Appendix H.8

Sonoma Technology, ***Research and Development of Ammonia Emission Inventories for the Central States Regional Air Planning Association (October 30, 2003)***

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RESEARCH AND DEVELOPMENT OF AMMONIA EMISSION INVENTORIES FOR THE CENTRAL STATES REGIONAL AIR PLANNING ASSOCIATION

FINAL REPORT
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QUALITY ASSURANCE STATEMENT

This report was reviewed and approved by the project Quality Assurance (QA) Officer or his delegated representatives, as provided in the project QA Plan (Coe, 2003).

Lyle R. Chinkin
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EXECUTIVE SUMMARY

The Central States Regional Air Planning Association (CENRAP) is researching visibility-related issues for its region and is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas. In support of the CENRAP's need to develop a regional haze plan, Sonoma Technology, Inc. (STI) developed a 2002 ammonia emission inventory for the region in keeping with the emissions estimation techniques presented in Appendix A—Ammonia Emission Estimation Methods for the CENRAP Ammonia Emission Inventory (Methods Document).

Consistent with the Methods Document, ammonia emissions were estimated for 13 source categories using the Carnegie Mellon University (CMU) model and supplemental technical work; 80% of technical work was dedicated to improving emissions estimates for two source categories—livestock production and fertilizer use. For these two categories, as well as biogenic sources, improvements were made to the activity data and/or emission factors used by the CMU model. For four other source categories (industrial point sources, landfills, ammonia refrigeration, and non-road mobile sources), emissions estimates were prepared independently of the CMU model, and for the remaining six source categories (publicly owned treatment works, wildfires, domestic animals, wild animals, human respiration, and on-road mobile sources), emissions estimates were derived by running the CMU model with no alterations.

In the resulting inventory, the most important source categories are estimated to be livestock and poultry, fertilizers, and biogenics. When combined, these three sources account for 87% of the annual ammonia emissions in the CENRAP region (see **Figure ES-1**). Seasonally, peaks in emission levels occur in spring and fall (especially during the months of April and October), times when manure and fertilizer are typically applied to croplands (see **Figure ES-2**).

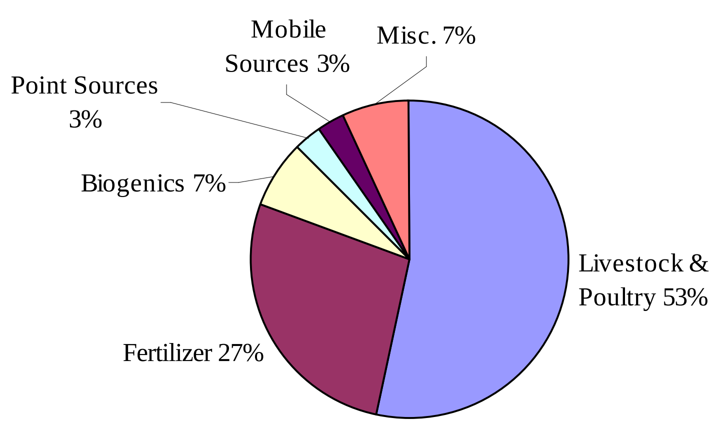

Figure ES-1. CENRAP 2002 ammonia emissions by source category.

