Biosystems and Agricultural Engineering Department. Emission reductions are achieved by creating highly reactive chemical species that convert targeted compounds to non-toxic molecules. Ruan and others (1997) showed 100 percent removal of NH_3 and H_2S concentrations during laboratory testing. This control technology is still in its preliminary stages, and additional research is needed to determine its efficiency and economic feasibility.

5.2.5.6 Covers

Covering an open manure storage surface can control emissions. There are different types of cover designs that have been studied. The main cover types include rigid, inflatable, synthetic floating, and natural floating covers. NH_3 reductions of greater than 80 percent were achieved by applying a rigid cover to a manure storage tank (De Bode 1991). Zhang and Gaakeer (1996) showed greater than 95 percent

reduction in NH_3 and H_2S emission rates using an inflated cover with an operating pressure of 0.4 inches of water. Floating synthetic and natural covers have been shown to reduce NH_3 by 45 to 90 percent. Clanton and others (1999) showed that natural covers using straw or PVC/rubber membrane reduced H_2S by up to 94 percent. Covers are another relatively new technology in the feedlot industry, further research is needed to determine the best type(s) of covers for the many different practices used to store animal manure.

5.2.5.7 Dilution of Liquid Waste

Research was completed in the Netherlands evaluating the control of NH_3 emissions by lowering the concentration in the slurry through dilution. Dilution with aerated liquid fraction after separation in a pig housing facility reduced NH_3 emissions by up to 70 percent (Hoeksma, et al., 1993). The drawback to this method of control is that dilution with water is not economically feasible for most farmers due to increased cost for storage, transportation, and application.

5.2.5.8 Reduction of Emitting Surfaces

The emitting surface is equal to the sum of the areas of the manure pit and the fouled surfaces of walls, solid floor, slats, and animals (Voermans and others 1996). A method becoming popular in Europe is using V-shaped gutters under the slats in pig housing facilities. The experiments by Voermans and others (1996) showed NH_3 emission reductions between 43 and 70 percent by altering the dimensions of the storage lagoon to reduce the emitting surface. Reduction of emitting surface provides a simple method for new or expanding feedlots to make reductions in air emissions without excessive additional costs.

5.2.5.9 Temperature Control

During the summer the NH_3 emission rate is higher than in the winter. A reduction in NH_3 emissions can be achieved by reducing the temperature of the manure. Voermans and others (1996) showed NH_3 emission reductions of up to 50 percent by lowering the temperature of the manure. Although difficult during the summer months, reduction in manure temperature can provide a simple and economical method to limit air emissions for manure storage piles and lagoons.

5.2.5.10 Manure Pit Additives

Manure pits emit various gases as a result of biological and chemical activity in the manure. Various chemical and biological additives have been introduced to manure pits to modify the biological and chemical activity in the pit, and therefore reduce emissions. The pollutants that are controlled vary with the composition of the additive. Heber and others (2000) tested an additive called Alliance, developed by Monsanto EnviroChem. This additive reduced NH_3 emissions from 10 to 80 percent, but had no effect on emissions of H_2S . Another additive called Pit Remedy, developed by B&S Research, was tested by Heber (1999). This additive reduced H_2S emissions up to 55 percent, and reduced emissions of volatile fatty acids by 37 to 95 percent. Despite the success of these additives, many are considered by researchers to be of only marginal benefit in reducing odors.

5.2.5.11 Lagoon Aeration

Manure waste lagoons typically operate under anaerobic conditions, resulting in the formation of significant quantities of reduced sulfur compounds and methane. One technique for reducing the formation of these compounds is providing aeration to the liquid phase of the lagoon in order to increase the level of aerobic activity and reduce the level of anaerobic activity. In a field study conducted by researchers at Purdue University, odor emissions measured from a 2.4 acre surface aerated lagoon were lower than emissions from non-aerated lagoons. Although a site-specific control efficiency was not measured in the study, the researchers reported an odor emission 82 percent less than from similar non-aerated lagoons with only half of the volumetric loading rate.

TABLE 5.19
ANIMAL AGRICULTURE
AIR EMISSION CONTROL EFFICIENCIES

Best Management Practice/ Control Technology ¹	Animal Agriculture Application/Process	Pollutant Controlled	Range of Published Control Efficiencies (%)
Oil Sprinkling for Dust Reduction	Confined Swine Barns	Particulate Matter (PM) Ammonia (NH ₃) Hydrogen Sulfide (H ₂ S)	40-90% Up to 30% Up to 20%
<i>Diet Manipulation</i>			
Food Additives	Swine Facilities	NH ₃	40-50%
Reduced Crude Protein Diets	Swine Facilities	NH ₃ H ₂ S	28-79% Up to 40%
	Dairy Facilities	NH ₃	Up to 28%
Alteration of Feed Coating	Swine Facilities	PM	35-70%
Air Filtration	Emissions from Mechanically Vented Feedlot Facilities	PM	50-60%
Biomass filter	Emissions from Mechanically Vented Feedlot Facilities	PM	62-67%
Biofilters	Emissions from Mechanically Vented Feedlot Facilities	NH ₃	9-99%
		H ₂ S Organic Constituents	50-90% Up to 46%
		PM	Up to 86%
Wet Scrubbers	Emissions from Mechanically Vented Feedlot Facilities	NH ₃	8-94%
Bioscrubber	Emissions from Mechanically Vented Feedlot Facilities	NH ₃	22-54%
Ozonation	Emissions from Mechanically Vented Feedlot Facilities	NH ₃	15-50%
Electrostatic Precipitators	Emissions from Mechanically Vented Feedlot Facilities	PM	40-60%
Non-Thermal Plasma	Emissions from Mechanically Vented Feedlot Facilities	NH ₃	Up to 100%
<i>Covers</i>			
Rigid Cover	Feedlot Manure Lagoons/Storage Tank	NH ₃	>80%
Inflatable Cover	Feedlot Manure Lagoons/Storage Tank	NH ₃	Up to 95%
		H ₂ S	Up to 95%
Floating Cover (Synthetic)	Feedlot Manure Lagoons/Storage Tank	NH ₃	45-90%
Floating Cover (Natural)	Feedlot Manure Lagoons/Storage Tank	NH ₃	45-90%
		H ₂ S	Up to 94%
Dilution of Liquid Waste	Feedlot Manure Lagoons/Storage Tank	NH ₃	Up to 70%
Reduction of Emitting Surfaces	Feedlot Manure Lagoons/Storage Tank	NH ₃	43-70%
Temperature Control	Reducing Temperature Manure Lagoons and Solid Manure Storage Piles	NH ₃	Up to 50%
Manure Pit Additives	Feedlot Manure Lagoons/Storage tank	NH ₃	10-80%
		H ₂ S	Up to 55%
		Volatile Fatty Acids	37-95%

¹ Some technologies listed are relatively new and still in the experimental stages. The selection of best management practices/control technologies should be tailored with facility-specific circumstances that include facility design and other management factors, climate, topography, and potential receptors.

5.3 EVALUATION OF DISPERSION MODELS

The available air emission dispersion models that are most appropriate to apply to modeling emissions from feedlot facilities were identified from the technical literature. Modeling studies performed to evaluate the impacts of animal agriculture activities in Minnesota as well as other states and countries were reviewed. The strengths and weaknesses of applying each model to feedlot emission sources were evaluated.

The available air dispersion models were evaluated to identify those most suitable for estimating ambient concentrations of toxic and odorous air pollutants due to feedlot operations. The features of three specific models for toxic air pollutants were compared, and recommendations were developed based on the advantages that each model offers. Dispersion models that were evaluated include:

- The Industrial Source Complex Short Term (ISCST3) Model (U.S.EPA, 1995).
- The AMS/EPA Regulatory Model (AERMOD) (U.S.EPA, 1998).
- The non-steady state CALPUFF model (Scire, et al., 1999).

The quality of input information is a key consideration for selecting a modeling approach. When inputs (e.g., emission rates) are uncertain, a simpler approach is generally appropriate. More sophisticated models generally require more and better input information in order to provide better concentration estimates.

5.3.1 Model Requirements

The basic modeling requirements for estimating air quality impacts of feedlot operations are established by the pollutants that are emitted, the physical setting and chemical characteristics of the emission sources, and the averaging times and source-receptor distances of primary concern.

Emission sources include livestock enclosures (various types of barns, sheds or buildings), manure storage areas (lagoons or storage piles) and manure spreading operations. Emissions from each of these operations are distributed over an area or volume. The pollutants of widest interest have been H₂S and NH₃. Averaging times for assessing potential impacts on human health range from one hour or less (for acute effects) to annual average (for chronic effects). For H₂S and NH₃, peak short-term (one hour) exposures are of primary concern. Nuisance effects associated with offensive odors can be caused by near-instantaneous concentration spikes as short as 10 to 20 seconds. Issues related to modeling for odor assessment are discussed below in Section 3.3.

Distances of primary concern for modeling range from 100 meters or less (the distance from an individual source to the facility fenceline) to about 5000 meters (to assess the combined impacts of multiple facilities in a region). For these distances, deposition and chemical transformation are expected to be relatively unimportant for H₂S and NH₃. Terrain is also relatively unimportant for feedlot applications in Minnesota. Dispersion rates used by the models vary with meteorological conditions and with the physical setting. The local environment is characterized as either rural or urban, and a surface roughness parameter is specified based on land use and topography. Rural dispersion conditions prevail in all cases, but surface roughness conditions vary with the geographic setting and the specific type of operations.

Emission rates for some feedlot sources are known to vary by time of day and as a function of meteorology, so the capability to specify time-varying emission rates is useful. In particular, emissions

from manure basins/lagoons depend on ambient temperature and wind speed (Ganzer 2000). Use of curtain walls that are raised/lowered with changing ambient temperature also leads to time-varying ventilation and emission rates. Emissions from basin/lagoon mixing and clean-out and from manure spreading are episodic in nature. Many livestock operations (aside from dairy) are cyclical, as each herd or flock of animals grows and is harvested, and emissions from individual feedlot operations follow those production cycles.

5.3.2 Candidate Models

Three candidate air quality models were identified as meeting the general requirements described above: the Industrial Source Complex model (ISCST3), the AMS/USEPA Regulatory Model (AERMOD), and the non-steady state CALPUFF Model. All three models have been approved for regulatory use by USEPA and MPCA and are designed to simulate impacts from distributed (area and volume) sources, over the range of source-receptor distances of concern. All three models provide predictions for averaging times ranging from minutes to years, and are designed to provide hourly concentration predictions based on hourly sequential input meteorological conditions.

These models represent different compromises between ease of use, flexibility and technical sophistication. The models are listed in order of increasing complexity. ISCST3 and AERMOD are steady-state Gaussian plume models that assume straight-line transport between source and receptor, based on the specified wind speed and direction. Dispersion rates which are dependent on the physical setting and on input meteorology define the rate of plume spread in the horizontal and vertical directions. CALPUFF is a non-steady state Lagrangian model which predicts transport and dispersion between source and receptor based on meteorological conditions that vary in space and time. ISCST3 and AERMOD predict dispersion and transport based on a single (hourly) input wind speed and direction, while CALPUFF (and the associated meteorological model CALMET) simulates spatially varying wind conditions.

For low-level emission sources such as feedlot operations, the differences between predictions from steady-state and puff models are expected to be greatest for stable, near-calm (low wind) conditions, which generally lead to the highest predicted short-term concentrations. The assumption of steady-state conditions is only valid when the transport time and source-receptor distance are small, relative to the spatial and temporal scale at which dispersion conditions are changing. The steady-state Gaussian plume equation for concentration varies inversely with wind speed. To avoid extremely high predicted concentrations as the wind speed approaches zero, ISCST3 and AERMOD impose a minimum value of 1 m/s. These models will predict hourly impacts (based on straight-line plume transport) at distances far beyond the one-hour transport time indicated by the input wind speed.

When wind inputs indicate calm conditions, CALPUFF simulates the growth of emitted puffs by ambient dispersion, independent of puff transport. This basic difference between steady-state and puff model approaches can lead to substantial differences in the predicted magnitude and spatial pattern of peak concentrations from feedlot operations, as demonstrated by recent dispersion modeling analysis of feedlots in west-central Minnesota performed by MPCA (Pratt 1998).

All three models simulate distributed (volume) sources by assigning an initial horizontal and vertical spread to the plume/puff. For area sources, all three models divide the source area into a series of line sources and then calculate concentrations via numerical integration. (After the first time step, CALPUFF assigns vertical/horizontal plume spread analogous to the volume source treatment.)

The following summary description of each model highlights specific aspects of each model that represent strengths or weaknesses for application to modeling feedlot operations.

Model	Description	Strength	Weakness
ISCST3	Dispersion rates based on two general dispersion regimes (rural or urban) and six discrete stability classes (Class A through F, very unstable to extremely stable).	Easiest model to use (fewest technical decisions).	Weak for stable/near-calm conditions
AERMOD	Dispersion rates based on urban/rural dispersion. Rates vary continuously based on meteorological conditions and surface roughness (not discrete stability classes).	Relatively easy to use, greatest flexibility for defining area source geometry.	Weak for stable/near-calm conditions
CALPUFF	Lagrangian puff dispersion, dispersion rates vary continuously based on meteorological conditions and surface roughness (optional), 3-D meteorological fields (optional)	Most realistic simulation of near-calm/stable and evolving/transient (sub-hourly) meteorology. This represents a significant improvement for multi-facility impact assessment. Affords greatest flexibility to specify time-varying emission rates.	Resource intensive (particularly to develop 3-D meteorology)

The recommended model for estimating air quality impacts of feedlot operations for a single facility is ISCST3. For this type of application, the advantages of ease of use and familiarity to the user community outweigh the technical advantages offered by AERMOD or CALPUFF. More sophisticated modeling techniques are not warranted for a single-facility application, given the relatively large uncertainties in emission estimates for feedlot sources. CALPUFF is recommended for multi-facility applications, based on the technical advantages it provides for near-calm scenarios.

For future model applications, this evaluation of modeling methods has identified two items that represent priorities for improved model inputs:

1. Improve characterization of emissions from “transient” events (e.g., lagoon basin mixing, manure spreading).
2. Improved accounting for variation of emissions with meteorology and time of day (e.g., livestock daily patterns, curtain walls).

The Feedlot Air Quality Stakeholders Report (MPCA, 2000) provides an informative comparison between predicted and observed air quality concentrations in the vicinity of selected feedlot sources for both ISCST3 and CALPUFF. The modeling section of the Stakeholders Report illustrates the differences between ISCST3 and CALPUFF predictions for near-calm conditions. This type of study, combining ambient and emissions measurements and modeling, should lead to improvements in both emissions estimates and modeling methods.

5.3.3 Odor Modeling

Modeling to estimate the potential for odors in the vicinity of feedlot operations faces a number of technical challenges and practical limitations. Odor perception is based on near-instantaneous concentration levels, the response to chemical mixtures is often non-linear, and trace constituents often combine with more prevalent chemical species to produce “objectionable” odors. At a practical level, these challenges mean that emissions estimates (and model predictions) are more uncertain for odors from feedlot sources than for air toxics.

The University of Minnesota (U of M) has researched using the INPUFF-2 Gaussian puff air dispersion model for predicting downwind odor impacts from animal feedlots. The user’s guide for INPUFF-2 (Petersen and Lavdas, 1986) and three publications by U of M researchers were reviewed by Earth Tech. The U of M publications include Zhu’s “Evaluation of INPUFF-2 Model for Predicting Downwind Odors From Animal Production Facilities” (Zhu 2000), Jacobson’s “Calibrating INPUFF-2 Model by Resident-Panelists for Long-Distance Odor Dispersion from Animal Feedlots” (Jacobson 2000), and Jacobson’s “Odor From Feedlots Setback Estimation Tool (OFFSET)” (Livestock and Poultry Odor Workshop II, (Janni 2000).

[Reference: Petersen, W.B. and L.G. Lavdas, INPUFF 2.0 - A MULTIPLE SOURCE GAUSSIAN PUFF DISPERSION ALGORITHM User’s Guide, Atmospheric Sciences Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA/600/8-86/024, July 1986]

The review findings indicate that the INPUFF-2 model is not an appropriate choice for assessing the impact of low-level, distributed emissions sources such as feedlot sources. This model, which is designed for point sources, does not account correctly for the spatial distribution of source emissions, and near-field predictions (within about 500 m of sources) are therefore not reliable. U of M researchers have applied empirical scaling factors to “tune” model predictions to match observed odor levels. In light of this model calibration, the model performance reported in U of M publications is not a valid demonstration that the approach is either valid or reliable.

The INPUFF-2 user’s guide states clearly that the model is designed to estimate the impacts of point sources. No treatment specific to area or volume sources is provided. The user can assign initial horizontal and vertical dispersion coefficients (σ_{y0} and σ_{z0}) to each source, but these parameters produce a non-uniform Gaussian distribution of emitted material. For a low-level area source such as a lagoon or manure storage basin, an initial σ_{y0} seriously distorts the actual (spatially uniform) emission density. INPUFF-2 also omits any provision for building-wake effects. Most point sources associated with feedlots are emitted at or below the height of adjacent buildings and are subject to building-wake downwash.

The “OFFSET” report does not appear to match the modeling procedures, such as the application of scaling factors, described in the other two U of M papers. It appears to represent an earlier approach that has been replaced by the Zhu approach. Therefore, the remaining comments focus on the Zhu paper (Zhu 2000) and the Jacobson paper (Jacobson 2000) from the 2nd International Conference for Air Pollution from Agricultural Operations.

The technical basis for the scaling factors introduced in the Zhu publication is unclear. The distinction between “mass based” and “concentration based” dispersion modeling is not valid. It is a straightforward process to convert model predictions between mass-based (e.g., $\mu\text{g}/\text{m}^3$) and concentration-based

(e.g., ppm) units. In general, difficulties for odor modeling arise because a mixture of chemicals, not a single species, produces the odors. However, if those chemicals all originate from a single source, they will all disperse in an identical manner, and the usual mass/concentration relationships will apply.

A related challenge for odor modeling is the need to account for initial dilution when modeling distributed area or volume sources. Zhu and Jacobson do not document the initial dilution of the sources they are modeling. The “dilution volume” is often difficult to quantify. The accuracy of the initial concentration and associated volume determine the accuracy of the source strength. The source strength will not be accurate if the initial concentration and associated volume are not accurate. Zhu and the Jacobson do not discuss or document the modeling approach used with INPUFF-2 for area and volume sources. It is unclear what initial horizontal and vertical dispersion coefficients (σ_{y0} and σ_{z0}) were used for modeling.

The “scaling factors” introduced by Zhu are equivalent to model calibration factors. While such calibration does not eliminate scatter, it effectively guarantees that the highest (near-source) predictions will not show a bias. Given this near-source calibration, the main test of the approach is how the model predicts farther downwind. The fact that model performance degrades within 400 meters of the source indicates that the model is not performing correctly. The U of M papers do not provide enough documentation about the range of dispersion conditions or the range of source dimensions in order to make any definitive suggestions for improvements. One alternative that should be investigated is to replace the scaling factors with a scaling method based on source dimensions.

Comparative modeling with ISCST3, CALPUFF, and INPUFF-2 using the same sources and meteorology is recommended. At distances within 200 meters, there should be minor differences between model predictions from puff and plume models for area and volume sources. The greater difference is likely to arise from the “initial sigma” approach used by INPUFF-2 and the more precise integration over the source employed in CALPUFF and ISCST3.

Despite the technical limitations of the OFFSET model in its present form, the University of Minnesota’s approach represents a useful first step towards providing a practical, predictive tool. It should also be noted that the OFFSET model has gained a measure of acceptance in Minnesota. A zoning ordinance in Nicollet County requires the use of OFFSET in the siting of any new feedlots in the county. At least one county official has reported that the use of OFFSET has assisted in reducing odor problems by providing practical and useful guidance in determining adequate setbacks.

5.4 Recommendations

With the increasing number and size of animal feedlot operations, odor and air toxics emissions from animal feedlots has become more of an environmental concern. In response, recent work has begun to address many of the questions and concerns regarding animal feedlots and air quality. A summary of the findings from the review of available literature includes:

- While it is likely that the emission factors for hydrogen sulfide and ammonia account for a large portion of the air toxics emissions on a mass basis, uncertainties about the emission rates of volatile organic compounds and other air toxics make it difficult at this time to assess what portion of the potential risk these compounds represent.
- Available emission factors are probably better suited for estimating long term average emission rates and evaluating chronic health impacts. There is a higher degree of uncertainty associated

with estimating worst-case short-term emission rates, which are used to evaluate acute health effects.

- There appear to be strengths and weaknesses for each of the USEPA air dispersion models, depending on intended use of the model (i.e., modeling of a single facility, or modeling of multiple facilities within a target area).
- Rather than the selection of the appropriate model, the variability and uncertainty in characterizing emission rates appears to be the greatest limitation for utilizing an air dispersion model to make an accurate predictive measurement of air quality impacts. Each dispersion model is dependent on the quality of the emission factor to make an accurate predictive measurement of the air emissions. Determining accurate emission factors for animal feedlots is difficult since there are many variables that impact air emissions.
- More detailed research efforts are needed to gain a better understanding of air emissions from animal feedlots and to develop a more reliable set of emission estimating tools for the various species of animal feedlot operations. Reliable emission factors will add a significant amount of validity to any predictive measurements made using the available air dispersion models.

6.0 PROGRAM APPROACHES

Historically, regulation of animal agricultural operations began with the water quality program and their efforts to control non-point source pollution. These regulatory programs were strictly targeted at addressing water quality concerns. In the early 1990s, animal agricultural operations began to become larger, more concentrated, and more industrialized. With the increase in these types of facilities, odor problems became more prevalent. More and more members of the public began to complain to state and local regulatory agencies about the nuisance created by these larger operations. By the late 1990s some regulatory agencies began to respond to the increase in public concern by enhancing either components of existing programs or establishing brand new programs to address odor concerns from animal agricultural operations.

At the federal level, very little has been done to address air quality and odor issues from animal agricultural operations. Despite a recognition of air emissions as a potential concern from these sources, EPA's 1998 draft strategy for addressing environmental and public health impacts from animal agricultural operations, contains no substantive provisions addressing air quality or odor issues. Consequently, states have been essentially left on their own to develop programs addressing air quality. This has led to substantial variability in the extent and stringency in those states that have developed programs.

Often, the extent of a program is dictated by the level of political activism that comes out either in favor of or against additional regulation. In Colorado, for instance, concerned and angered citizens were able to secure a referendum in a state election which required the state to promulgate rules to control odors at animal agricultural operations. The referendum passed and very stringent state-wide regulations have since been put in place and are now being enforced. In Iowa, however, the state legislature established an advisory committee charged with evaluating any proposed regulatory programs affecting the agricultural industry in the state. This committee has very strong representation from the farming industry and has not looked favorably on new regulatory programs. Consequently, despite having an estimated 3,000 large animal agricultural operations and receiving many odor complaints from neighbors, the State of Iowa has no virtually no program in place for addressing odors from animal agricultural operations.

These states represent extremes. Most states we examined have some level of odor prevention or control in their regulatory structure. In many cases, these provisions have been established within the pre-existing water quality regulatory programs.

6.1 SELECTION OF PROGRAMS FOR EVALUATION

In carrying out this evaluation of program approaches, we did not survey the entire country to catalog the provisions of each states' program. Rather, we have focused on a smaller number of state programs, which we examined in more detail. We have identified programs for evaluation that span the full range of coverage and stringency. The goal of the evaluation was to review the range of possible program approaches and identify the advantages and disadvantages of each, in terms of their ability to cost-effectively prevent and/or mitigate odor and air quality issues at animal agricultural operations. The programs identified for this evaluation include Minnesota, Iowa, Colorado, North Carolina, Wyoming, and Missouri. We have also included discussion of a program for addressing odors in East Harris County, Texas. While targeted at the petrochemical industry, we have included this program in our evaluation because of its somewhat unique approach.

6.2 DISCUSSION OF PROGRAMS

Each of the programs are discussed in detail below. Following the discussion of each, a comparison of the various elements of the programs is included in a table format.

6.2.1 Iowa

Iowa for all intents and purposes, does not have a “program” for addressing air quality issues from animal agricultural operations, despite having an estimated 3000 animal operations that have the capacity for more than 1000 animal units. There are no provisions in their air quality rules and the only provision in the water quality rules is a requirement that operations using spray irrigation to apply manure must identify methods or practices that will be used to reduce potential odors. In practice, Iowa implements this provision by requiring that spray irrigation systems for manure utilize low flow nozzles.

6.2.2 Wyoming

Wyoming promulgated new water quality rules for addressing animal agricultural operations in 1999. The regulations were developed in response to 1997 legislation that required the state to develop standards that would require large swine feeding operations to develop “Waste and manure management plans to prevent pollution of waters of the state, to minimize odors for public health concerns, pathogens and vectors capable of transporting infectious diseases and to specify land application requirements.” The regulation further states that water quality permits for animal agricultural operations can be denied if the management plan does not incorporate Best Available Technology for the control of odors, pathogens, and vectors. Discussions with State of Wyoming staff responsible for implementing these regulations indicate that approximately twelve facilities are likely to be subject to these regulations. The cutoff date for the requirements is any facility that files a permit application request for an increase in capacity after February 28, 1997. To date, only several facilities have undergone the permitting process and been required to develop management plans. Typical measures that have been proposed by facilities and approved by the state include ensuring adequate lagoon depth to provide for an aerobic layer, installation of aerators in lagoons, and agreeing not to conduct spray irrigation during periods of high wind. The regulation in Wyoming is focused strictly on swine issues, even though Wyoming DEQ representatives indicated that complaints are received relative to beef operations as well as swine.

6.2.3 Missouri

Missouri is one of the states that have developed an air quality specific program approach. Promulgated in 1999, the regulation applies to all animal agricultural operations greater than 7000 animal units defined by the state as Class 1A Animal Feeding Operations. A total of 20 Class 1A operations currently exist in the state. These facilities were required by the state to submit odor control plans by July 1, 2000. These plans were required to contain the following elements:

1. A listing of all potentially innovative and proven odor control options for the facility. Odor control options may include odor reductions achieved through: odor prevention, odor capture and treatment, odor dispersion, add-on control devices, modifications to feed-stock or waste handling practices, or process changes.
2. A detailed discussion of feasible odor control options for the facility. The discussion shall include options determined by the facility to be infeasible. Determination of infeasibility should

be well documented and based on physical, chemical and engineering principles demonstrating that technical difficulties would preclude the success of the control option.

3. A ranking of feasible odor control options from most to least effective. Ranking factors shall include odor control effectiveness, expected odor reduction, energy impacts and economic impacts.
4. An evaluation of the most effective odor control options. Energy, environmental and economic impacts shall be evaluated on a case-by-case basis.
5. A description of the odor control options to be implemented by the facility.
6. A schedule for implementation.
7. An odor monitoring plan.

The format of this regulation mirrors that of federal regulations calling for application of Best Available Control Technology on major new industrial sources of air pollution.

All twenty of the sources required to submit plans have done so. The state is currently in the process of reviewing the plans. They are required by the regulation to review and either approve or disapprove them. The plans must be fully implemented by January 1, 2002. After this date an ambient odor standard of 5.4:1 dilutions applies to each Class 1A facility.

6.2.4 North Carolina

During the 1990s, North Carolina saw a massive increase in the numbers of animal agricultural operations. Currently, the state contains an estimated 10 million pigs, mostly concentrated in eastern North Carolina. In response to a growing number of complaints throughout the 1990s, North Carolina passed regulations to address the growing concerns in October 1999. Although these are strictly air quality regulations designed to address odors from swine facilities, their applicability is based on a definition of an "Animal Operation" derived from state water quality regulations. The definition limits applicability of the air quality regulations to operations that have liquid waste management systems in place. Five required management practices must be implemented by all facilities which meet the definition of an animal operation. These practices include:

1. The carcasses of dead animals shall be disposed of within 24 hours after becoming aware of the death of an animal.
2. Waste from animal wastewater application spray systems shall be applied in such a manner and under such conditions to prevent drift from the irrigation field of the wastewater spray beyond the boundary of the animal operation.
3. Animal wastewater application spray system intakes shall be located near the liquid surface of the animal wastewater lagoon.
4. Ventilation fans shall be maintained according to the manufacturer's specifications.
5. Animal feed storage containers located outside of animal containment buildings shall be covered except when necessary to remove or add feed.

Beyond these management practice requirements, certain swine operations fall under the regulation's complaint response and odor management program. Facilities fall under these provisions depending on their size and how far their property boundary is from an inhabitable structure, business, school, hospital, church, outdoor recreation facility, national/state park, historic property, or childcare center. Facilities meeting the thresholds for these provisions are required to submit an odor management plan to the North Carolina Air Quality Division that describes how odors are currently being controlled and how

these odors will be controlled in the future. Plans submitted for existing sources (in existence or began construction prior to February 28, 1999) receive no initial review from the Air Quality Division. Plans submitted for new sources are reviewed and approved prior to the initiation of construction.

The most significant component of the North Carolina regulation is its complaint response system. Under this system, when a citizen makes a complaint to the state, they are requested to utilize a form provided by the Air Quality Division to log complaints as well as weather conditions for a 30-day period. Once a copy of a complaint logbook is received by the Division, it is evaluated and prioritized based on the information in the logbook as well as other complaints that may have been received in the same location. Air Quality Division Regional office staff will then conduct a formal investigation of the complaint using the following guidelines:

1. The inspection will be scheduled, to the extent possible, during similar weather conditions and during the same time of day that the complainant has reported typical objectionable odor conditions.
2. When evaluating an existing animal operation (in operation prior to February 28, 1999), the odor observation is made at the point of residence or occupation of the complainant.
3. An odor “snapshot” is made by the evaluation team. Any odors are assigned a ranking by the inspector(s) using the following scale: 0=no odor; 1=perceptible; 2=faint; 3=easily noticeable; 4=strong; 5=very strong.
4. After investigation, an odor evaluation report is submitted by the inspectors to the Regional Supervisor.
5. The regional office submits a recommendation to the Division of Air Quality Director.
6. The Division of Air Quality Director makes the final decision of an objectionable odor.

An “objectionable odor” is actually established in the regulation as a standard, which is determined based on the complaints, the investigation and ultimately a determination by the DAQ Director. If a determination that an animal operation has caused an objectionable odor, the NCDAQ then calls for a Best Management Plan (BMP), which is essentially a revision of the original submitted plan. The BMP must be submitted within 90 days of receiving the notification that an objectionable odor has occurred. The DAQ has 30 days to review the plan for completeness and must approve or disapprove (and request further revision) within 90 days. Within 30 days after receiving approval, the operation must implement the components of the BMP. Within 60 days after the BMP has been fully implemented, the DAQ is required to make a determination of whether the BMP was implemented properly and is adequate to prevent objectionable odors. If not, the DAQ then notifies the operation that it is required to prepare and submit a revised BMP, which must be prepared and submitted under the same time schedules as described for the initial BMP above. If the revised plan fails to adequately control odors, the facility is required to install add-on control equipment and must submit a permit application for this installation within 90 days of receiving notification that their revised BMP was not adequate.

To date, approximately 25 animal operations have had objectionable odor determinations made against them. Each of these is currently in the process of providing Best Management Plans to the DAQ. Thus far, no operation has been taken to the final step in the process where add-on control technology is required.

6.2.5 Colorado

Colorado's regulations are probably the most stringent and proactive of any in the country. The regulations were promulgated in February 1999, in response to a referendum on the state ballot that required the development of regulations to address odor concerns from "Housed commercial swine feeding operations." The regulations apply to commercial swine operations greater than approximately 800 Animal Units. The regulations have several significant components, including ambient odor standards, control technology requirements, a requirement for a detailed odor management plan, minimum set-back distances and a requirement to obtain an air quality operating permit.

The ambient odor standards establish two separate concentration standards. A dilution standard of 7:1 applies at and beyond an operation's boundary and a dilution standard of 2:1 applies at any receptor, defined as an occupied dwelling, school, place of business or a municipal boundary. A dilution standard of 7:1 means that an air sample taken at a facility boundary and diluted with 7 equal volumes of fresh air, will be in violation of the standard if an odor can be detected in the diluted sample.

Control technology provisions of the regulations require that all anaerobic process wastewater vessels and impoundments must employ covers that "...capture, recover, incinerate, or otherwise manage odorous gases to minimize, to the greatest extent practicable, the emission of gases into the atmosphere." This control technology requirement applies at all new and existing facilities that meet the size thresholds of the rule. The required cover must completely cover the anaerobic process and have no uncontrolled vents. The regulations identifies two approved types of covers, which include rigid covers, such as geodesic domes, and synthetic covers made of reinforced polypropylene, high-density polyethylene, or other synthetic material, including geosynthetic membranes and geomembrane covers. Synthetic covers are required to have a minimum thickness of 40 mils. The regulation also allows for alternative covers to be used, if approved by the Colorado Air Pollution Control Division (APCD). In order to evaluate alternative covers, the APCD has developed a testing protocol to measure emissions from a covered lagoon or other impoundment.

The regulation establishes minimum setback distances for any new land waste application site of a new waste impoundment (lagoon). A minimum of a 1-mile setback must exist between either of these structures and any occupied dwelling, public or private school, or municipal boundary, unless the owner or governing body for any structure within a lesser distance provides written consent.

Permit requirements apply to all facilities subject to the regulation. Existing facilities were required to submit permit applications by April 15, 1999. Since then, the APCD has issued operating permits to 110 facilities. The permits establish requirements and compliance schedules for installation of covers and treatment equipment, when applicable, and require that an odor management plan be implemented as part of the permit. The odor management plan requirements state that the plan includes construction, design, and operation plans for odor controls and management practices, so that off-site odor emissions are minimized "to the greatest extent feasible." The plans must also identify the odor monitoring that the facility intends to conduct in order to ensure compliance with the odor standards identified above.

In addition to the requirements identified above, the Colorado regulation requires application of a specific set of work practice standards, designed to minimize odor emissions from:

1. Building ventilation.
2. Dust management.
3. Manure management.
4. Solid waste and process wastewater collection, storage and treatment systems.
5. Manure composting sites.
6. Land application.
7. Carcass disposal.

Discussions with representatives of Colorado's Air Pollution Control Division have indicated that most of the 110 facilities that are subject to the regulations have achieved substantial compliance with the rule. Some are on schedules under which they are still implementing measures to comply with the rule and some are having minor non-compliance issues.

6.2.6 Minnesota

Minnesota's current approach for addressing odors and air quality issues has two main components. First, the state has a two-component Ambient Air Quality Standard for hydrogen sulfide. The standards are:

1. 50 parts per billion ($70 \mu\text{g}/\text{m}^3$) as a ½ hour average, not to be exceeded over 2 times per year; and
2. 30 parts per billion ($42 \mu\text{g}/\text{m}^3$) as a ½ hour average, not to be exceeded more than 2 times in any 5 consecutive days.

This standard applies to all areas of the state. Minnesota's new animal agricultural regulations do not establish any control measures to specifically address hydrogen sulfide. Historically, exceedences of the standard that could be traced to a specific source would be addressed in the air quality permitting or enforcement processes.