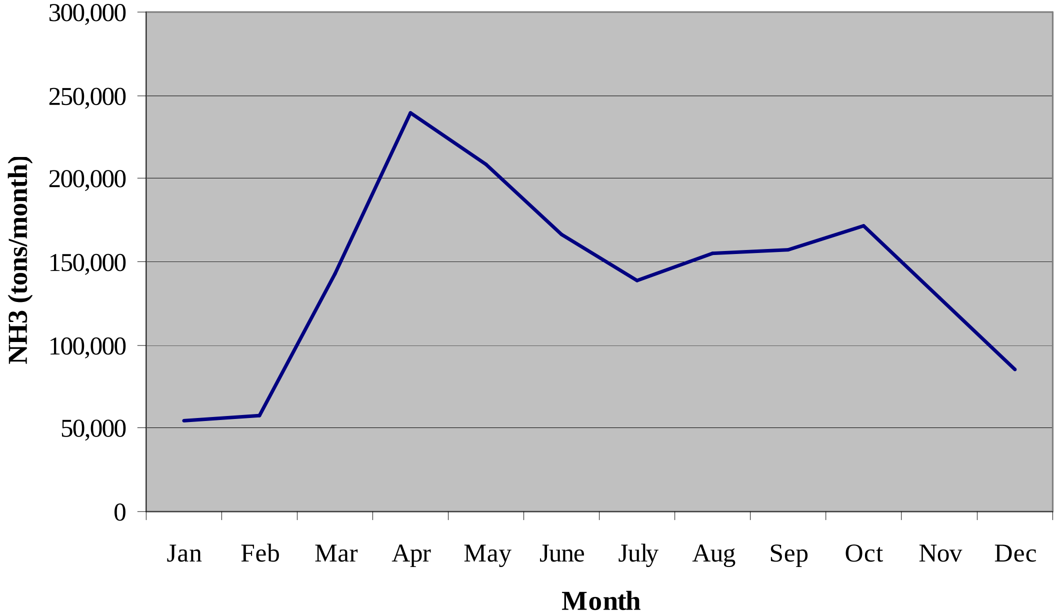

Figure ES-2. Monthly variability in total 2002 emissions for the CENRAP region.

As anticipated, emissions from livestock and poultry made the largest contribution to total estimated emissions for the CENRAP region and for each individual state (with the exception of Louisiana). This source category was especially significant in the states of Iowa and Oklahoma, where emissions from livestock and poultry accounted for over 60% of the total inventory (see **Table 2-1**). Fertilizer application was the second most significant source of ammonia emissions in the region, and this source category was especially important in Kansas and Nebraska, accounting for about 36% of the total inventory in those states. (Actual emissions estimates by source category and state are tabulated in Appendix B.)

The source with the greatest uncertainty in the inventory is biogenic emissions, because the emission rates and character of the natural environment as a source or a sink of ammonia are not studied as extensively as they are for other source categories. Significant uncertainties also exist in the available ammonia emission factors for agricultural activities, as they fail to adequately consider some important governing principles (such as climate, manure management, and animal diet). In addition, two source categories that may be significant at local geographic scales were necessarily omitted from the inventory due to lack of information: ammonia injection for NO_x controls and biosolids (or sewage sludges).

In order to improve the CENRAP's emission inventory in the future, we recommend research efforts, such as studies of activity data, which will allow the CENRAP to take advantage of next-generation emissions models that are currently under development for biogenics, livestock, and fertilizers. In addition, we recommend a survey of power plants in the CENRAP states to assess the emissions from ammonia-injection control technologies. Lastly, recognizing that a viable emissions model for sewage sludges may not be available for a long time, we recommend that an emissions inventory be developed for this source category through the initiation of emissions measurement programs and systems to gather or track pertinent activity data.

1. INTRODUCTION

The Central States Regional Air Planning Association (CENRAP) is researching visibility-related issues for its region, which includes the states of Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota, and is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas. To develop an effective regional haze plan, the CENRAP must develop a conceptual model of the phenomena that lead to episodes of low visibility in the CENRAP region. It is widely recognized that the formation of secondary particulate matter—which is generated from chemical transformations in the atmosphere of gaseous precursor species such as ammonia, nitrogen oxides, sulfur oxides, and volatile organic compounds—contributes significantly to regional haze issues in the CENRAP region. Therefore, development of accurate and comprehensive emission inventories of these precursor species is important.

In support of the CENRAP's need to develop a regional haze plan, Sonoma Technology, Inc. (STI) responded to the CENRAP Work Assignment Number 02-0214-RP-003-001, "Research and Development of Ammonia Emission Inventories for the Central States Regional Air Planning Association." The project objectives were to identify and evaluate information resources that may be immediately applied to mitigate known weaknesses in the Carnegie Mellon University (CMU) model—an ammonia emissions modeling tool and database system that was developed by CMU and recently evaluated by STI—and to apply the findings to improve the CMU ammonia emission inventories for the CENRAP region. As directed by the CENRAP Emissions Work Group, STI dedicated at least 80% of its technical effort to improving emission estimates for two types of emissions sources—livestock production and fertilizer use—while the remainder of the work was directed toward improving emission estimates for other types of emissions sources (such as wastewater treatment plants, biogenics, or on- and off-road mobile sources).