Recently, the Minnesota Department of Health proposed an acute Inhalation Health Risk Value (HRV) for hydrogen sulfide of $8 \mu\text{g}/\text{m}^3$ as a 1-hour average. HRVs represent concentrations of chemicals emitted to air that are unlikely to pose a significant risk of harmful effects to humans. The HRVs are publicly reviewed, health-based criteria. In the case of hydrogen sulfide, the State Ambient Air Quality Standards actually provide a greater margin of protection than the HRV.

In addition to the hydrogen sulfide standard, Minnesota's new water quality regulations require facilities with a capacity to house more than 1000 animal units to include an Air Emission Plan in their water quality permit application. The plan must include:

1. Methods and practices that will be used to minimize air emissions.
2. Measures to be used to mitigate air emissions in the event of an exceedance of the state ambient hydrogen sulfide standard.
3. A complaint response protocol describing the procedures the owner will use to respond to complaints directed at the facility, including:
 - a. A list of each potential odor source at the facility.
 - b. A determination of the odor sources most likely to generate significant amounts of odors.
 - c. A list of anticipated odor control strategies for addressing each of the significant odor sources.

6.2.7 East Harris County Texas

The East Harris County Texas approach to addressing odors is a non-regulatory program that relies on an interaction between community citizens and the industrial sources in the area. This program is not specifically designed to address odors from animal agricultural facilities, but rather the many petroleum refining and other process chemical manufacturers in the area, which is home to the heavily industrialized Houston Shipping Channel and the nearby Bayport Industrial Complex. The area covers approximately 10,500 acres and is occupied by over 50 chemical companies engaged in producing, handling and storing numerous chemicals.

Many of the chemical companies in this area have historically undertaken community outreach efforts, in order to maintain communication between the community and the industry regarding issues of chemical releases, risks and what is being done to minimize risk. From these outreach efforts, a special community outreach program known as NONE, the Nuisance Odor Network, was developed in 1997 as an attempt to provide a mechanism for citizens to call in their odor complaints and have the complaints investigated immediately. The NONE program is operated completely by companies that are part of an organization of plant managers called the Association of Bayport Companies (ABC). NONE was formed by grouping the companies in the Bayport area into six distinct zones with one member company in each zone serving as the outreach center for the zone. Citizen's wishing to register an odor complaint call the closest outreach center. The outreach center will then contact other chemical plants in its zone and the other outreach centers. Through these contacts, NONE attempts to identify the source of the odors and respond back to the caller with this information and any additional follow up that occurred in response to the complaint. In addition, whenever a call is received and the network activated, NONE will notify the Harris County Pollution Control Department that an odor complaint has been received and is being investigated. If the source of the odor was determined, the plant where the odor originated will notify the Department with information concerning the odor.

While this system is very proactive on the part of industry, it is certainly not comprehensive in its ability to trace all odors. For a 1-year period from August 1998 through July 1999, a total of 173 complaints were registered, mainly concentrated in three of the six zones. Of these complaints, only 35 (20 percent) were traced to their sources.

It might be beneficial to consider the East Harris County non-regulatory approach for the animal agriculture industry in areas where numerous operations are in close proximity to each other. Although not fully understood relative to air emissions, the animal agricultural industry is certainly less complex than a congregation of over 50 petroleum and petrochemical plants. This aspect could lead to possibly a more successful record of tracing nuisance odors to their source. A program such as NONE would probably be most useful in an area of high concentration of animal agricultural operations.

6.3 COMPARISON OF REGULATORY PROGRAMS

Regardless of the specifics of any program approach, certain general aspects are common. These include ambient standards, applicability, prevention or control requirements, compliance monitoring/tracking and enforcement. Each of these is discussed relative to the air quality and odor programs described above and compared in a table format.

6.3.1 Ambient Standards

Historically in air quality programs, technology and work practice standards are designed to ensure that the ambient standards are met. There are currently national ambient standards for particulate matter, sulfur dioxide, oxides of nitrogen, ozone, lead and carbon monoxide. These standards apply throughout the country. Some states have also developed ambient standards for additional pollutants. For example, Minnesota has established an ambient air quality standard for hydrogen sulfide, even though the federal government has not promulgated an ambient standard for this pollutant. Ambient standards for odor are less common. Several of the more recent program approaches addressing animal agricultural facilities have incorporated ambient odor standards into their regulatory scheme, as shown below.

TABLE 6.1

**COMPARISON OF AMBIENT AND ODOR STANDARDS
APPLICABLE TO ANIMAL AGRICULTURE OPERATIONS**

Program	Description of Standard
Minnesota	H ₂ S Ambient Standard of 30 ppb as a 30-minute average. Facilities can claim exemption from standard when handling manure.
Iowa	None
Colorado	Odor standards of: 7:1 Dilutions at property boundary. 2:1 Dilutions at any off-site receptor. 6000:1 Dilution emission standard for lagoons using alternative covers.
Wyoming	None
Missouri	Ambient odor standard of 5.4 dilutions at facility boundary.
North Carolina	Odor identified as meeting the definition of "objectionable."

6.3.2 Applicability

The applicability of a program is generally the first stated component of a regulation, policy or program. Applicability can be established based on the size of a facility in terms of its production level or its emission level. With regard to animal agricultural operations, this is usually characterized in terms of the number of animal units at a facility or the capacity of a facility to handle a certain number of animal units. Applicability can also be determined based on the age of a facility. Generally new facilities are regulated more stringently than existing facilities. Applicability can also be defined based on the type of activity. For instance, some programs apply only to certain animal species, usually swine, while others are not limited to certain species.

TABLE 6.2

**COMPARISON OF APPLICABILITY PROVISIONS OF ODOR AND
AIR QUALITY REGULATIONS APPLICABLE TO
ANIMAL AGRICULTURE OPERATIONS**

Program	Applicability of Odor Provisions
Minnesota	All species, greater than or equal to 1000 A.U.
Iowa	Only facilities that utilize spray irrigation to spread liquid manure waste.
Colorado	Swine facilities only, greater than approximately 800 animal units.
Wyoming	Swine facilities only, that are designed for 1000 or more A.U.
Missouri	All species, greater than 7000 A.U.
North Carolina	Management practices required of all operations greater than approximately 100 A.U., only if they have liquid manure waste system. Additional requirements required based on size and distance to neighboring property.

6.3.3 PREVENTION/MITIGATION REQUIREMENTS

The main focus of most regulatory programs are the actual control, prevention, or management practice provisions that facilities are required to implement. These are the program components that generally receive the most scrutiny during their development. The range of requirements varies significantly throughout the country. Some programs require virtually nothing in terms of odor prevention or control. At the other end of the spectrum, Colorado has established a detailed and extensive list of control measures and management practices that some animal agricultural facilities must implement. Table 6.3 below identifies the various prevention and mitigation requirements of the state regulations compared in this evaluation.

TABLE 6.3
COMPARISON OF PREVENTION/MITIGATION REQUIREMENTS
APPLICABLE TO ANIMAL AGRICULTURE OPERATIONS

Program	Prevention or Mitigation Requirements
Minnesota	Air Emission Plan required as part of water quality permit application. Plan must include methods to minimize air emissions, methods to mitigate any H ₂ S standard exceedences and a complaint response protocol. Minimum set backs also established.
Iowa	Low flow nozzles are required on spray irrigation systems.
Colorado	Cover and control required on all anaerobic process wastewater vessels and impoundments. Approved covers are listed. Alternative covers can be used if they meet an emission standard. 1-mile setbacks to any neighbor unless the affected neighbor approves less. Air Quality Operating permits are required which must also include an Odor Management Plan.
Wyoming	Requires Odor Management plan as part of water quality permit. Plan requires that description of "Procedures and methods to control odors from animal confinement areas, lagoons, animal waste storage facilities and land application sites."
Missouri	Odor Control Plans were required to be submitted by 7/1/2000. Plans required to identify all sources of odor and detail how emissions will be addressed.
North Carolina	Five listed management practices required for all animal operations greater than 100 A.U. Odor management plans required to be submitted with water quality permit application. Plans required to describe how odors are currently being controlled and how they will be controlled in the future. Complaints trigger evaluation to determine compliance with "Objectionable Odor" standard.

6.3.4 COMPLIANCE MONITORING AND TRACKING

Without provisions to ensure that implementation of regulatory requirements has actually occurred, a program with even very stringent requirements can prove ineffective at minimizing air quality concerns. Table 6.4 below identifies the compliance tracking requirements of the state regulations compared in this evaluation.

TABLE 6.4

COMPARISON OF COMPLIANCE MONITORING AND TRACKING REQUIREMENTS APPLICABLE TO ANIMAL AGRICULTURE OPERATIONS

Program	Compliance Tracking Mechanism
Minnesota	Specific monitoring or reporting provisions not contained in rule. Inspections and complaint responses to be carried out by county or state agency staff.
Iowa	Complaints received based only on odors receive no response. If water quality or set back issue is raised in complaint, state inspectors will investigate.
Colorado	Initial compliance test required within 180 days of permit issuance. Semi-annual ambient odor testing and any control equipment performance testing is also required. Semi-annual deviation reports required to be submitted to state.
Wyoming	No specific provisions described in program. Inspections of facilities subject to complaints are carried out by state agency staff.
Missouri	Interim progress reports on status of implementation of odor control plans required by March 1, 2001. Full compliance with odor control plan required by January 1, 2002. Subsequently, state may require 2-year ambient air monitoring program if it believes the odor standard is being violated.
North Carolina	System is driven by complaints. Review of an Odor Management Plan does not take place until a complaint is received. Following receipt of complaints, State District Offices evaluate odors and make recommendation of whether facility has created an "Objectionable Odor." Once declared, the facilities Odor Management Plan must be revised. If plan revisions do not result in improvements, ultimately addition of odor control and abatement equipment is to be required.

6.3.5 ENFORCEMENT/IMPLEMENTATION STATUS

Because the increased awareness and activity related to odors and air emissions from animal agricultural facilities has been very recent, most of the programs that have been developed to address these concerns are in their infancy. Very little enforcement activity has taken place as noted in the table below.

TABLE 6.5

COMPARISON OF ENFORCEMENT/IMPLEMENTATION STATUS OF REGULATIONS APPLICABLE TO ANIMAL AGRICULTURE OPERATIONS

Program	Enforcement/Implementation Status
Minnesota	Current permits have been issued based on previous plan submittals.
Iowa	No enforcement actions taken on air quality issues.
Colorado	To date, all 110 facilities subject to rule have been issued permits with control requirements. Facilities are in the process of installing/implementing control measures. Several minor violations have been observed. No formal enforcement action taken.
Wyoming	Regulations state that a permit can be denied if Best Available Technology (BAT) is not used to control odors. To date, only a small number of facilities have been subject to the BAT requirements through the permitting process.
Missouri	Twenty facilities in the state were subject to the requirements for Control Plan submittal by 7/1/2000. All facilities have submitted plans. State has completed a completeness review of all plans and is currently in the process of carrying out detailed technical reviews.
North Carolina	Odor Management Plan review by the Air Program is only initiated upon receipt of complaints. In approximately 2 years since adoption of standards, approximately 25-30 facilities have had "Objectionable Odor" declarations made. These facilities are undergoing plan review and update. No formal legal enforcement action has been taken to date against any facility.

6.4 LESSONS AND IMPLICATIONS FOR THE MINNESOTA PROGRAM

While in some ways more comprehensive, the Minnesota program for addressing air quality and odors from animal agricultural operations is typical of other recently developed programs in the following respects. It utilizes existing authorities for issuing water quality permits as a mechanism for requiring air quality measures, while at the same time recognizing the need for additional measures to address the increased potential for air quality and odor concerns at animal agricultural facilities. In contrast North Carolina, Colorado and Missouri all have programs for addressing air and odor issues using dedicated air quality rules. Missouri and Colorado incorporate strategies that are typical of how a state would regulate industrial sources of pollution, such as a manufacturing plant or a power utility boiler facility. Missouri's approach is similar to Minnesota's in that the main component of the odor management procedure is the development of a plan that each facility must develop on a case by case basis and utilize to minimize odor emissions. Missouri's program does go somewhat further than Minnesota's in prescribing that add-on control technology, in addition to management practices, should be utilized to reduce odors, if it has been shown to be feasible in a top down control technology analysis. Colorado goes even further than both Minnesota and Missouri in requiring that control technology and specified management practices be employed at animal agricultural facilities. North Carolina, takes a somewhat more unique strategy in designing a regulatory program that is driven largely by community complaints. The ultimate success of these and other recent program approaches in addressing concerns over odors and air quality has yet to be determined. They are either currently still in the initial stages of implementing new regulations or have only recently begun to evaluate the effect of new regulations on odor concerns. Follow up evaluation of

these programs over the next several years should yield valuable information on their long-term effectiveness.

While Minnesota's program for addressing air quality and odor concerns is not the most stringent, it shouldn't be concluded that it will not be as effective in minimizing odor and air quality concerns. It should provide the Minnesota Pollution Control Agency with sufficient flexibility to fit the specific control measures required at a particular facility to the specific aspects of the operation and the level of local concern and complaint regarding odors at the facility.

Generally, one of the early phases of any environmental regulatory effort is the collection and analysis of data on the levels of environmental release generated by an industry category. The purpose of this phase is to identify whether additional regulation of an industry is warranted, and if so, to identify what aspects of the industry and to what level the regulations should focus. Relative to air quality and the animal agricultural industry, there is much data that still needs to be gathered to better characterize the sources of air emissions and their ultimate impact on air quality. While more prescriptive air emission control measures may prove to be warranted for various aspects of animal agricultural operations, these measures will have to be based on sufficient background data.

With the exception of the East Harris County, all of the programs evaluated here are regulatory programs. Beyond these strict regulatory programs, flexible incentive programs can also provide mechanisms for emission reduction in the animal agricultural industry. These programs are not designed to establish specific regulatory standards such as emission or ambient air limits, but instead provide incentive for facilities to reduce emissions by providing financial benefits or more flexible operation if emissions are reduced. Examples of these types of programs are identified in Section 5.6 of the Technical Work Paper for Human Health Issues. These programs are also discussed in greater detail in a very recent US EPA report on using economic incentives for protecting the environment (US EPA, 2001).

7.0 CONSEQUENCES OF TRENDS

During the last decade, animal agriculture has undergone significant changes in terms of the number of facilities operating and the size of a typical facility. This section discusses the trend toward larger, more concentrated animal agricultural operations and how this trend could affect air quality and odor issues and their control.

7.1 IDENTIFICATION OF THE TRENDS

The trends in the animal agricultural industry have been identified and discussed in numerous sections of the Literature Summaries for the GEIS. These trends include a decrease in the numbers of farms and an increase in the size of individual farms. A third trend has been the increase in the extent of contract farming, i.e., processors or large producers contracting with smaller farms to raise animals. The trends have not occurred consistently throughout the country, nor across the various sectors of the animal agricultural industry. In Minnesota these trends have shown their greatest extent in the hog industry, where the number of hogs sold grew from just over 9 million in 1992 to nearly 13 million in 1997, but the number of hog farms decreased from 13,749 to 7,717 during the same period. The use of contract raising is most predominant in the poultry industry. It is estimated that more than 70 percent of the value of poultry is currently raised under a production contract, where the figure is estimated at 33 percent for hogs and 10 percent for cattle.

7.2 CONSEQUENCES OF THE TRENDS

As farm size and animal concentration increase, there is an increased potential for odor and air quality concerns to be raised by members of the local community. All other factors being equal, the increase in numbers alone dictates that more pollution can be generated by a larger operation than a smaller one. It is also documented that the numbers of complaints and volume of citizen concern regarding these facilities has risen in recent years. Some of this increased concern may be a reaction to the social and economic dislocation associated with the shift to larger, more industrialized farming, although it is not possible to identify whether or not this is a significant factor. Most of the complaints center on odor and nuisance issues and many citizens are becoming more vocal about their concerns and in some cases are organizing grass-roots efforts to promote more stringent control of animal operations. These efforts have led to increased regulation of animal agricultural operations in several states, most notably Colorado, where a very stringent air quality regulation was passed in 1999. A notable aspect of the Colorado and several other regulations is their treatment of animal agricultural operations as more traditional industrial point sources of pollution.

An increase in the size and concentration of an animal operation does not necessarily mean that an increase in odor and air pollution will result. Other factors, including the type of waste handling and the management practices employed are very important to determining the extent of odor and other air emissions. These factors are not related to size. Establishing more comprehensive management practices that result in fewer odor and air quality concerns.

To date, extensive study of the effect of various factors, such as size and varying management practices on the levels of odor and other air emissions has not occurred. In addition, there is a gap in federal policy regarding air emissions from animal agricultural facilities. In 1998, U.S. EPA released a draft unified strategy for addressing environmental and human health impacts from animal feeding operations. Although the strategy noted in its introduction that air quality and odors represent a significant concern,

there is virtually no mention of air quality or odors in the listings of specific policy directives. The policy focuses nearly exclusively on water quality concerns.

Regulation of air emissions from this industry is at a cross-roads. Historically, the farming industry has been treated like a small or area source and has not been subjected to the kind of study and regulation that a traditional large industry has been. But farms are getting bigger and becoming more industrialized and the continued increase in size and concentration of animal operations is likely to lead to more and more public concern over their health and environmental impacts. To allay concerns, it will likely be necessary to treat these operations in the same manner as a manufacturing industry. Steps in developing a more comprehensive air program for addressing animal agriculture facilities would include the following:

- Fill data gaps in the demographic feedlot information for a number of heavily agricultural counties.
- Monitor research efforts nationally and internationally to gain a better understanding of air emissions from animal agriculture facilities in order to develop a more reliable set of emission estimating tools for the various species of animal agriculture operations.
- Develop a comprehensive state-wide emissions inventory of criteria air pollutants, toxic air contaminants, and odorous air pollutants; this inventory would help establish some perspective of the magnitude of emissions associated with the animal agriculture industry in relation to other regulated and non-regulated sources of air emissions in the state.
- Enhance the usefulness of the Minnesota Pollution Control Agency's Incident Management System database system by adding fields to prompt MPCA officials to gather more information on odor descriptors and weather conditions, which would yield a more effective odor management system that would focus on the odor 'episode' (location/citizen, duration, frequency) in addition to the odor 'source'.
- Conduct additional ambient air monitoring focused on defining the impact of animal agriculture facilities, especially to define concentrations of volatile organic compounds downwind of animal agriculture facilities as well as at appropriate "background" locations. Considerable effort has been devoted to measuring hydrogen sulfide concentrations downwind of animal agriculture facilities; however, collection of ambient hydrogen sulfide concentration data in a variety of locations would help to establish a 'background' level and help determine the contribution of feedlots to that background level.
- Evaluate new facility designs, management practices, and control equipment to determine their cost-effectiveness in preventing or reducing emissions from animal agriculture facilities. The top-down BACT type of approach used by Missouri and described in Section 6 provides a well established and effective method to carry out these evaluations.
- Monitor the effectiveness of regulatory and non-regulatory programs recently implemented in other states to determine their suitability as models for implementation in Minnesota.
- Implement flexible incentive programs to provide non-regulatory mechanisms for reducing air emissions and odors.

8.0 REFERENCES

8.1 REFERENCES CITED

- Asman W.A.H. *Ammonia Emissions in Europe: Updated Emission and Emission Variations*. National Institute of Public Health and Environmental Protection. Bilthoven, The Netherlands. July (1989).
- Asman W.A.H. E.F. Pinstorboer, J.F.M. Maas, J.W. Erisman, A. Waijer-Ypelaan, J. Slanina. *Gradients of the Ammonia Concentration in a Nature Reserve: Model Results and Measurements*. Atmospheric Environment. 23(10): 2259-2265. (1989)
- Asman W.A.H. *Factors Influencing Local Dry Deposition of Gases with Special Reference to Ammonia*. Atmospheric Environment. 32(3):415-421. (1998)
- Battye R., W. Battye, C. Overcash, and S. Fudge. *Developments and Selection of Ammonia Emission Factors*, prepared for the U.S. Environmental Protection Agency. (1994).
- Beauchamp R.O., J.S. Bus, J.A. Popp, C.J. Boreiko, D.A. Andjelkovich. *A Critical Review of the Literature on Hydrogen Sulfide Toxicity*. CRC Critical Reviews in Toxicology. 13(1):25-57. (1984)
- Bouwman A.F., K.W. Van Der Hoek. *Scenarios of Animal Waste Production and Fertilizer use and Associated Ammonia Emission for the Developing Countries*. Atmospheric Environment. 31:4095-4102. (1997)
- Bubenick D.V. *Acid Rain Information Book*. Noyes Publications. Park Ridge, NJ. Second Edition. p.95 (1984)
- Bundy D., B. Cote, A. Sutton. *Performance Standard for the Implementation of Colorado Air Quality Control Commission's Regulation No. 2, Part B, Section IV.A. Anaerobic Process Wastewater Vessels and Impoundments*. Housed Commercial Swine Feeding Operation Baseline Panel. August (2000).
- Carpenter G.A., J.T. Fryer. *Dust in Livestock Buildings: Review of Some Aspects*. Journal of Agricultural Engineering Research. 46(3):171-186. ill. (1990).
- Chiba L.I., E.R. Peo, A.J. Lewis, M.C. Brumm, R.D. Fritschen, J.D. Crenshaw. *Effects of Dietary Fat on Pig Performance and Dust Levels in Modified-Open-Front and Environmentally Regulated Confinement Buildings*. Journal of Animal Science. 61(4):763-781. ill. (1985).
- Chiumenti R., F. da Borso, L. Donantoni. *Dust and Ammonia Reductions in Exhaust Air from Piggeries Using a Mechanical Wet Separation System*. In: Hall JE, editor. Animal Waste Management. Rome Italy: FAO. p 301-307. (1994).
- Clanton C.J., D.R. Schmidt, L.D. Jaconson, R.E. Nicolai, P.R. Goodrich, K.A. Janni. *Swine Manure Storage Covers for Odor Control*. Applied Engineering in Agriculture (in press).

- DeBode M.J.C. *Minimizing Dust in Livestock Buildings: Possible Alternatives to Mechanical Separation*. Journal of Agricultural Engineering Research 47(4):235-248. (1990).
- Dong L., A.J. Heber, J.A. Patterson, B.R. Strobel, D.D. Jones, A.L. Sutton. *Bioscrubber for Removing Ammonia from Swine House Exhaust Air*. In: Voermans JA, Monteny G, editors. Proc. of the Intl. Symp. on Ammonia and Odour Control from Animal Production Facilities Vinkeloord, The Netherlands. Rosmalen, The Netherlands: NVTL. 2:93-110. (1997).
- Earth Tech, Inc. *Technical Work Paper For Human Health Issues Animal Agriculture Generic Environmental Impact Statement*. Minnesota Planning Department - Environmental Quality Board, St Paul, MN. (2000)
- ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals). *Ammonia Emissions to Air in Western Europe*. Brussels (Technical Report No. 62). (1994) (Cited in Environment Canada 2000).
- European Environment Agency. *Environment in the European Union at the Turn of the Century*. Chapter 3.4 Transboundary Air Pollution. European Environment Agency. p. 133-154. (2000)
- Fekete K.E., L. Gyenes. *Regional Scale Transport Model for Ammonia and Ammonium*. Atmospheric Environment. 27A:1099-1104. (1993)
- Fouche G.E. *The Data Management System Developed to Implement North Carolina's New Agricultural Odor Rules*. Proceedings of the AW&MA Annual Meeting. Salt Lake City, UT. June (2000).
- Giddens J. *Contamination of Water by Air Pollutants, Especially Ammonia from Animal Manures*. Department of Agronomy, University of Georgia, Athens Georgia. (1975). (Cited in Environment Canada 2000).
- Godbout S., S.P. Lemaay, R. Joncas, J.P. Larouche, D.Y. Martin, M. Leblanc, A. Marquis, J.F. Bernier, R.T. Zijlstra, E.M. Barber and D. Masse. *Reduction of Odour and Gas Emissions from Swine Buildings using Canola Oil Sprinkling and Alternative Diets*. Proc. of the 2nd International Conference on Air Pollution from Agricultural Operations. Des Moines IA. October 9-11, 2000. p. 211-219.
- Heber, A.J. *Analysis of Ambient Hydrogen Sulfide Concentrations Near A Hog Production Facility*. Executive Summary of Final Report to B&S research, Purdue University. <http://danpatch.ecn.purdue.edu/~odor/exesum6.html>. Site last visited February, 2001.
- Heber, A.J., Jiqin Ni, Teng Teeh Lim, and Alan L. Sutton. *Effect of Monsanto's Manure Additive (Alliance) Used in Swine Finishing Buildings on Indoor Air Quality and Emissions of Ammonia and Hydrogen Sulfide*. <http://danpatch.ecn.purdue.edu/~odor/exesum>. Site last visited February 2001.

- 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. *Manure Treatment to Reduce Gas Emissions from Large Swine Houses*. In. Voermans JAM, Monteny G, editors. *Procs. of the Intl. Symp. on Ammonia and Odor Control from Animal Production Facilities Vindeloord, The Netherlands*. Rosmalen, The Netherlands: NVTL. 2:449-457. (1997).
- Heber A.J., C.R. Martin. *Effect of Additives on Aerodynamic Segregation of Dust from Swine Feed*. *Transactions of the ASAE* 31(2):558-63. (1988).
- Hobbs P.J., T.H. Misselbrook, T.R. Cumby. *Production and Emission of Odours and Gases from Aging Pig Waste*. *Journal of Agricultural Engineering Research* 72(3):291-298. (1999).
- Hoeksma P., n. Verdoes, F.J. Monteny. *Two Options for Manure Treatment to Reduce Ammonia Emission from Pig Housing*. In: M.W.A. Versteegen, L.A. den Hartog, G.J.M van Kempen en J.H.M Metz (eds): *Nitrogen flow in pig production and environmental consequences*. *Procs. of the First International Symposium*, Wageningen, The Netherlands. p. 301-306. (1993).
- Hoff S.J., L. Dong, X.W. Li, D.S. Bundy, J.D. Harmon. *Odor Removal using Biomass Filters*. In: Bottcher R.W., Hoff S.J., editors. *Livestock Environment: 5th International Symposium*. Bloomington, MN. St. Joseph, MI: American Society of Agricultural Engineers. I. p. 101-108. (1997).
- Hutchinson G. F. Viets. *Nitrogen Enrichment of Surface Water by Absorption of Ammonia Volatilized from Cattle Feedlots*. *Science* 166:514-515. (1969) (Cited in Environment Canada 2000).
- Jacobson L.D., et.al. *Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to Air Quality and Odor (H)*. University of Minnesota. St. Paul, MN: (1999).
- Jacobson L.D., H. Guo, D.R. Schmidt, R.E. Nicolai. *Calibrating Inpuff-2 by Resident-Panelists for Long-Distance Odor Dispersion from Animal Feedlots*. . *Procs. of the 2nd International Conference on Air Pollution from Agricultural Operations*. Des Moines IA. October 9-11, p. 278-285. (2000).
- Janni K., L.D. Jacobson, J. Bicudo, D. Schmidt. *Livestock and Poultry Odor Workshop*. University of Minnesota. St. Paul, MN. Feb 10,17,24. (2000).
- Kershner D.L., P.E. Dougherty. *Law and Policy for Feedlot*. A report on the ABA-Special Committee on Agricultural Management Roundtable on Environmental Issues in Animal Feedlots. Council for Agricultural Science and Technology. <http://www.cast-science.org/9711aba2.htm>. Site last visited December (2000).
- Kiryuchuk, S., K. Donham, S. Reynolds, L. Burmeister, E. Barber, P. Thorne, A. Senthilselvan, R. Rautiainen. *Oil/Water Sprinkling Intervention in a Swine Building*. *Procs. of the International Symposium on Dust Control in Animal Production Facilities*. Scandinavian Congress Center, Aarhus. May 30 to June 2. (1999).

- Lais S. E. Hartung, T. Junbluth. *Reduction of Ammonia and Odour Emissions by Bioscrubbers*. In: Voermans JAM, Monteny g, editors. *Procs. of the Intl. Symp. on Ammonia and Odour Control from Aniamal Production Facilities Vindeloord, The Netherlands*. Rosmalen, The Netherlands: NVTL.2.2. p. 533-536. (1997).
- Luebs, R., K. Davis, A. Laag. *Enrichment of the Atmosphere with Nitrogen Compounds Volatilized from a Large Dairy Area*. *J. Environ. Qual.* 3(1):137-141. (1973) (Cited in Environment Canada 2000).
- Moller F. *Stovreduktion I Stalde ve Ionisering. (Dust Reduction by Ionization)*. In: SJF Orientering nr 74. Bygholm, 8700 Horsens, Denmark: National Institute of Agricultural Engineering.
- MPCA *Staff Paper on Air Toxics*. Initial Report. Minnesota Pollution Control Agency. St. Paul, MN: November (1999).
- National Research Council, Division of Medial Sciences Assembly of Life Sciences. Subcommittee on Ammonia. *Ammonia*. National Research Council. University Park Press. Baltimore, MD. P. 11-19, 21-39, 67-77.(1979)
- Ni J., A.J. Herber, R.K. Duggirala, B.L. Haymore, C.A. Dielhl. *Ammonia Emissions from a Large Mechanically-Ventilated Swine Building During Warm Weather*. St. Joseph, Mich.: American Society of Agricultural Engineers. ASAE Paper No. 98-4051. (1998).
- North Carolina Agricultural Research Service. *Options for Managing Odor*. Report from the Swine Odor Task Force. <http://www.mtcnet.net/~jdhogg/ozone/odor/swineodor.html>. March (1995) Site late visited on December , 2000.
- Pearson C.C. *Air Cleaning with Wet Scrubbers*. *Farm Buildings and Engineering*. 6(2):36-39. (1989).
- Pratt G. *Dispersion Modeling Analysis of Air Emissions from Feedlots in Nine Townships in West-Central Minnesota*. St. Paul, MN: Minnesota Pollution Control Agency Air Quality Division. (1998).
- Oliaei F. *Minnesota Air Quality and Emissions Trends*. Minnesota Pollution Control Agency. St. Paul, MN. <http://www.pca.state.mn.us/air/pubs/agtrends.pdf> 137-147. Sit last accessed December (2000).
- Priem R. *Deodorization by Means of Ozone*. *Agriculture and Environment*. 3(2/3):227-237. (1997).
- Quinn P.K., R.J. Charlson, T.S. Bates. *Simultaneous observations of Ammonia in the Atmosphere and Ocean*. *Nature*. 335: 336-338. (1988).
- Rom H.B., F. Moller, P.J., Dahl, M., Levring. *Diet Composition and Modified Climatic Properties – Means to Reduce Ammonia Emission in Fattening Pig Unit*. *Procs. of the 2nd International Conference on Air Pollution from Agricultural Operations*. Des Moines IA. October 9th, p. 108-115. (2000).

- Ruan R., W. Han, A. Ning, P.L. Chen, P.R. Goodrich. *Reduction of Harmful Gases and Odorous Compounds by Non-Thermal Plasma*. St. Joseph, MI: American Society of Agricultural Engineers. ASAE Paper No. 97-4038. (1997).
- Safely L.M., M.E. Casada. *Global Methane Emissions from Livestock and Poultry Manure*. United States Environmental Protection Agency. Document 400/1-91/048. (1992).
- Sciences International, Inc. *Draft: Toxicological Profile for Hydrogen Sulfide*. U.S. Department of Health and Human Services. Public Health Service Agency for Toxic Substances and Disease Registry. September. (1997)
- Seedorf J., J. Hartung, M. Schroder, K.H. Linkert, V.R. Phillips, M.R. Holden, R.W. Sneath, J.L. Short, R.P. White, S. Pedersen. *Concentrations and Emissions of Airborne Endotoxins and Microorganisms in Livestock Buildings in Northern Europe*. Journal of Agricultural Engineering Research 70(1):97-109. (1998).
- Sutton A.L., K.B. Kephart, M.W.A. Verstegen, T.T. Canh, P.J. Hoobs. *Potential for Reduction of Odorous Compounds in Swine Manure Through Diet Modification*. Journal of Animal Science 77:430-439. (1999).
- Sullivan J., Boesel G., Criswell R., Larkin A., Leezer D. *MPCA Feedlot Air Quality Summary: Data Collection, Enforcement, and Program Development*. Minnesota Pollution Control Agency. St. Paul, MN: March (1999).
- Sullivan J., Personal Communication. Minnesota Pollution Control Agency. St. Paul, MN: November (2000)
- Sullivan J., Personal Communication. Minnesota Pollution Control Agency. St. Paul, MN: January (2001)
- Sweeten J.M. *Odor and Dust from Livestock Feedlots*. Texas A&M University System. <http://www.agen.tamu.edu/users/rel/agair/Sweeten/OdorandDust.pdf> Site last accessed December (2000).
- Takai H., L.D. Jacobson, S. Pedersen. *Reduction of Dust Concentration and Exposure in Pig Buildings by Adding Animal Fat in Feed*. Journal of Agricultural Engineering Research 63(2):113-120. (1996).
- Takai H., S. Pedersen, J.O. Johnsen, J.H.M. Metz, P.W.G.G. Koerkamp, G.H. Uenk, V.R. Phillips, M.R. Holden, R.W. Sneath, J.L. and J.L. Short. *Concentration and Emission of Airborne Dust in Livestock Buildings in Northern Europe*. Journal of Agricultural Engineering Research 70(1):59-77. (1998).
- USEPA. *Air Emission Models for Waste and Wastewater*. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, EPA-453/R-94-080A. (1994).
- USEPA *The United States Experience with Economic Incentives for Protecting the Environment*. Office of Policy, Economics, and Innovation. EPA-240-R-01-002, January, 2001.

- Voermans J.A.M., N. Verdoes, J.J.J. Smeets. *Possibilities of Ammonia Reduction of Sow Farms*. In: Conference Proceedings: International Conference on Air Pollution from Agricultural Operations. Kansas City, MO. Ames, IA: Mid West Plan Service. 119-125. (1996).
- WEF. *Toxic Air Emissions from Wastewater Treatment Facilities*. Water Environment Federation, Alexandria, VA, p 202. (1995).
- WHO. *Ammonia*. Geneva. Environmental Health Criteria. World Health Organization. p 209. (1986) (Cited in Environment Canada 2000).
- WHO. *Hydrogen Sulfide*. Environmental Health Criteria. World Health Organization. P.15-17. (1981)
- Zhang Y, W. Gaakeer. *A Low Cost Balloon-Type Lagoon Cover to Reduce Odour Emission*. In: Conference Proceedings: International Conference on Air Pollution from Agricultural Operations. Kansas City, MO. Ames, IA: Mid West Plan Service. 395-401. (1996).
- Zhang Y., A. Tanaka, E.M. Barber, F.F. R. Feddes. *Effects of Frequency and Quantity of Sprinkling Canola Oil on Dust Reduction in Swine Buildings*. Transactions of the ASAE 39(3):1077-1081. (1996).
- Zhu J., L.D. Jacobson, D.R Schmidt, R. Nicolai. *Evaluation of INPUFF-2 Model for Predicting Downwind Odors from Animal Production Facilities*. Applied Engineering in Agriculture. 16(2):159-164. (2000).
- Zhu J., D. Schmidt, L.S. Jacobson, R.E. Nicolai. *Daily Variations in Odor and Gas Emissions from Animal Facilities*. Unpublished.