1.1 BACKGROUND AND KEY ISSUES

1.1.1 Secondary Formation of Fine Particulate Matter in the CENRAP Region

Visibility impairment is primarily caused by particulate matter of aerodynamic diameter less than 2.5 microns ($PM_{2.5}$). $PM_{2.5}$ may be directly emitted from sources such as fugitive dust and combustion soot, which are termed sources of "primary $PM_{2.5}$". Condensable organic aerosols form from air emissions of semi-volatile and heavy organic compounds. In addition, $PM_{2.5}$ forms from photochemical reactions of gaseous precursors, including sulfur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC), and ammonia (NH_3). This mechanism of $PM_{2.5}$ formation is termed "secondary formation".

The chemical composition of ambient $PM_{2.5}$ provides an understanding of the types of emissions sources that contribute to regional haze issues in different regions (see **Figure 1-1**). Ammonium sulfate, ammonium bisulfate, and ammonium nitrate are important secondary $PM_{2.5}$ constituents. In urban and ammonia-depleted areas of the eastern United States, sulfate is relatively a more significant contributor to $PM_{2.5}$ than it is in the western United States.

Conversely, nitrate is more important in urban and ammonia-rich areas of the western United States than it is in eastern areas. In both the eastern and western United States, the carbonaceous fraction of $PM_{2.5}$ is significant in urban areas. However, in more pristine areas, the contribution of geologic dust to ambient $PM_{2.5}$ becomes more important and may contribute up to 50% of observed $PM_{2.5}$ concentrations. Areas with abundant gaseous NH_3 experience rapid transformation of the atmospheric oxidation products of SO_x and NO_x emissions into fine aerosols of ammonium sulfate and ammonium nitrate.

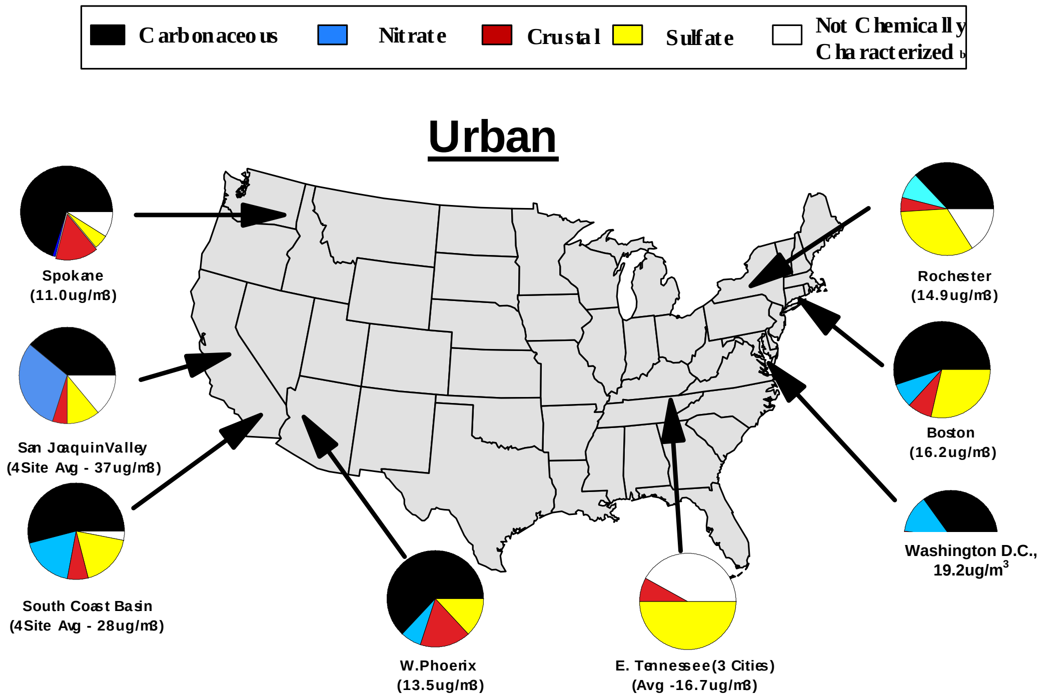

Figure 1-1. Compositions of annual average concentrations of $PM_{2.5}$ observations in urban locations (U.S. Environmental Protection Agency, 1998).