8.2 LITERATURE SUMMARY UPDATE

This literature summary update was compiled from a review of the most recent published animal agriculture air quality research and from contacts made with researchers and authors associated with the most promising animal feedlot odor and air quality research programs. This compilation includes a list of the most recent and promising research cited in this Technical Work Paper (TWP), as well as other relevant animal feedlot odor and air quality literature that was not included in the Summary of the Literature Related to Airy Quality and Odor that was recently prepared as a part of the Generic Environmental Impact Statement on Animal Agriculture in 1999.

1.0 Executive Summary

There were no additional sources of information relevant to this section that were not included in the initial Literature Summary.

2.0 Odor Complaints

Sullivan J., Personal Communication. Minnesota Pollution Control Agency. St. Paul, MN: November (2000)

3.0 Air Quality Data

MPCA Staff Paper on Air Toxics. Initial Report. Minnesota Pollution Control Agency. St. Paul, MN: November (1999).

Sullivan J., Boesel G., Criswell R., Larkin A., Leezer D. *MPCA Feedlot Air Quality Summary: Data Collection, Enforcement, and Program Development*. Minnesota Pollution Control Agency. St. Paul, MN: March (1999).

4.0 Environmental Fate

Asman W.A.H. *Factors Influencing Local Dry Deposition of Gases with Special Reference to Ammonia*. Atmospheric Environment. 32(3):415-421. (1998)

Asman W.A.H. E.F. Pinstorboer, J.F.M. Maas, J.W. Erisman, A. Waijer-Ypelaan, J. Slanina. *Gradients of the Ammonia Concentration in a Nature Reserve: Model Results and Measurements*. Atmospheric Environment. 23(10): 2259-2265. (1989)

Beauchamp R.O., J.S. Bus, J.A. Popp, C.J. Boreiko, D.A. Andjelkovich. *A Critical Review of the Literature on Hydrogen Sulfide Toxicity*. CRC Critical Reviews in Toxicology. 13(1):25-57. (1984)

Bouwman A.F., K.W. Van Der Hoek. *Scenarios of Animal Waste Production and Fertilizer use and Associated Ammonia Emission for the Developing Countries*. Atmospheric Environment. 31:4095-4102. (1997)

Bubenick D.V. *Acid Rain Information Book*. Noyes Publications. Park Ridge, NJ. Second Edition. p.95 (1984)

Earth Tech, Inc. *Technical Work Paper For Human Health Issues Animal Agriculture Generic Environmental Impact Statement*. Minnesota Planning Department - Environmental Quality Board, St Paul, MN. (2000)

ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals. *Ammonia Emissions to Air in Western Europe*. Brussels (Technical Report No. 62). (1994) (Cited in Environment Canada 2000).

Environment Canada. *Priority Substances List Assessment Report Ammonia in the Aquatic Environment*. Canadian Environmental Protection Act. May (2000).

European Environment Agency. *Environment in the European Union at the Turn of the Century*. Chapter 3.4 Transboundary Air Pollution. European Environment Agency. p. 133-154. (2000)

Fekete K.E., L. Gyenes. *Regional Scale Transport Model for Ammonia and Ammonium*. Atmospheric Environment. 27A:1099-1104. (1993)

Giddens J. *Contamination of Water by Air Pollutants, Especially Ammonia from Animal Manures*. Department of Agronomy, University of Georgia, Athens Georgia. (1975). (Cited in Environment Canada 2000).

Hutchinson G. F. Viets. *Nitrogen Enrichment of Surface Water by Absorption of Ammonia Volatilized from Cattle Feedlots*. Science 166:514-515. (1969) (Cited in Environment Canada 2000).

Luebs, R., K. Davis, A. Laag. *Enrichment of the Atmosphere with Nitrogen Compounds Volatilized from a Large Dairy Area*. J. Environ. Qual. 3(1):137-141. (1973) (Cited in Environment Canada 2000).

Moller, D. H. Schieferdecker. *A Relationship Between Agricultural NH₃ Emissions and the Atmospheric SO₂ Content Over Industrial Areas*. Atmospheric Environment. 19(5):695-700. (1985) (Cited in Environment Canada 2000).

National Research Council, Division of Medical Sciences Assembly of Life Sciences. Subcommittee on Ammonia. *Ammonia*. National Research Council. University Park Press. Baltimore, MD. P. 11-19, 21-39, 67-77.(1979)

Oliaei F. Minnesota Air Quality and Emissions Trends. Minnesota Pollution Control Agency. St. Paul, MN. <http://www.pca.state.mn.us/air/pubs/agtrends.pdf> 137-147. Site last accessed December (2000).

Quinn P.K., R.J. Charlson, T.S. Bates. *Simultaneous observations of Ammonia in the Atmosphere and Ocean*. Nature. 335: 336-338. (1988).

Sciences International, Inc. *Draft: Toxicological Profile for Hydrogen Sulfide*. U.S. Department of Health and Human Services. Public Health Service Agency for Toxic Substances and Disease Registry. September. (1997)

Sweeten J.M. *Odor and Dust from Livestock Feedlots*. Texas A&M University System. <http://www.agen.tamu.edu/users/rel/agair/Sweeten/OdorandDust.pdf> Site last accessed December (2000).

WHO. *Ammonia*. Geneva. Environmental Health Criteria. World Health Organization. p 209. (1986) (Cited in Environment Canada 2000).

WHO. *Hydrogen Sulfide*. Environmental Health Criteria. World Health Organization. P.15-17. (1981)

5.0 Dispersion Modeling Feasibility Evaluation

Aneja, V.P., I.P. Cauhan, and J.T. Walker. *Characterization of Atmospheric Ammonia Emissions from Swine Storage and Treatment Lagoons*. Journal of Geophysical Research, 105(D0):11,535-11,545. (2000).

Ashbaugh L., N. Freitas, T. James, R. Flochini. *Ammonia Emissions from a Large Dairy in California's San Joaquin Valley*. Proceedings of the A&WMA Specialty Conference "Emission Inventory: Living in a Global Environment." New Orleans, LA. December (1998).

Auvermann B.W., Romanillos A. *Effect of Stocking Density Manipulation on Fugitive PM₁₀ Emissions from Cattle Feedyards*. Proceedings of the AW&MA Annual Meeting. Salt Lake City, UT. June (2000).

- Baidoo, S.K. *Environmental Impact of Swine, Poultry Nutrition Discussed*. Feedstuffs. p. 12-14. June (2000).
- Brewer, S.K., T.A. Costello. *In-Situ Measurement of Ammonia Volatilization from Broiler Litter Using an Enclosed Air Chamber*. Transactions of the American Society of Agricultural Engineers, St. Joseph, MI. p. 8. (1999)
- Corsi R.L., V.M. Torres, S. Fredenberg, M. Dondelle, K. Dombrowski, S. Takahama, T. Taylor, S. Anderson. *A Screening Assessment of Non-Point Source Ammonia Emission in Texas*. Proceedings of the AW&MA Annual Meeting. Salt Lake City, UT. June (2000).
- Elam C.J., J.W. Algeo, T. Westing, L. Hokit. *Measurement and Control of Feedlot Particulate Matter*. Bulletin C. How to Control Feedlot Pollution. California Cattle Feeders Association, Bakersville, CA. January (1971).
- Gharib S., G.R. Cass. *Ammonia Emissions in the South Coast Air Basin 1984*. Open File Report 84-2, Environmental Quality Laboratory, California Institute of Technology. Pasadena, CA. (1984).
- Godbout S., S.P. Lemay, R. Joncas, J.P. Larouche, D.Y. Martin, M. Leblanc, A. Marquis, J.F. Bernier, R.T. Zijlstra, E.M. Barber, D. Masse. *Reduction of Odour and Gas Emissions from Swine Buildings using Canola Oil Sprinkling and Alternative Diets*. Procs. of the 2nd International Conference on Air Pollution from Agricultural Operations. Des Moines IA. p. 211-219. October 9-11 (2000).
- Guarino, M., A. Casoli, P. Navarotti. *Dust Concentration and Mortality Distribution in an Enclosed Laying House*. Transactions of the American Society of Agricultural Engineers. 42(4):1127-1133.
- Hoeksma P., N. Verdoes, F.J. Monteny. *Two Options for Manure Treatment to Reduce Ammonia Emission from Pig Housing*. In: M.W.A. Verstegen, L.A. den Hartog, G.J.M van Kempen en J.H.M Metz (eds): Nitrogen flow in pig production and environmental consequences. Procs. of the First International Symposium,. Wageningen, The Netherlands. p. 301-306. (1993).
- Hutchinson, G.L., A.R. Mosier, C.E. Andre. *Ammonia and Amine Emissions from a Large Cattle Feedlot*. Journal of Environmental Quality. 11(2): 288-293. (1982).
- Jacobson L.D., H. Guo, D.R. Schmidt, R.E. Nicolai. *Calibrating INPUFF-2 by Resident-Panelists for Long-Distance Odor Dispersion from Animal Feedlots*. Procs. of the 2^d International Conference on Air Pollution from Agricultural Operations. Des Moines IA. October 9-11, p. 278-285. (2000).
- James T.N., L. Freitas, L. Ashbaugh, and D. Meyer. *Field Estimates of Ammonia Volatilization from Cattle Production Facilities*. In: Emission Inventory: Planning for the Future, Air & Waste Management Association. Pittsburgh, PA. p. 259-267. (1997).
- Janni K., L.D. Jacobson, J. Bicudo, D. Schmidt. *Livestock and Poultry Odor Workshop*. University of Minnesota. St. Paul, MN. February (2000).

- Kiryuchuk, S., K. Donham, S. Reynolds, L. Burmeister, E. Barber, P. Thorne, A. Senthilselvan, R. Rautiainen. *Oil/Water Sprinkling Intervention in a Swine Building*. Proc. of the International Symposium on Dust Control in Animal Production Facilities. Scandinavian Congress Center, Aarhus. May 30 to June 2. (1999).
- Luebs, R.E., K.R. Davis, A.E. Laag. *Diurnal Fluctuation and Movement of Atmospheric Ammonia and Related Gases from Dairies*. Journal of Environmental Quality, 3(3): 265-269. (1974).
- McGinn, S. *Strategies for Reducing Odour from Feedlots and During Land Application Manure*. Southern Alberta Beef Review. 2(2): April 2000.
- Ni, J.Q., A.J. Heber, T.T. Lim, and C.A. Diehl. *Continuous Measurement of Hydrogen Sulfide Emission from Two Large Swine Finishing Buildings*. Paper No. 9941342, ASAE/CSAE International Meeting, Toronto. American Society of Agricultural Engineers, St. Joseph, MI. p. 15 (1999).
- Ni, J.W., A.J. Heber, K.J. Fakhoury, P. Shao, A.L. Sutton, D. Kelley, J. A. Patterson, and S.T. Kim. *Laboratory Measurement of Hydrogen Sulfide and Sulfur Dioxide Releases from Swine Manure of Different Solids Content*. Paper No. 004082, ASAE International Meeting, Milwaukee, WI. American Society of Agricultural Engineers, St. Joseph, MI. p. 13. (2000)
- Peters, J.A., T.R. Blackwood. *Source Assessment: Beef Cattle Feedlots*. EPA-600/ 2-77-107, U.S. Environmental Protection Agency, Research Triangle Park, NC. p. 101. June (1977).
- Rom H.B., F. Moller, P.J., Dahl, M., Levring. *Diet Composition and Modified Climatic Properties – Means to Reduce Ammonia Emission in Fattening Pig Unit*. Proc. of the 2nd International Conference on Air Pollution from Agricultural Operations. Des Moines IA. October 9th, p. 108-115. (2000).
- Schmidt C.E., J. Lester, E. Winegar. *Assessment of PM₁₀ Precursor Air Emissions from Dairy Industry Livestock Waste in Southern California*. Journal of Air and Waste Management Association. In review (1997).
- Stowell, R.R., S. Foster, H. Keener, D. Elwell. *Ammonia Emissions from a High-Rise Swine Finishing Facility*. Paper No. 004080, ASAE International Meeting, Milwaukee, WI. American Society of Agricultural Engineering, St. Joseph, MI. p. 13. (2000).
- Sweeten J.M., N.A. Cole, D.B. Parker, B.W. Auvermann. *Particle Size Distribution of Cattle Feedlot Dust Emissions*. Transactions of the American Society of Agricultural Engineers. 41(5):1447-1481. (1998).
- Sweeten J.M., L. Erickson, P. Woodford, C.B. Parnell, K. Thu, T. Coleman, R. Flocchini, C. Reeder, J. R. Master, W. Hambleton, G. Bluhm, D. Tristao. *Air Quality Research and Technology Transfer White Paper and Recommendations for Concentrated Animal Feeding Operations*. USDA Agricultural Air Quality Task Force. Washington D.C.. July (2000).
- Tanaka, A. *Effects of Finished Compost Used for a Part of Amendments on Composting*. Paper No. 004077, ASAE International Meeting, Milwaukee, WI. American Society of Agricultural Engineers, St. Joseph, MI. p.9. (2000).

Warn T.E., S. Zelmanowitz, and M. Saeger. 1990. *Development and Selection of Ammonia Emission Factors for the 1985 NAPAP Emissions Inventory*. EPA-600/7-90-014. Prepared by the U.S. Environmental Protection Agency, Washington D. C. for the National Acid Precipitation Assessment Program. June (1990).

Zhu J., L.D. Jacobson, D.R Schmidt, R. Nicolai. *Evaluation of INPUFF-2 Model for Predicting Downwind Odors from Animal Production Facilities*. *Applied Engineering in Agriculture*. 16(2):159-164. (2000).

6.0 Programmatic Approaches

Bundy D., B. Cote, A. Sutton. *Performance Standard for the Implementation of Colorado Air Quality Control Commission's Regulation No. 2, Part B, Section IV.A. Anaerobic Process Wastewater Vessels and Impoundments*. Housed Commercial Swine Feeding Operation Baseline Panel. August (2000)

Fouche G.E. *The Data Management System Developed to Implement North Carolina's New Agricultural Odor Rules*. Proceedings of the AW&MA Annual Meeting. Salt Lake City, UT. June (2000).

Kershen D.L., P.E. Dougherty. *Law and Policy for Feedlot*. A report on the ABA-Special Committee on Agricultural Management Roundtable on Environmental Issues in Animal Feedlots. Council for Agricultural Science and Technology. <http://www.cast-science.org/9711aba2.htm>. Site last visited December (2000)

North Carolina Agricultural Research Service. *Options for Managing Odor*. Report from the Swine Odor Task Force. <http://www.mtcnet.net/~jdhogg/ozone/odor/swineodor.html>. March (1995) Site late visited on December 2000.

7.0 Consequences of Trends

There were no additional sources of information relevant to this section that were not included in the initial Literature Summary.

APPENDIX A

**EMISSION FACTORS USED IN COMPILATION OF
AIR POLLUTANT EMISSION FACTORS**

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Swine Feedlots

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor	Information Source
All	manure treatment lagoon	305 to 4017 FgN/m ² /min		Aneja et al., 2000
Boars > 50 kg	stable + storage	3.18 kg NH ₃ /animal/yr	X	Asman, 1992
Boars > 50 kg	Spreading	3.8 kg NH ₃ /animal/yr	X	Asman, 1992
Breeding Sows >50 kg	stable + storage	8.09 kg NH ₃ /animal/yr	X	Asman, 1992
Breeding Sows >50 kg	spreading	8.04 kg NH ₃ /animal/yr	X	Asman, 1992
Breeding Sows 20-50 kg	stable + storage	2.42 kg NH ₃ /animal/yr	X	Asman, 1992
Breeding Sows 20-50 kg	spreading	2.8 kg NH ₃ /animal/yr	X	Asman, 1992
Composite Swine		8.512 kg NH ₃ /animal/yr	X	Asman, 1992
Fattening Pigs	stable + storage	3.18 kg NH ₃ /animal/yr	X	Asman, 1992
Fattening Pigs	Spreading	3.8 kg NH ₃ /animal/yr	X	Asman, 1992
Finishing	underfloor liquid manure storage	13 g/day/head		Ni et al., 1999
Finishing	solid manure handling	41 g/day/head		Stowell et al., 2000
Finishing		0.028 lb/pig place/day		Ni et al, 1998
Finishing	litter	1429-3751 mg/500 kg/hr		Groot Koerkamp et al., 1998
Finishing	litter	2076-2592 mg/500 kg/hr		Groot Koerkamp et al., 1998
Hogs & pigs		5.6 kg/head/yr		Corsi et al., 2000
Mature Boars	stable + storage	5.52 kg NH ₃ /animal/yr	X	Asman, 1992
Mature Boars	spreading	5.48 kg NH ₃ /animal/yr	X	Asman, 1992
Other Sows	stable + storage	8.09 kg NH ₃ /animal/yr	X	Asman, 1992
Other Sows	spreading	8.04 kg NH ₃ /animal/yr	X	Asman, 1992
Pig		1.5 kg/pig/yr		Clark and McQuitty, 1987
Pig	fully slatted	24.0 lb/ 1000 lbwt/yr		Hartung, 1994
Pig	partly slatted	43.4 lb/1000 lbwt/yr		Hartung, 1994
Pig	liquid	15.0 lb/1000 lbwt/yr		Hartung, 1994
Pig	bedding	3.4 lb/1000 lbwt/yr		Hartung, 1994
Pig	fully slatted	13 lb/1000 pigs/day		Heber et al., 1997
Pig	lagoon	10.5, 6.2, 4.9 kg/ha/day		Harper, 1998
Sows		0.40 lb/sow place/day		Collins, 1990
Sows	litter	744-3248 mg/500 kg/hr		Groot Koerkamp et al., 1998
Sows	slats	1049-1701 mg/500 kg/hr		Groot Koerkamp et al., 1998
Swine	ranging	17.69 kg/animal/yr		1985 NAPAP
Swine	confined	1.95 kg/animal/yr		1985 NAPAP
Swine		2.8 kg NH ₃ /animal/yr		Buijsman et al., 1987
Swine		3.35 kg NH ₃ /animal/yr		1990 NAPAP
Weaners	slats	649-1562 mg/500 kg/hr		Groot Koerkamp et al., 1998