In order to develop a preliminary[1] understanding of the components that contribute to ambient levels of $PM_{2.5}$ in the CENRAP region, STI analyzed a data set of speciated $PM_{2.5}$ data for the region that was compiled by researchers at the Center for Air Pollution Impact and Trend Analysis at Washington University (Schichtel et al., 1999). The data were collected during various time periods and using various analytical sampling techniques; thus, the results should be considered uncertain until a more rigorous evaluation can be completed. Nevertheless, the data indicated several important characteristics. The preliminary data summaries shown in **Figures 1-2 and 1-3** indicate that at sites where sulfates and nitrates were measured, these secondary compounds together comprised approximately 30% to 60% of $PM_{2.5}$. In addition, sulfate concentrations are 2 to 10 times larger than nitrate concentrations. Furthermore, the

[1] It is recognized that more-recent monitoring data have become available since this preliminary analysis was done. While the data sources cited provide the level of understanding needed for this background discussion, it is recommended that future efforts include analysis of the most recent monitoring data.

highest ratios of sulfates to nitrates and the highest average concentrations of $PM_{2.5}$ were observed in the southeastern portions of the CENRAP region. This is consistent with observations presented by Falke (1999) shown in **Figure 1-4**. However, it is important to note that Falke's analyses also indicated relatively high levels of uncertainty in the western portion of the CENRAP region (**Figure 1-5**). Other potential uncertainties in the monitoring data also can affect analyses of $PM_{2.5}$ data. For example, Malm et al. (2000) reported differences as large as a factor of two between IMPROVE and CastNet (CDN) observations at Big Bend National Park, Texas, (the only CENRAP Class I site studied) (see **Figure 1-6**). Examination of estimated SO_2 emission rates and population densities across the United States (**Figures 1-7 and 1-8**) helps explain why $PM_{2.5}$ concentrations are somewhat higher and sulfates are so important in the southeast portion of the CENRAP region.

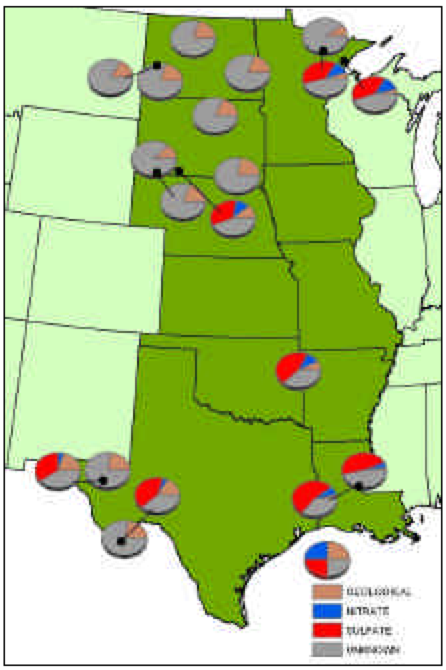

Figure 1-2. Contributions of chemical components to observed $PM_{2.5}$ concentrations in the CENRAP region.

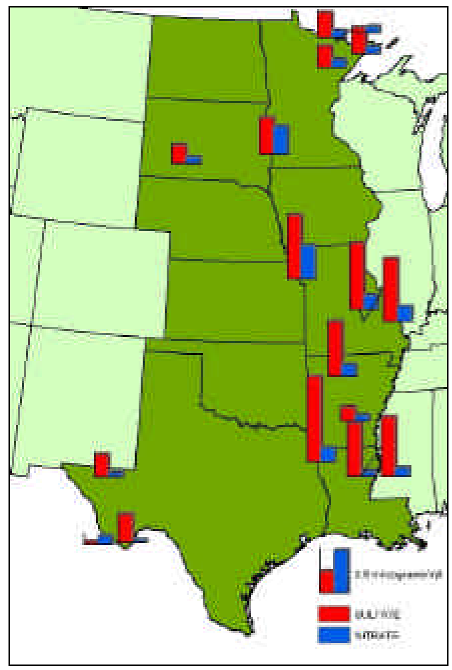

Figure 1-3. Concentrations of particulate sulfates and nitrates observed in the CENRAP region.

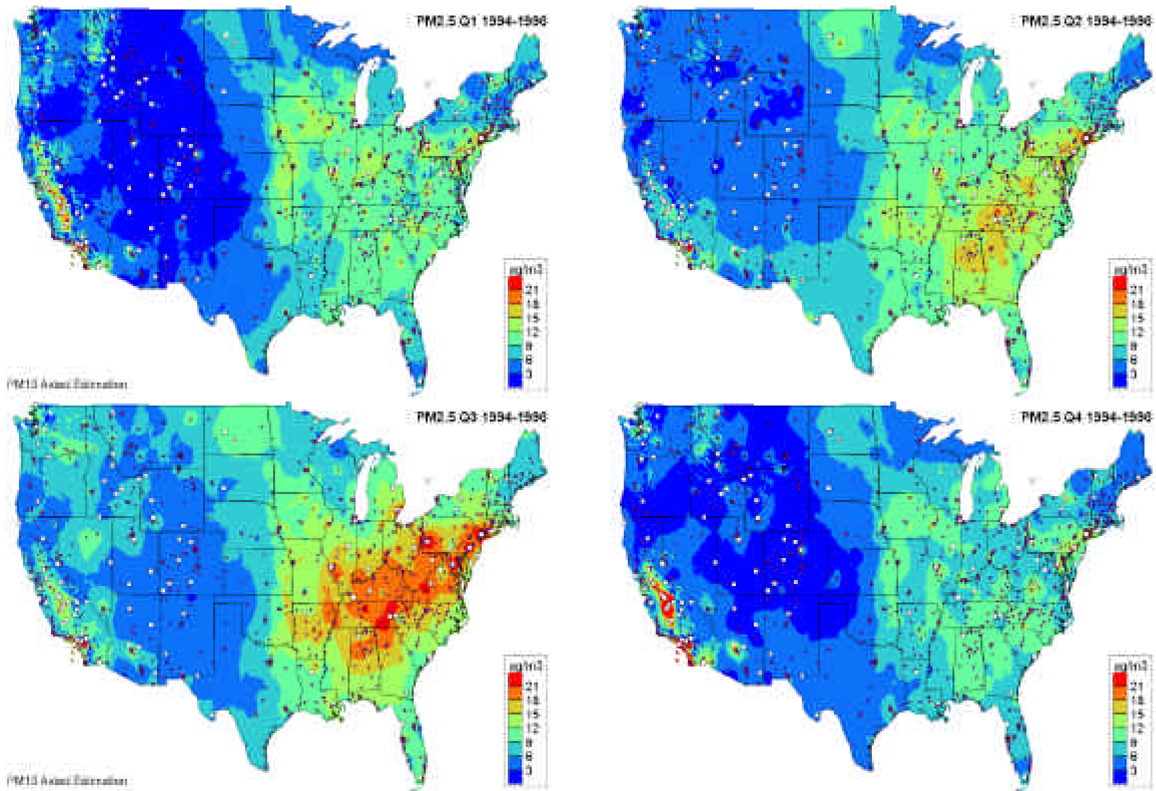

Figure 1-4. Estimated seasonal average concentrations of $PM_{2.5}$ (1994-1996) (Falke, 1999).