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Swine Feedlots

Hydrogen Sulfide (H₂S) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Farrowing		5.5 ug/s/m ²	X	Zhu, 1998
Finishing	underfloor liquid manure storage	6.3 mg/head/day	X	Ni et al., 1999
Finishing	naturally ventilated	0.00033 lb/day/pig place	X	Heber et al., 1997
Finishing	deep-pitted liquid manure storage	0.16 lb/day/pig place		Hobbs et al., 1999
Finishing	deep-pitted liquid manure storage	0.0015 lb/day/pig place	X	Ni et al, 1998
Finishing	Facility Total (Generic)	7.4 ug/s/m ²	X	Zhu, 1998
Generic	pit barn	3.36E-6 to 2.93E-5 g/m2/s		Gantzer
Generic	open basins	2.60E-5 to 2.36E-4 g/m2/s		Gantzer
Gestation		0.7ug/s/m ²	X	Zhu, 1998
Nursery		7.4 ug/s/m ²	X	Zhu, 1998

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Swine Feedlots

Methane (CH₄) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Swine		20.0 kg CH ₄ /animal/yr	X	Safley and Casada, 1992

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Swine Feedlots

Particulate Matter (PM) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Fatteners (PM<5um)	litter (England Study)	73 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM<5um)	litter (Denmark Study)	69 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM<5um)	slats (England Study)	133 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM<5um)	slats (Netherlands Study)	40 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM<5um)	slats (Denmark Study)	57 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM<5um)	slats (Germany Study)	34 mg/h/500 kg	X	Takai et al., 1998
Sows (PM<5um)	litter (England Study)	49 mg/h/500 kg	X	Takai et al., 1998
Sows (PM<5um)	litter (Germany Study)	46 mg/h/500 kg	X	Takai et al., 1998
Sows (PM<5um)	slats (England Study)	13 mg/h/500 kg	X	Takai et al., 1998
Sows (PM<5um)	slats (Netherlands Study)	18 mg/h/500 kg	X	Takai et al., 1998
Sows (PM<5um)	slats (Denmark Study)	141 mg/h/500 kg	X	Takai et al., 1998
Sows (PM<5um)	slats (Germany Study)	19 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM<5um)	slats (England Study)	60 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM<5um)	slats (Netherlands Study)	122 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM<5um)	slats (Denmark Study)	51 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM<5um)	slats (Germany Study)	69 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM>5um)	litter (England Study)	561 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM>5um)	litter (Denmark Study)	890 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM>5um)	slats (England Study)	895 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM>5um)	slats (Netherlands Study)	418 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM>5um)	slats (Denmark Study)	604 mg/h/500 kg	X	Takai et al., 1998
Fatteners (PM>5um)	slats (Germany Study)	532 mg/h/500 kg	X	Takai et al., 1998
Sows (PM>5um)	litter (England Study)	144 mg/h/500 kg	X	Takai et al., 1998
Sows (PM>5um)	litter (Germany Study)	753 mg/h/500 kg	X	Takai et al., 1998
Sows (PM>5um)	slats (England Study)	121 mg/h/500 kg	X	Takai et al., 1998
Sows (PM>5um)	slats (Netherlands Study)	151 mg/h/500 kg	X	Takai et al., 1998
Sows (PM>5um)	slats (Denmark Study)	949 mg/h/500 kg	X	Takai et al., 1998
Sows (PM>5um)	slats (Germany Study)	162 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM>5um)	slats (England Study)	687 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM>5um)	slats (Netherlands Study)	1309 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM>5um)	slats (Denmark Study)	1364 mg/h/500 kg	X	Takai et al., 1998
Weaners (PM>5um)	slats (Germany Study)	724 mg/h/500 kg	X	Takai et al., 1998

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Swine Feedlots

Endotoxin Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Fattening Pigs		5.2 ug/hr/500 kg	X	Seedorf et al., 1998
Sows		3.7 ug/hr/500kg	X	Seedorf et al., 1998
Weaners		8.9 ug/hr/500 kg	X	Seedorf et al., 1998
Fattening Pigs		49.8 ug/hr/500 kg	X	Seedorf et al., 1998
Sows		37.4 ug/hr/500 kg	X	Seedorf et al., 1998
Weaners		66.6 ug/hr/500 kg	X	Seedorf et al., 1998

Recommended Swine Emission Factors Corroborated by Other References

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	US EPA NH ₃ Report	University of Minnesota Literature Survey
Hogs and Pigs -Composite		20.3kg NH3/animal/yr	Asman, 1992	X	X	
Boars > 50 kg	Stable + storage	3.18 kg NH3/animal/yr	Asman, 1992	X	X	
Boars > 50 kg	Spreading	3.8 kg NH3/animal/yr	Asman, 1992	X	X	
Breeding Sows >50 kg	Stable + storage	8.09 kg NH3/animal/yr	Asman, 1992	X	X	
Breeding Sows >50 kg	Spreading	8.04 kg NH3/animal/yr	Asman, 1992	X	X	
Breeding Sows 20-50 kg	Stable + storage	2.42 kg NH3/animal/yr	Asman, 1992	X	X	
Breeding Sows 20-50 kg	Spreading	2.8 kg NH3/animal/yr	Asman, 1992	X	X	
Fattening Pigs	Stable + storage	3.18 kg NH3/animal/yr	Asman, 1992	X	X	
Fattening Pigs	Spreading	3.8 kg NH3/animal/yr	Asman, 1992	X	X	
Mature Boars	Stable + storage	5.52 kg NH3/animal/yr	Asman, 1992	X	X	
Mature Boars	Spreading	5.48 kg NH3/animal/yr	Asman, 1992	X	X	
Other Sows	Stable + storage	8.09 kg NH3/animal/yr	Asman, 1992	X	X	
Other Sows	Spreading	8.04 kg NH3/animal/yr	Asman, 1992	X	X	

Recommended Swine Emission Factors Corroborated by Other References

Hydrogen Sulfide (H₂S) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Farrowing		0.00078 lb/day/pig place	Zhu, 1998		X
Finishing	underfloor liquid manure storage	6.3 mg/head/day	Ni et al., 1999	X	X
Finishing	naturally ventilated	0.00033 lb/day/pig place	Heber et al., 1997		X
Finishing	deep-pitted liquid manure storage	0.0015 lb/day/pig place	Ni et al, 1998	X	X
Finishing		0.001 lb/day/pig place	Zhu, 1998		X
Gestation		0.0001 lb/day/pig place	Zhu, 1998		X
Nursery		0.0065 lb/day/pig place	Zhu, 1998		X

Recommended Swine Emission Factors Corroborated by Other References

Methane (CH₄) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Swine		20.0 kg CH ₄ /animal/yr	Safley and Casada, 1992	X	X

Recommended Swine Emission Factors Corroborated by Other References

Particulate Matter (PM) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Fatteners (PM<5um)	litter (England Study)	73 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM<5um)	litter (Denmark Study)	69 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM<5um)	slats (England Study)	133 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM<5um)	slats (Netherlands Study)	40 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM<5um)	slats (Denmark Study)	57 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM<5um)	slats (Germany Study)	34 mg/h/500 kg	Takai et al., 1998		X
Sows (PM<5um)	litter (England Study)	49 mg/h/500 kg	Takai et al., 1998		X
Sows (PM<5um)	litter (Germany Study)	46 mg/h/500 kg	Takai et al., 1998		X
Sows (PM<5um)	slats (England Study)	13 mg/h/500 kg	Takai et al., 1998		X
Sows (PM<5um)	slats (Netherlands Study)	18 mg/h/500 kg	Takai et al., 1998		X
Sows (PM<5um)	slats (Denmark Study)	141 mg/h/500 kg	Takai et al., 1998		X
Sows (PM<5um)	slats (Germany Study)	19 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM<5um)	slats (England Study)	60 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM<5um)	slats (Netherlands Study)	122 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM<5um)	slats (Denmark Study)	51 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM<5um)	slats (Germany Study)	69 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM>5um)	litter (England Study)	561 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM>5um)	litter (Denmark Study)	890 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM>5um)	slats (England Study)	895 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM>5um)	slats (Netherlands Study)	418 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM>5um)	slats (Denmark Study)	604 mg/h/500 kg	Takai et al., 1998		X
Fatteners (PM>5um)	slats (Germany Study)	532 mg/h/500 kg	Takai et al., 1998		X
Sows (PM>5um)	litter (England Study)	144 mg/h/500 kg	Takai et al., 1998		X
Sows (PM>5um)	litter (Germany Study)	753 mg/h/500 kg	Takai et al., 1998		X
Sows (PM>5um)	slats (England Study)	121 mg/h/500 kg	Takai et al., 1998		X
Sows (PM>5um)	slats (Netherlands Study)	151 mg/h/500 kg	Takai et al., 1998		X
Sows (PM>5um)	slats (Denmark Study)	949 mg/h/500 kg	Takai et al., 1998		X
Sows (PM>5um)	slats (Germany Study)	162 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM>5um)	slats (England Study)	687 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM>5um)	slats (Netherlands Study)	1309 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM>5um)	slats (Denmark Study)	1364 mg/h/500 kg	Takai et al., 1998		X
Weaners (PM>5um)	slats (Germany Study)	724 mg/h/500 kg	Takai et al., 1998		X

Recommended Swine Emission Factors Corroborated by Other References

Endotoxin Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Fattening Pigs		5.2 ug/hr/500 kg	Seedorf et al., 1998		X
Sows		3.7 ug/hr/500kg	Seedorf et al., 1998		X
Weaners		8.9 ug/hr/500 kg	Seedorf et al., 1998		X
Fattening Pigs		49.8 ug/hr/500 kg	Seedorf et al., 1998		X
Sows		37.4 ug/hr/500 kg	Seedorf et al., 1998		X
Weaners		66.6 ug/hr/500 kg	Seedorf et al., 1998		X

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Beef and Dairy Feedlots

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor
Beef (Confined)		0.77 kg NH ₃ /Animal/Yr	
Beef (Ranging)		20.14 kg NH ₃ /Animal/Yr	
Breeding Bulls >2 years	Stable & Storage	10.58 kg NH ₃ /Animal/Yr	X
Breeding Bulls >2 years	Spreading	17.33 kg NH ₃ /Animal/Yr	X
Breeding Bulls >2 years	Grazing	0 kg NH ₃ /Animal/Yr	X
Beef Cattle		5.9 kg NH ₃ /Animal/Yr	
Beef Cows		15 kg NH ₃ /hd/yr	
Cattle		18.0 kg NH ₃ /Animal/Yr	
Cattle		87.6 lbs NH ₃ /hd/year	
Cattle		48.9 lbs NH ₃ /hd/year	
Cattle		11-25 lbs NH ₃ /hd/year	
Cattle	Feedlots	18 lbs NH ₃ /hd/yr	
Cattle	Litter	371-900 mg NH ₃ /500kg/hr	
Cattle	Slats	346-686 mg NH ₃ /500kg/hr	
Cattle		74 +130 lbs NH ₃ /hd/year	
Dairy Cows	Cubicles	842-1,769 mg NH ₃ /500kg/hr	
Dairy Cows	Feedlots	30 lbs NH ₃ /hd/yr	
Dairy Cows	Free-Stall	11.2 +1.1 kg NH ₃ /head/month	
Dairy Cows	Free-Stall	24 lbs/hd/yr - 227 lbs NH ₃ /hd/yr	
Dairy (Confined)		12.25 kg NH ₃ /Animal/Yr	
Dairy (Ranging)		20.41 kg NH ₃ /Animal/Yr	
Dairy Cows	Free-stall Dairy barns	7-13 g NH ₃ /LU/day	
Dairy Cows	Litter	260-890 mg NH ₃ /500/kg/hr	
Dairy Cows	Manure Stockpiles	11.2 + 4.2 kg NH ₃ /cow/year	
Dairy and Calf Cows	Stable & Storage	12.87 kg NH ₃ /Animal/Yr	X
Dairy and Calf Cows	Spreading	21.09 kg NH ₃ /Animal/Yr	X
Dairy and Calf Cows	Grazing	5.76 kg NH ₃ /Animal/Yr	X
Generic Cows		22 kg NH ₃ /hd/yr	
Fattening Calves	Stable & Storage	1.6 kg NH ₃ /Animal/Yr	X
Fattening Calves	Spreading	3.63 kg NH ₃ /Animal/Yr	X
Fattening Calves	Grazing	0 kg NH ₃ /Animal/Yr	X
Fattening/Grazing Cattle >2 yr	Stable & Storage	0kg NH ₃ /Animal/Yr	X
Fattening/Grazing Cattle >2 yr	Spreading	0kg NH ₃ /Animal/Yr	X
Fattening/Grazing Cattle >2 yr	Grazing	18.8 kg NH ₃ /Animal/Yr	X
Young Cattle	Stable & Storage	3.87 kg NH ₃ /Animal/Yr	X
Young Cattle	Spreading	6.34 kg NH ₃ /Animal/Yr	X
Young Cattle	Grazing	2.83 kg NH ₃ /Animal/Yr	X
Young Cattle for Fattening	Stable & Storage	0 kg NH ₃ /Animal/Yr	X
Young Cattle for Fattening	Spreading	0 kg NH ₃ /Animal/Yr	X
Young Cattle for Fattening	Grazing	8.22 kg NH ₃ /Animal/Yr	X

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Beef and Dairy Feedlots

Hydrogen Sulfide (H₂S) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor
Dairy Cows	Naturally Vented Free-Stall Dairy Barns	0.4 ug/s/m ² (average)	X

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Beef and Dairy Feedlots

Methane (CH₄) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor
Cattle	Feedlots	23.0 kg CH ₄ /animal/yr	X
Dairy	Feedlots	70.0 kg CH ₄ /animal/yr	X
Dairy	Pasture/Feedlot	10 MCF	
Dairy	Pasture/Feedlot	0.3MCF	
Dairy	Liquid Slurry	20-90 MCF	
Dairy	Liquid Slurry	55.3 MCF	
Dairy	Solid	10 MCF	
Dairy	Solid	45.7 MCF	

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Beef and Dairy Feedlots

Particulate Matter (PM) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor
Beef (PM>5um)	Litter (England Study)	PM>5um 36 mg/h 500 kg wt	X
Beef (PM>5um)	Slats (Netherlands Study)	PM>5um 144 mg/h 500 kg wt	X
Beef (PM>5um)	Slats (Denmark Study)	PM>5um 78 mg/h 500 kg wt	X
Beef (PM>5um)	Litter (Germany Study)	PM>5um 135 mg/h 500 kg wt	X
Beef (PM>5um)	Slats (Germany Study)	PM>5um 117 mg/h 500 kg wt	X
Calves (PM>5um)	Litter (England Study)	PM>5um 64 mg/h 500 kg wt	X
Calves (PM>5um)	Slats (Netherlands Study)	PM>5um 63mg/h 500 kg wt	X
Calves (PM>5um)	Litter (Denmark Study)	PM>5um 190 mg/h 500 kg wt	X
Calves (PM>5um)	Litter (Germany Study)	PM>5um 192 mg/h 500 kg wt	X
Calves (PM>5um)	Slats (Germany Study)	PM>5um 142 mg/h 500 kg wt	X
Cattle	Feedyards	127 kg TSP (1,000 hd)/day	
Cattle	Feedyards	32 kg PM10 (1,000 hd)/day	
Dairy (PM>5um)	Litter (England Study)	PM>5um 142 mg/h 500 kg wt	X
Dairy (PM>5um)	Slats (England Study)	PM>5um 21mg/h 500 kg wt	X
Dairy (PM>5um)	Litter (Netherlands Study)	PM>5um 60 mg/h 500 kg wt	X
Dairy (PM>5um)	Slats (Netherlands Study)	PM>5um 216 mg/h 500 kg wt	X
Dairy (PM>5um)	Litter (Denmark Study)	PM>5um 79 mg/h 500 kg wt	X
Dairy (PM>5um)	Slats (Denmark Study)	PM>5um 115 mg/h 500 kg wt	X
Dairy (PM>5um)	Litter (Germany Study)	PM>5um 76 mg/h 500 kg wt	X
Dairy (PM>5um)	Slats (Germany Study)	PM>5um 338 mg/h 500 kg wt	X
Beef (PM<5um)	Litter (England Study)	PM<5um 26 mg/h 500 kg wt	X
Beef (PM<5um)	Slats (Netherlands Study)	PM<5um 29 mg/h 500 kg wt	X
Beef (PM<5um)	Slats (Denmark Study)	PM<5um 5 mg/h 500 kg wt	X
Beef (PM<5um)	Litter (Germany Study)	PM<5um 6 mg/h 500 kg wt	X
Beef (PM<5um)	Slats (Germany Study)	PM<5um 7 mg/h 500 kg wt	X
Calves (PM<5um)	Litter (England Study)	PM<5um 28 mg/h 500 kg wt	X
Calves (PM<5um)	Slats (Netherlands Study)	PM<5um 17 mg/h 500 kg wt	X
Calves (PM<5um)	Litter (Denmark Study)	PM<5um 14 mg/h 500 kg wt	X
Calves (PM<5um)	Litter (Germany Study)	PM<5um 22 mg/h 500 kg wt	X
Calves (PM<5um)	Slats (Germany Study)	PM<5um 40 mg/h 500 kg wt	X
Dairy (PM<5um)	Litter (England Study)	PM<5um 84 mg/h 500 kg wt	X
Dairy (PM<5um)	Slats (England Study)	PM<5um 18 mg/h 500 kg wt	X
Dairy (PM<5um)	Litter (Netherlands Study)	PM<5um 13 mg/h 500 kg wt	X
Dairy (PM<5um)	Slats (Netherlands Study)	PM<5um 54 mg/h 500 kg wt	X
Dairy (PM<5um)	Litter (Denmark Study)	PM<5um 9 mg/h 500 kg wt	X
Dairy (PM<5um)	Slats (Denmark Study)	PM<5um 13 mg/h 500 kg wt	X
Dairy (PM<5um)	Litter (Germany Study)	PM<5um 6 mg/h 500 kg wt	X
Dairy (PM<5um)	Slats (Germany Study)	PM<5um 29 mg/h 500 kg wt	X