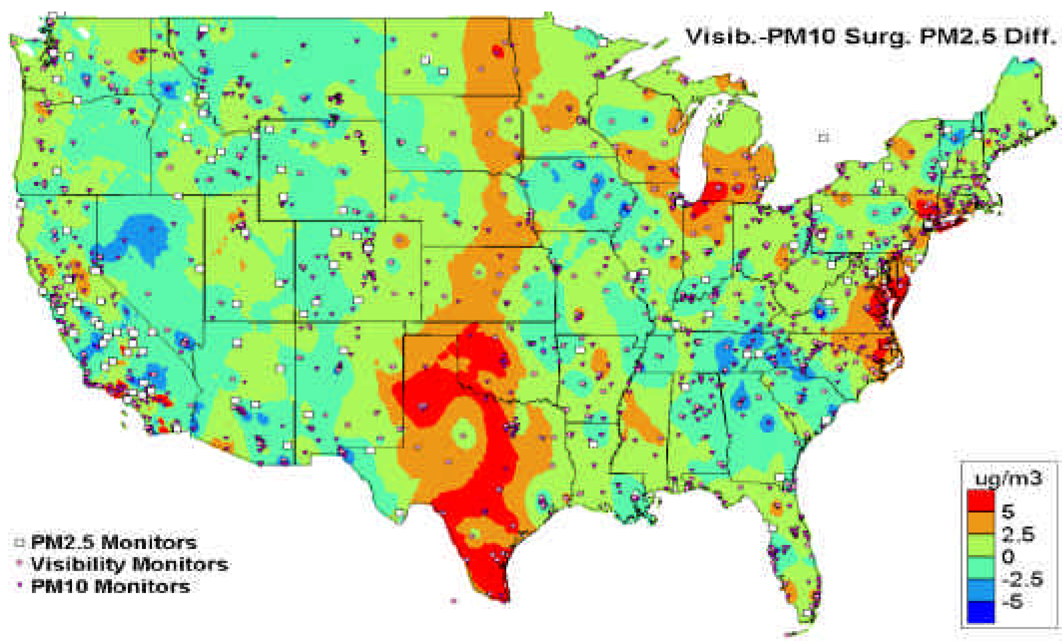

Figure 1-5. Uncertainty in estimated seasonal average $PM_{2.5}$ concentrations (Falke, 1999).

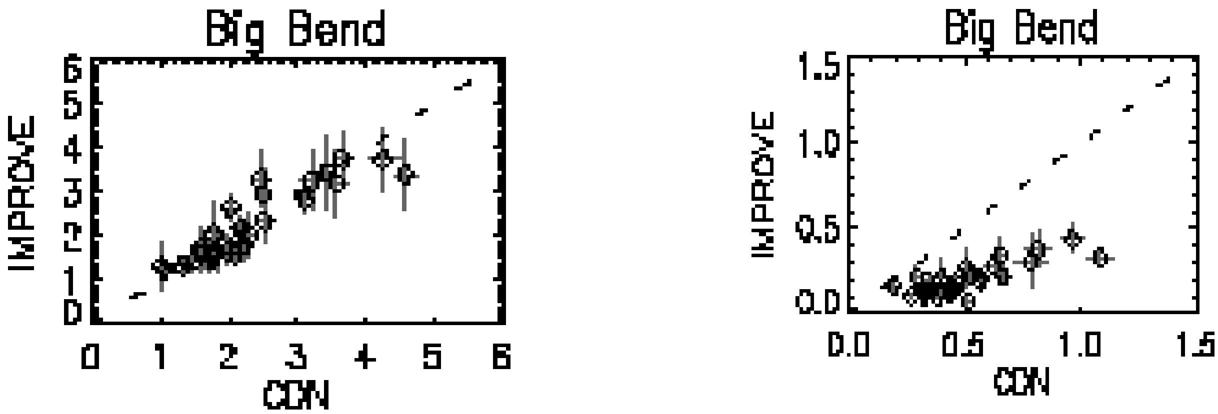

Figure 1-6. Comparison of IMPROVE and CDN measurements of sulfate (right) and nitrate (left) at Big Bend National Park, Texas (Malm et al., 2000).

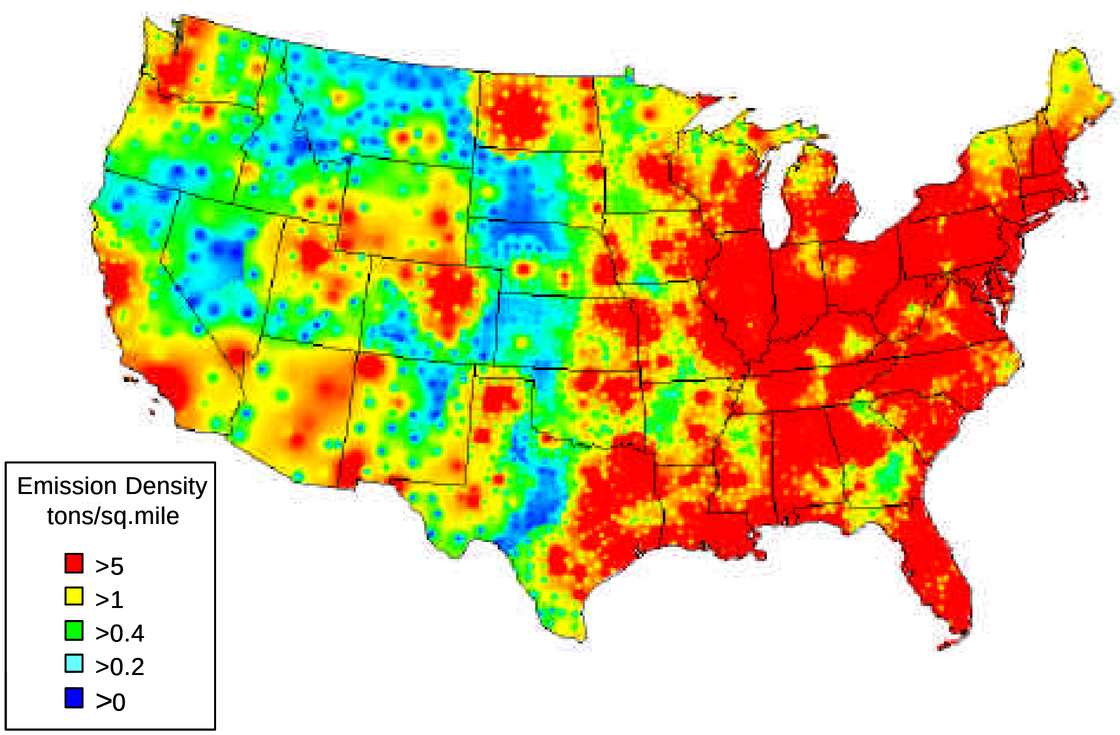

Figure 1-7. Annual SO_2 emissions in 1998 (U.S. Environmental Protection Agency, 2000).

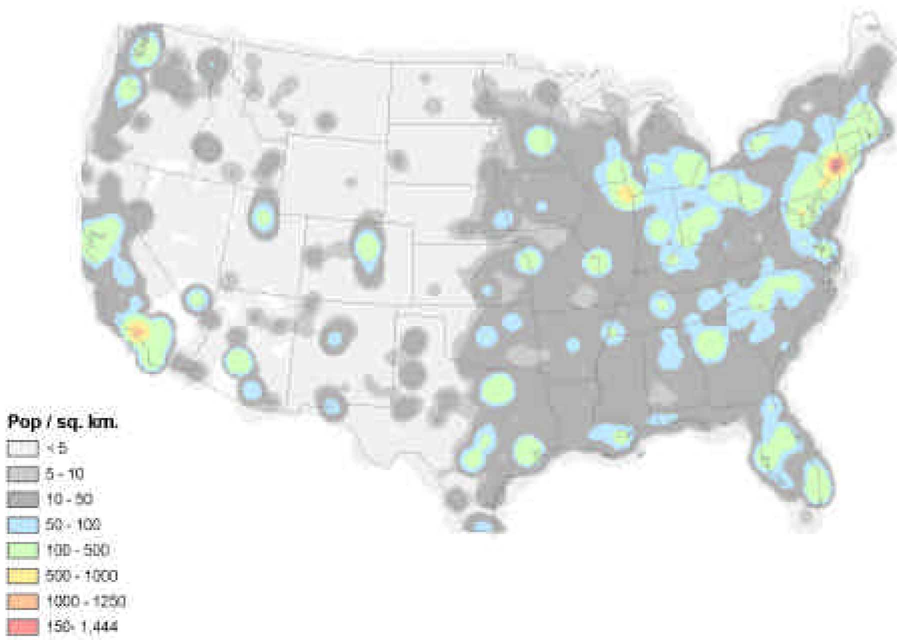

Figure 1-8. Population density in the United States in 2000 (U.S. Census Bureau, 2001).

1.1.2 Prior Statuses of Ammonia Emission Inventories

As a whole, few areas of the CENRAP region historically have experienced significant air quality problems and, therefore, monitoring and emissions estimates were relatively scarce. The most comprehensive sources of emissions estimates were the EPA's National Emissions Inventory (NEI), which is used as the basis of the EPA's National Emission Trends (NET) document series and analyses, and the CMU ammonia modeling tool and database system. Through previous studies, STI identified the following weaknesses and areas needing improvement in the NEI and CMU databases.

- Potentially important anthropogenic sources of ammonia include agricultural sources (animal husbandry and fertilizer application), mobile sources, natural (or "biogenic") sources, ammonia injection for NO_x control at power plants, and wastewater treatment plants. In many cases, the associated emission factors, activity parameters, seasonal profiles, and spatial patterns are highly uncertain and in need of improvement. The CMU model provides a framework for the development of county-level ammonia inventories, but it required significant improvements in its emission factors and activity data in order to represent the most up-to-date and geographically specific information possible.
- The NEI is estimated on an annual average basis. As Figure 1-4 illustrates, regional haze has a seasonal character and is partly driven by photochemical processes. Adjustments were necessary to develop seasonal, diurnal, and, possibly, day-of-week emission estimates.