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Beef and Dairy Feedlots

Endotoxin Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor
Beef (Endotoxins >5um)		3.7 ug/h 500 kg wt	X
Calves (Endotoxins >5um)		21.4 ug/h 500 kg wt	X
Cows (Endotoxins >5um)		2.9 ug/h 500 kg wt	X
Sows (Endotoxins >5um)		37.4 ug/h 500 kg wt	X
Beef (Endotoxins <5um)		5um 0.6 ug/h 500 kg wt	X
Calves (Endotoxins <5um)		2.7ug/h 500 kg wt	X
Cows (Endotoxins <5um)		0.3 ug/h 500 kg wt	X
Sows (Endotoxins >5um)		3.7ug/h 500 kg wt	X

Recommended Beef and Dairy Emission Factors Corroborated by Other References

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	US EPA NH ₃ Report	University of Minnesota Literature Survey
Dairy and Calf Cows	Stable & Storage	12.87 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Dairy and Calf Cows	Spreading	21.09 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Dairy and Calf Cows	Grazing	5.76 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Fattening Calves	Stable & Storage	1.6 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Fattening Calves	Spreading	3.63 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Fattening Calves	Grazing	0 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Fattening/Grazing Cattle >2 yr	Stable & Storage	0kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Fattening/Grazing Cattle >2 yr	Spreading	0kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Fattening/Grazing Cattle >2 yr	Grazing	18.8 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Young Cattle	Stable & Storage	3.87 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Young Cattle	Spreading	6.34 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Young Cattle	Grazing	2.83 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Young Cattle for Fattening	Stable & Storage	0 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Young Cattle for Fattening	Spreading	0 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Young Cattle for Fattening	Grazing	8.22 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	

Recommended Cattle and Dairy Emission Factors Corroborated by Other References

Hydrogen Sulfide (H₂S) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Dairy Cows	Naturally Vented Free-Stall Dairy Barns	0.4 ug/s/m ² (average)	Zhu, 1998		X

Recommended Dairy/Beef Emission Factors Corroborated by Other References

Methane (CH₄) Emission Factors

				USDA Report	University of Minnesota Literature Survey
Animal Description	Management Practice	Representative Emission Factor	Source of Information		
Cattle	Feedlots	23.0 kg CH ₄ /animal/yr	Safley and Casada, 1992	X	X
Dairy	Feedlots	70.0 kg CH ₄ /animal/yr	Safley and Casada, 1992	X	X

Recommended Dairy/Beef Emission Factors Corroborated by Other References

Particulate Matter (PM) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Beef (PM>5um)	Litter (England Study)	PM>5um 36 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM>5um)	Slats (Netherlands Study)	PM>5um 144 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM>5um)	Slats (Denmark Study)	PM>5um 78 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM>5um)	Litter (Germany Study)	PM>5um 135 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM>5um)	Slats (Germany Study)	PM>5um 117 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM>5um)	Litter (England Study)	PM>5um 64 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM>5um)	Slats (Netherlands Study)	PM>5um 63mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM>5um)	Litter (Denmark Study)	PM>5um 190 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM>5um)	Litter (Germany Study)	PM>5um 192 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM>5um)	Slats (Germany Study)	PM>5um 142 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Litter (England Study)	PM>5um 142 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Slats (England Study)	PM>5um 21mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Litter (Netherlands Study)	PM>5um 60 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Slats (Netherlands Study)	PM>5um 216 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Litter (Denmark Study)	PM>5um 79 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Slats (Denmark Study)	PM>5um 115 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Litter (Germany Study)	PM>5um 76 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM>5um)	Slats (Germany Study)	PM>5um 338 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM<5um)	Litter (England Study)	PM<5um 26 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM<5um)	Slats (Netherlands Study)	PM<5um 29 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM<5um)	Slats (Denmark Study)	PM<5um 5 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM<5um)	Litter (Germany Study)	PM<5um 6 mg/h 500 kg wt	Takai et al., 1998		X
Beef (PM<5um)	Slats (Germany Study)	PM<5um 7 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM<5um)	Litter (England Study)	PM<5um 28 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM<5um)	Slats (Netherlands Study)	PM<5um 17 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM<5um)	Litter (Denmark Study)	PM<5um 14 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM<5um)	Litter (Germany Study)	PM<5um 22 mg/h 500 kg wt	Takai et al., 1998		X
Calves (PM<5um)	Slats (Germany Study)	PM<5um 40 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Litter (England Study)	PM<5um 84 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Slats (England Study)	PM<5um 18 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Litter (Netherlands Study)	PM<5um 13 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Slats (Netherlands Study)	PM<5um 54 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Litter (Denmark Study)	PM<5um 9 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Slats (Denmark Study)	PM<5um 13 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Litter (Germany Study)	PM<5um 6 mg/h 500 kg wt	Takai et al., 1998		X
Dairy (PM<5um)	Slats (Germany Study)	PM<5um 29 mg/h 500 kg wt	Takai et al., 1998		X

Recommended Dairy/Beef Emission Factors Corroborated by Other References

Endotoxin Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Beef (Endotoxins >5um)		3.7 ug/h 500 kg wt	Seedorf et al., 1998		X
Calves (Endotoxins >5um)		21.4 ug/h 500 kg wt	Seedorf et al., 1998		X
Cows (Endotoxins >5um)		2.9 ug/h 500 kg wt	Seedorf et al., 1998		X
Sows (Endotoxins >5um)		37.4 ug/h 500 kg wt	Seedorf et al., 1998		X
Beef (Endotoxins <5um)		5um 0.6 ug/h 500 kg wt	Seedorf et al., 1998		X
Calves (Endotoxins <5um)		2.7ug/h 500 kg wt	Seedorf et al., 1998		X
Cows (Endotoxins <5um)		0.3 ug/h 500 kg wt	Seedorf et al., 1998		X
Sows (Endotoxins >5um)		3.7ug/h 500 kg wt	Seedorf et al., 1998		X

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Poultry Feedlots

Ammonia (NH₃) Emission Factors

Animal Description	Management	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Broilers	Total	0.23 kg NH ₃ /head/yr		Corsi et al., 2000
Broiler	Total Broiler	2208-8294 mg NH ₃ /500 kg/hr		Groot Koerkamp et al., 1998
Broilers	Total: (Stable + Storage + Spreading + Grazing)	0.167 kg NH ₃ /animal/yr	X	Asman, 1992
Broilers	Stable + Storage	0.065 kg NH ₃ /animal/yr	X	Asman, 1992
Broilers	Spreading	0.102 kg NH ₃ /animal/yr	X	Asman, 1992
Broilers	Litter (First Grow-out Cycle)	149 mg NH ₃ -N/m ² /hr		Brewer and Costello, 1999
Broilers	Reused Litter	208 mg NH ₃ -N/m ² /hr		Brewer and Costello, 1999
Mother Animals < 6 Months	Total: (Stable + Storage + Spreading + Grazing)	0.269 kg NH ₃ /animal/yr	X	Asman, 1992
Mother Animals < 6 Months	Stable + Storage		X	Asman, 1992
Mother Animals < 6 Months	Spreading	0.128 kg NH ₃ /animal/yr	X	Asman, 1992
Mother Animals > 6 Months	Total: (Stable + Storage + Spreading + Grazing)	0.598 kg NH ₃ /animal/yr	X	Asman, 1992
Mother Animals > 6 Months	Stable + Storage	0.315 kg NH ₃ /animal/yr	X	Asman, 1992
Mother Animals > 6 Months	Spreading	0.283 kg NH ₃ /animal/yr	X	Asman, 1992
Laying Hens < 18 Weeks	Total: (Stable + Storage + Spreading + Grazing)	0.17 kg NH ₃ /animal/yr	X	Asman, 1992
Laying Hens < 18 Weeks	Stable + Storage	0.05 kg NH ₃ /animal/yr	X	Asman, 1992
Laying Hens < 18 Weeks	Spreading	0.12 kg NH ₃ /animal/yr	X	Asman, 1992
Laying Hens > 18 Weeks	Total: (Stable + Storage + Spreading + Grazing)	0.305 kg NH ₃ /animal/yr	X	Asman, 1992
Laying Hens > 18 Weeks	Stable + Storage	0.1 kg NH ₃ /animal/yr	X	Asman, 1992
Laying Hens > 18 Weeks	Spreading	0.205 kg NH ₃ /animal/yr	X	Asman, 1992
Pullets (laying age)	Total	0.44 kg NH ₃ /head/yr		Corsi et al., 2000
Ducks	Total: (Stable + Storage + Spreading + Grazing)	0.117 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys for Slaughter	Total: (Stable + Storage + Spreading + Grazing)	0.858 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys for Slaughter	Stable + Storage	0.429 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys for Slaughter	Spreading	0.429 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys < 7 Weeks	Total: (Stable + Storage + Spreading + Grazing)	0.89 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys < 7 Weeks	Stable + Storage	0.445 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys < 7 Weeks	Spreading	0.445 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys > 7 Weeks	Total: (Stable + Storage + Spreading + Grazing)	1.278 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys > 7 Weeks	Stable + Storage	0.639 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys > 7 Weeks	Spreading	0.639 kg NH ₃ /animal/yr	X	Asman, 1992
Turkeys	Total	0.89 kg NH ₃ /head/yr		Corsi et al., 2000
Poultry	Total: (Stable + Storage + Spreading + Grazing)	0.249 kg NH ₃ /animal/yr	X	Asman, 1992
Poultry	Stable + Storage	0.095 kg NH ₃ /animal/yr	X	Asman, 1992
Poultry	Spreading	0.154 kg NH ₃ /animal/yr	X	Asman, 1992
Poultry	Total	0.26 kg NH ₃ /animal/yr		Buijsman et al., 1987
Layer	Deep Litter	7382-10892 mg NH ₃ /500 kg/hr		Groot Koerkamp et al., 1998
Layer	Battery	602-9316 mg NH ₃ /500 kg/hr		Groot Koerkamp et al., 1998
Layer	Battery Cages, Basement	83 g NH ₃ /bird/yr		Hartung and Phillips, 1994
Layer	Battery Cages, Belts	34 g NH ₃ /bird/yr		Hartung and Phillips, 1994
Layer	Battery Cages, Belts, Drying	31 g NH ₃ /bird/yr		Hartung and Phillips, 1994

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Poultry Feedlots

Hydrogen Sulfide (H₂S) Emission Factors

Animal Description	Management	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Broiler	Mechanically Ventilated	0.2 ug H ₂ S/s/m ²	X	Zhu et al., 1998

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Poultry Feedlots

Methane (CH₄) Emission Factors

Animal Description	Management	Emission Factor	Most Representative Emission Factors	Information Source
Caged Layer	Waste Storage	0.3 kg CH ₄ /animal/yr	X	Safley and Casada, 1992
Broiler	Waste Storage	0.09 kg CH ₄ /animal/yr	X	Safley and Casada, 1992
Turkey and Ducks	Waste Storage	0.16 kg CH ₄ /animal/yr	X	Safley and Casada, 1992

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Poultry Feedlots

Particulate Matter (PM) Emission Factors

Animal Description	Management	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Layers (PM>5um)	Perchery (England Study)	1771 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM>5um)	Perchery (Netherlands Study)	4340 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM>5um)	Perchery (Denmark Study)	3131 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM>5um)	Cage (England Study)	872 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM>5um)	Cage (Netherlands Study)	398 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM>5um)	Cage (Denmark Study)	642 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM>5um)	Cage (Germany Study)	633 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM>5um)	Litter (England Study)	6218 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM>5um)	Litter (Netherlands Study)	4984 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM>5um)	Litter (Denmark Study)	1856 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM>5um)	Litter (Germany Study)	2805 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM>5um)	Total Housing Facility (England Study)	3138 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM>5um)	Total Housing Facility (Netherlands Study)	3640 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM>5um)	Total Housing Facility (Denmark Study)	3509 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM>5um)	Total Housing Facility (Germany Study)	2118 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM>5um)	Total Housing Facility (Overall Average)	3165 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Perchery (England Study)	467 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Perchery (Netherlands Study)	682 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Perchery (Denmark Study)	637 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Cage (England Study)	161 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Cage (Netherlands Study)	46 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Cage (Denmark Study)	82 mg PM/500 kg/hr	X	Takai et al., 1998
Layers (PM<5um)	Cage (Germany Study)	24 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM<5um)	Litter (England Study)	706 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM<5um)	Litter (Netherlands Study)	725 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM<5um)	Litter (Denmark Study)	245 mg PM/500 kg/hr	X	Takai et al., 1998
Broilers (PM<5um)	Litter (Germany Study)	394 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM<5um)	Total Housing Facility (England Study)	373 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM<5um)	Total Housing Facility (Netherlands Study)	721 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM<5um)	Total Housing Facility (Denmark Study)	618 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM<5um)	Total Housing Facility (Germany Study)	248 mg PM/500 kg/hr	X	Takai et al., 1998
Poultry (PM<5um)	Total Housing Facility (Overall Average)	504 mg PM/500 kg/hr	X	Takai et al., 1998

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Poultry Feedlots

Endotoxin Emission Factors

Animal Description	Management	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Layers (Endotoxins>5um)	Total Housing Facility	538.3 ug/500 kg/hr		Seedorf et al., 1998
Broilers (Endotoxins>5um)	Total Housing Facility	817.4 ug/500 kg/hr	X	Seedorf et al., 1998
Layers (Endotoxins<5um)	Total Housing Facility	38.7 ug/500 kg/hr	X	Seedorf et al., 1998
Broilers (Endotoxins<5um)	Total Housing Facility	46.7 ug/500 kg/hr	X	Seedorf et al., 1998

Recommended Poultry Emission Factors Corroborated by Other References

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	US EPA NH ₃ Report	University of Minnesota Literature Survey
Broilers	Total: (Stable + Storage + Spreading + Grazing)	0.167 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Broilers	Stable + Storage	0.065 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Broilers	Spreading	0.102 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Mother Animals < 6 Months	Total: (Stable + Storage + Spreading + Grazing)	0.269 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Mother Animals < 6 Months	Stable + Storage	0.141 kg NH ₃ /animal/yr	Asman, 1992		X	X
Mother Animals < 6 Months	Spreading	0.128 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Mother Animals > 6 Months	Total: (Stable + Storage + Spreading + Grazing)	0.598 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Mother Animals > 6 Months	Stable + Storage	0.315 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Mother Animals > 6 Months	Spreading	0.283 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Laying Hens < 18 Weeks	Total: (Stable + Storage + Spreading + Grazing)	0.17 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Laying Hens < 18 Weeks	Stable + Storage	0.05 kg NH ₃ /animal/yr		X	X	
Laying Hens < 18 Weeks	Spreading	0.12 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Laying Hens > 18 Weeks	Total: (Stable + Storage + Spreading + Grazing)	0.305 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Laying Hens > 18 Weeks	Stable + Storage	0.1 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Laying Hens > 18 Weeks	Spreading	0.205 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Ducks	Total: (Stable + Storage + Spreading + Grazing)	0.117 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys for Slaughter	Total: (Stable + Storage + Spreading + Grazing)	0.858 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys for Slaughter	Stable + Storage	0.429 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys for Slaughter	Spreading	0.429 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys < 7 Weeks	Total: (Stable + Storage + Spreading + Grazing)	0.89 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys < 7 Weeks	Stable + Storage	0.445 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys < 7 Weeks	Spreading	0.445 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys > 7 Weeks	Total: (Stable + Storage + Spreading + Grazing)	1.278 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys > 7 Weeks	Stable + Storage	0.639 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Turkeys > 7 Weeks	Spreading	0.639 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Poultry	Total: (Stable + Storage + Spreading + Grazing)	0.249 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Poultry	Stable + Storage	0.095 kg NH ₃ /animal/yr	Asman, 1992	X	X	
Poultry	Spreading	0.154 kg NH ₃ /animal/yr	Asman, 1992	X	X	

Recommended Poultry Emission Factors Corroborated by Other References

Hydrogen Sulfide (H₂S) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota Literature Survey
Broiler	Mechanically Ventilated	0.2 ug H ₂ S/s/m ²	Zhu et al., 1998		X

Recommended Poultry Emission Factors Corroborated by Other References

Methane (CH₄) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	University of Minnesota	Literature Survey
Caged Layer	Waste Storage	0.3 kg CH ₄ /animal/yr	Safley and Casada, 1992			
Broiler	Waste Storage	0.09 kg CH ₄ /animal/yr	Safley and Casada, 1992	X	X	X
Turkey and Ducks	Waste Storage	0.16 kg CH ₄ /animal/yr	Safley and Casada, 1992	X	X	X

Recommended Poultry Emission Factors Corroborated by Other References

Particulate Matter (PM) Emission Factors

Animal Description	Management Practice	Emission Factor	Source of Information	USDA Report University of Minnesota Literature Survey
Layers	Perchery (England Study)	1771 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Perchery (Netherlands Study)	4340 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Perchery (Denmark Study)	3131 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (England Study)	872 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (Netherlands Study)	398 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (Denmark Study)	642 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (Germany Study)	633 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (England Study)	6218 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (Netherlands Study)	4984 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (Denmark Study)	1856 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (Germany Study)	2805 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (England Study)	3138 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Netherlands Study)	3640 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Denmark Study)	3509 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Germany Study)	2118 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Overall Average)	3165 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Perchery (England Study)	467 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Perchery (Netherlands Study)	682 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Perchery (Denmark Study)	637 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (England Study)	161 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (Netherlands Study)	46 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (Denmark Study)	82 mg PM/500 kg/hr	Takai et al., 1998	X
Layers	Cage (Germany Study)	24 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (England Study)	706 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (Netherlands Study)	725 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (Denmark Study)	245 mg PM/500 kg/hr	Takai et al., 1998	X
Broilers	Litter (Germany Study)	394 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (England Study)	373 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Netherlands Study)	721 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Denmark Study)	618 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Germany Study)	248 mg PM/500 kg/hr	Takai et al., 1998	X
Poultry	Total Housing Facility (Overall Average)	504 mg PM/500 kg/hr	Takai et al., 1998	X

Recommended Poultry Emission Factors Corroborated by Other References

Endotoxin Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report University of Minnesota Literature Survey
Layers	Total Housing Facility	538.3 ug/500 kg/hr	Seedorf et al., 1998	X
Broilers	Total Housing Facility	817.4 ug/500 kg/hr	Seedorf et al., 1998	X
Layers	Total Housing Facility	38.7 ug/500 kg/hr	Seedorf et al., 1998	X
Broilers	Total Housing Facility	46.7 ug/500 kg/hr	Seedorf et al., 1998	X

Emission Factors Evaluated in Compilation of Air Pollutant Emission Factors for Sheep Feedlots

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Emission Factor	Selected as Most Representative Emission Factor	Information Source
Ewes	Stable & Storage	0.7 kg NH ₃ /Animal/Yr	X	Asman, 1992
Ewes	Spreading	1.28 kg NH ₃ /Animal/Yr	X	Asman, 1992
Ewes	Grazing	1.39 kg NH ₃ /Animal/Yr	X	Asman, 1992
Sheep	Total	3.1 kg NH ₃ /Animal/Yr		Buijsman et.al, 1987
Sheep		2.7 kg/hd/yr		Corsi et al., 2000
Ranging Sheep	Total	2.04 kg NH ₃ /Animal/Yr		Warn, et al., 1990
Confined Sheep	Total	0.86 kg NH ₃ /Animal/Yr		Warn, et al., 1990

Recommended Poultry Emission Factors Corroborated by Other References

Ammonia (NH₃) Emission Factors

Animal Description	Management Practice	Representative Emission Factor	Source of Information	USDA Report	US EPA NH ₃ Report	University of Minnesota Literature Survey
Ewes	Stable & Storage	0.7 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Ewes	Spreading	1.28 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Ewes	Grazing	1.39 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	
Sheep	Total	3.1 kg NH ₃ /Animal/Yr	Asman, 1992	X	X	

APPENDIX B

**ODOR COMPLAINT RECORDS AND
FEEDLOT DEMOGRAPHIC SUPPORTING INFORMATION**

The information contained within this appendix includes a summary of the MPCA odor complaint database and the EQB feedlot demographic information, as well as graphic illustrations of the comparisons made between the two data sets. Although the MPCA odor database and the EQB feedlot demographic data both showed weaknesses and did not contain enough data from which statistically significant correlations could be drawn, a number comparisons were evaluated to seek out any possible general trends or correlations between the odor complaints and the animal and human demographic parameters.

These comparisons yielded no striking relationships or general patterns in the data. The strongest correlation observed between the two data sets was in comparing the total number of odor complaints per county to the average feedlot size within each county. However, the correlation coefficient (r^2) was only 0.1074. A good correlation coefficient typically ranges from 0.5 to 1.0, and is generally determined by the expected and allowable variability in the data set. The total county population and land area used for these comparative analyses was obtained from the U.S Census Bureau's 1999 county demographic estimates.

**SUMMARY OF THE MPCA FEEDLOT ODOR COMPLAINT DATABASE
FOR ALL LOGGED FEEDLOT COMPLAINTS FROM JUNE 1996 TO SEPTEMBER 2000**

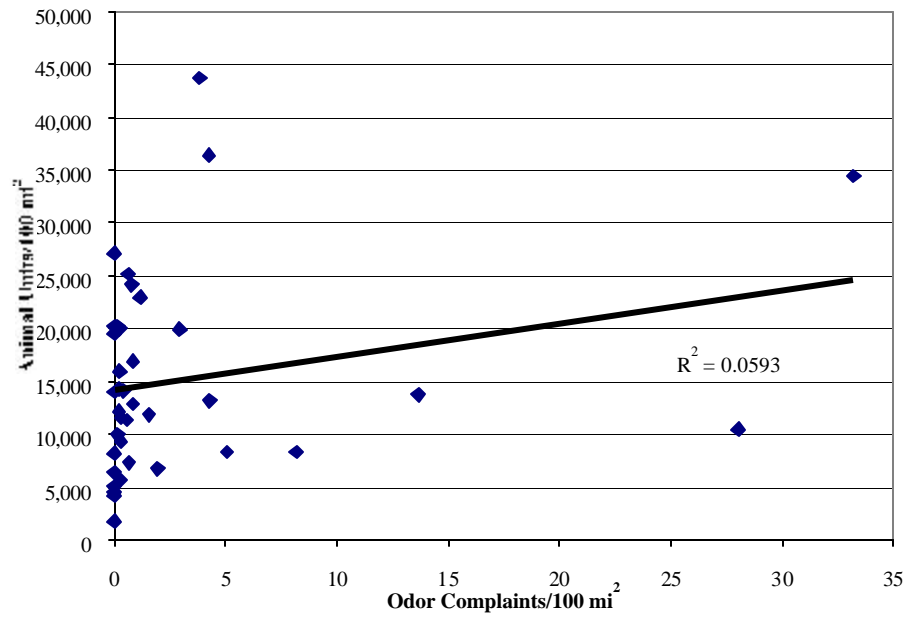
County	Dairy	Swine	Poultry	Other Species	Unknown Species	Total County Complaints
Aitkin	0	0	0	0	0	0
Anoka	0	1	0	0	0	1
Becker	1	0	0	0	0	1
Beltrami	0	0	0	0	0	0
Benton	2	1	0	0	1	4
Big Stone	0	0	0	0	0	0
Blue Earth	1	23	0	0	8	32
Brown	0	6	0	0	0	6
Carlton	0	0	0	0	0	0
Carver	29	30	0	0	41	100
Cass	1	1	0	0	0	2
Chippewa	0	0	0	0	1	1
Chisago	0	0	0	0	0	0
Clay	0	0	1	0	0	1
Clearwater	0	0	0	0	0	0
Cook	0	0	0	0	0	0
Cottonwood	0	26	0	0	0	26
Crow Wing	0	2	0	0	1	3
Dakota	0	10	0	0	1	11
Dodge	0	0	0	0	1	1
Douglas	0	0	0	0	0	0
Faribault	0	0	0	0	0	0
Fillmore	0	3	0	0	2	5
Freeborn	0	1	0	0	0	1
Goodhue	0	1	2	0	2	5
Grant	0	0	0	0	0	0
Hennepin	0	0	1	0	0	1
Houston	0	0	0	0	1	1
Hubbard	0	1	1	0	1	3
Isanti	0	0	2	0	0	2
Itasca	0	0	0	0	0	0
Jackson	0	1	0	0	3	4
Kanabec	0	0	0	0	0	0
Kandiyohi	0	0	0	0	1	1
Kittson	0	0	0	0	0	0
Koochiching	0	0	0	0	0	0
Lac Qui Parle	0	0	0	0	5	5
Lake	0	2	0	0	0	2
Lake of the Woods	0	0	0	0	0	0
LeSueur	0	0	0	0	1	1
Lincoln	0	23	0	0	0	23
Lyon	1	6	0	0	4	11
Mahnomen	0	0	0	0	0	0
Marshall	5	0	0	0	0	5
Martin	0	14	0	0	13	27
McLeod	1	1	0	0	0	2

County	Dairy	Swine	Poultry	Other Species	Unknown Species	Total County Complaints
Meeker	2	1	1	0	1	5
Mille Lacs	0	0	0	0	0	0
Morrison	1	7	0	0	5	13
Mower	0	5	0	0	1	6
Murray	0	0	0	0	1	1
Nicollet	3	145	0	0	2	150
Nobles	0	0	0	0	0	0
Norman	0	0	2	0	1	3
Olmstead	0	0	0	0	5	5
Otter Tail	12	1	0	0	3	16
Pennington	0	0	0	0	1	1
Pine	0	0	0	0	0	0
Pipestone	0	0	0	0	0	0
Polk	0	0	0	0	0	0
Pope	0	4	0	0	0	4
Ramsey	0	0	0	0	0	0
Red Lake	0	0	0	0	0	0
Redwood	0	2	0	0	0	2
Renville	0	153	9	0	5	167
Rice	0	66	0	0	2	68
Rock	0	2	0	0	1	3
Roseau	0	9	0	0	0	9
Scott	0	0	0	0	1	1
Sherburne	0	0	0	0	0	0
Sibley	1	2	0	0	2	5
St. Louis	0	0	0	0	3	3
Stearns	8	1	2	0	10	21
Steele	0	0	0	0	0	0
Stevens	0	0	0	0	0	0
Swift	0	0	0	0	0	0
Todd	1	0	0	0	1	2
Traverse	0	0	0	0	0	0
Wabesha	0	0	0	0	0	0
Wadena	0	0	1	0	0	1
Waseca	0	20	0	0	3	23
Washington	0	0	0	0	0	0
Watonwan	0	17	0	0	5	22
Wilkin	0	0	0	0	0	0
Winona	0	0	0	0	0	0
Wright	47	2	0	0	5	54
Yellow Medicine	16	7	0	0	0	23
Odor Complaints Without County Identification	3	1	0	0	12	16
Statewide Feedlot Complaints	135	597	22	0	157	911

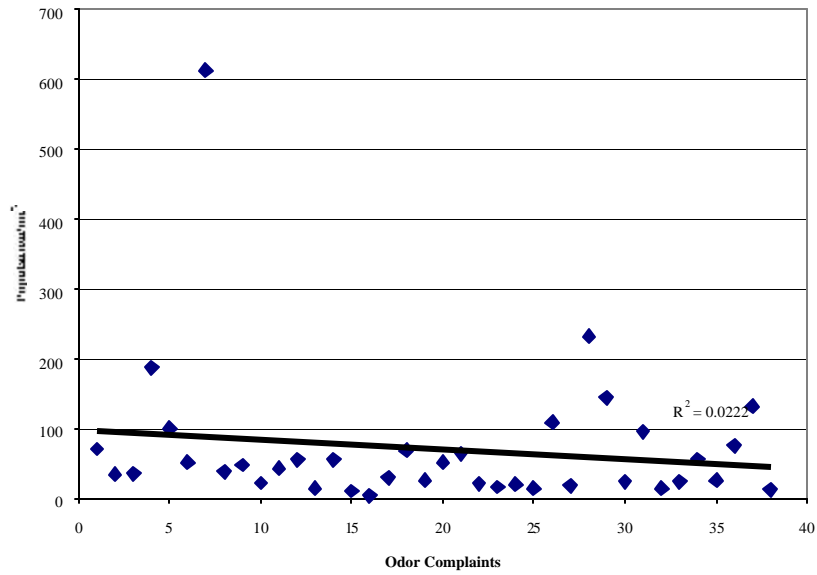
**MINNESOTA ENVIRONMENTAL QUALITY BOARD (EQB)
COUNTY ANIMAL FEEDLOT DEMOGRAPHIC INFORMATION**

County	Total Feedlots	Total Animal Units	Average Animal Units (AU)	Feedlots >500 AU	Feedlots >1,000 AU
Blue Earth	474	172558.74	364.05	135	35
Brown	619	149454.00	241.44	73	25
Carlton	94	4186.91	44.54	0	0
Carver	502	52419.30	104.42	8	1
Chisago	225	11428.00	50.79	2	1
Crow Wing	86	8053.00	93.64	1	1
Dakota	338	22749.70	67.31	10	1
Dodge	397	63457.00	159.84	34	5
Douglas	421	58809.00	139.69	6	0
Faribault	621	125462.10	202.03	62	10
Freeborn	487	98436.20	202.13	43	11
Goodhue	265	19339.352	72.98	5	0
Jackson	1537	174916.05	113.80	91	17
LeSueur	328	65583.92	199.95	39	4
Lincoln	458	60317.00	131.70	29	7
Marshall	89	10324.00	116.00	3	3
Martin	649	283631.00	437.03	101	62
McLeod	532	75279.00	141.50	12	0
Morrison	652	149793.00	229.74	109	19
Mower	794	133906.45	168.65	59	3
Nicollet	427	147140.00	344.59	83	19
Pennington	54	5388	99.78	1	0
Pine	574	36395.00	63.41	4	1
Pipestone	574	112281.00	195.61	57	26
Pope	326	39750.00	121.93	8	3
Rice	827	113807.00	137.61	33	6
Rock	581	146150.70	251.55	88	0
Scott	625	35391.00	56.63	6	4
Sherburne	135	5764.00	42.70	2	0
Sibley	614	79162.00	128.93	18	0
Stearns	2773	328132.00	118.33	141	34
Swift	190	51508.00	271.09	26	10
Todd	699	100136.00	143.26	23	9
Washington	890	15867.00	17.83	0	0
Watonwan	352	29297.00	83.23	7	1
Winona	881	72427.00	82.21	17	5
Wright	475	39506.00	83.17	5	1
Yellow Medicine	508	101378.79	199.56	40	18

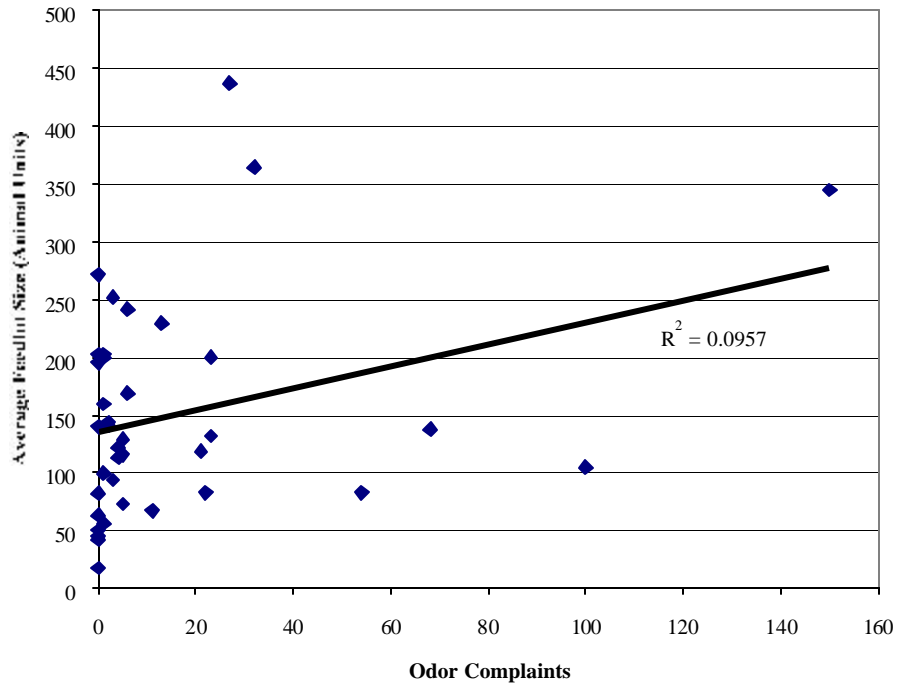
Comparison of County Total Feedlot Odor Complaints and County Animal Unit Density



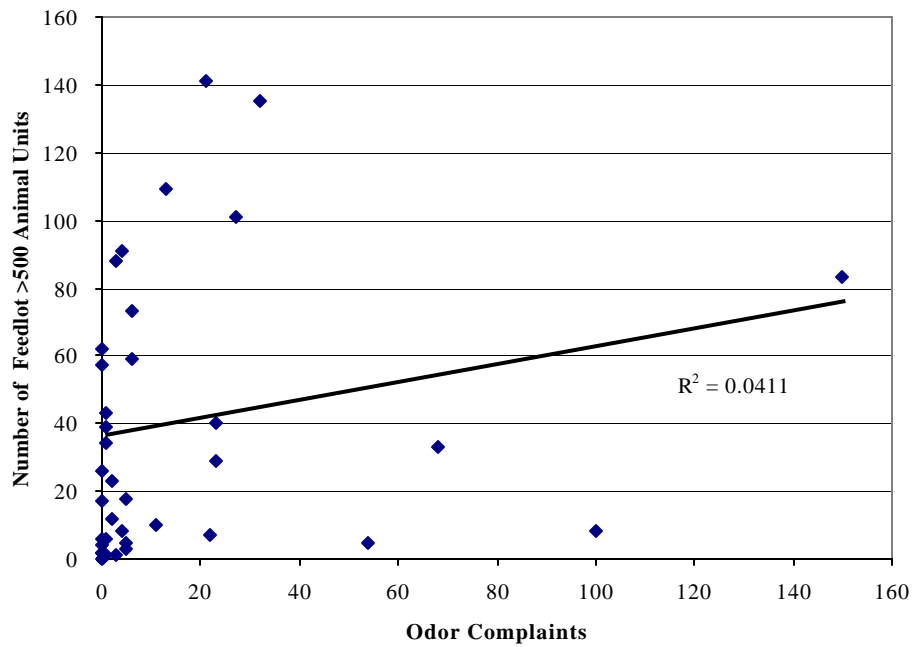
Comparison of County Total Feedlot Odor Complaints and County Population Density



Comparison of County Total Feedlot Odor Complaints and Average Feedlot Size



Comparison of County Total Feedlot Odor Complaints and Feedlots >500 Animal Units



Comparison of County Total Feedlot Odor Complaints and Feedlots >1000 Animal Units