- For mobile sources, improved activity inputs would be helpful, such as region-specific or state-specific fleet characteristics and improved vehicle miles traveled (VMT) estimates for rural areas. (Note that this improvement will be completed through a separate work assignment with the CENRAP.)
- For smaller point sources, STI found that the NET inventory can be highly inaccurate. For example, in the region surrounding Memphis, Tennessee, STI found that the 1996 NET inventory underestimated emissions of VOCs and NO_x by factors of 10 or more.
- To support modeling sensitivity runs, measures of uncertainty for all emission estimates are highly valuable for policy decisions and prioritization of future research efforts. Because the CENRAP ammonia inventory was compiled entirely from pre-existing emission factors and data, which lacked associated quantitative uncertainties, we are limited to providing only qualitative assessments of the emissions estimates. These are discussed in the Executive Summary and in Section 3, Recommendations for Further Research.

1.1.3 Project Priorities

To meet the CENRAP's primary goals, STI balanced the immediate need for a practical and cost-effective ammonia emission inventory with the need to incorporate the latest research and best available information. Thus, STI dedicated the majority of its resources to areas that the CENRAP has indicated are the highest priority: emissions from livestock management and fertilizer application. In addition, STI provided technology transfer services and documentation so that the work products of this project may be easily modified or applied by third parties, such as the CENRAP's Modeling Work Group or the CENRAP States' emissions and air quality specialists.

1.2 CURRENT STATUS OF THE CENRAP EMISSION INVENTORY

The resultant emission inventory produced through this work assignment is illustrated in **Figures 1-9, and 1-10** and tabulated in Appendix B. In all cases, we have applied generally accepted emission factors and the most complete and up-to-date activity data sets that could be identified and acquired. However, we also understand that available ammonia emission factors are uncertain, that they fail to adequately consider some important governing principles (such as climate, manure management, and animal diet), and that they continue to be the subject of research. These considerations are especially important for those areas of the inventory that we qualitatively consider to contribute the greatest degrees of uncertainty to the total estimated emissions: biogenic emissions (often called "natural soils"), livestock emissions, and fertilizer emissions. To help mitigate the effects of these uncertainties in the future, we have provided the CENRAP with an inventory and system of data files that can be updated with revised emission factors and activity data as new information become available (see Appendix D).

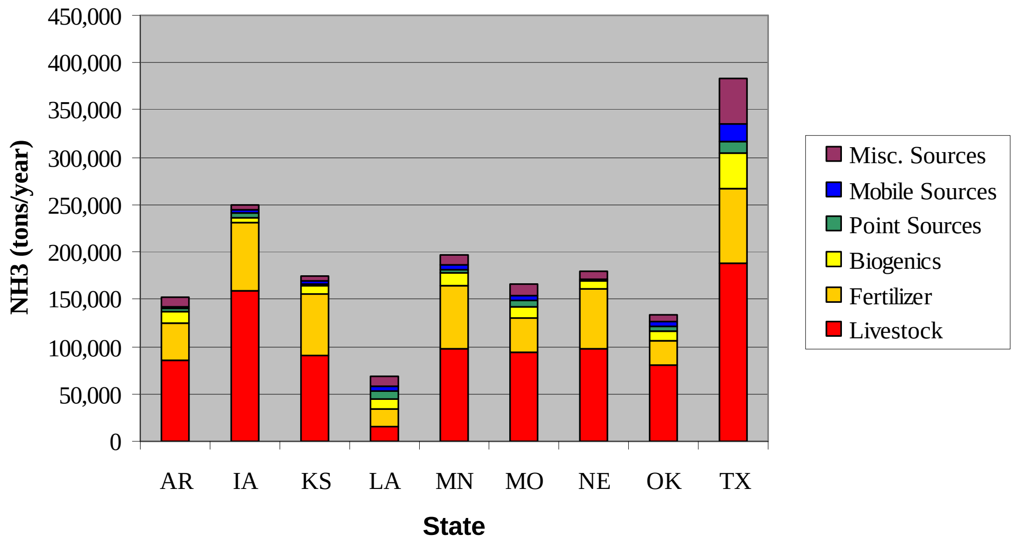

Figure 1-9. Total annual ammonia emissions by source category for each state of the CENRAP region.

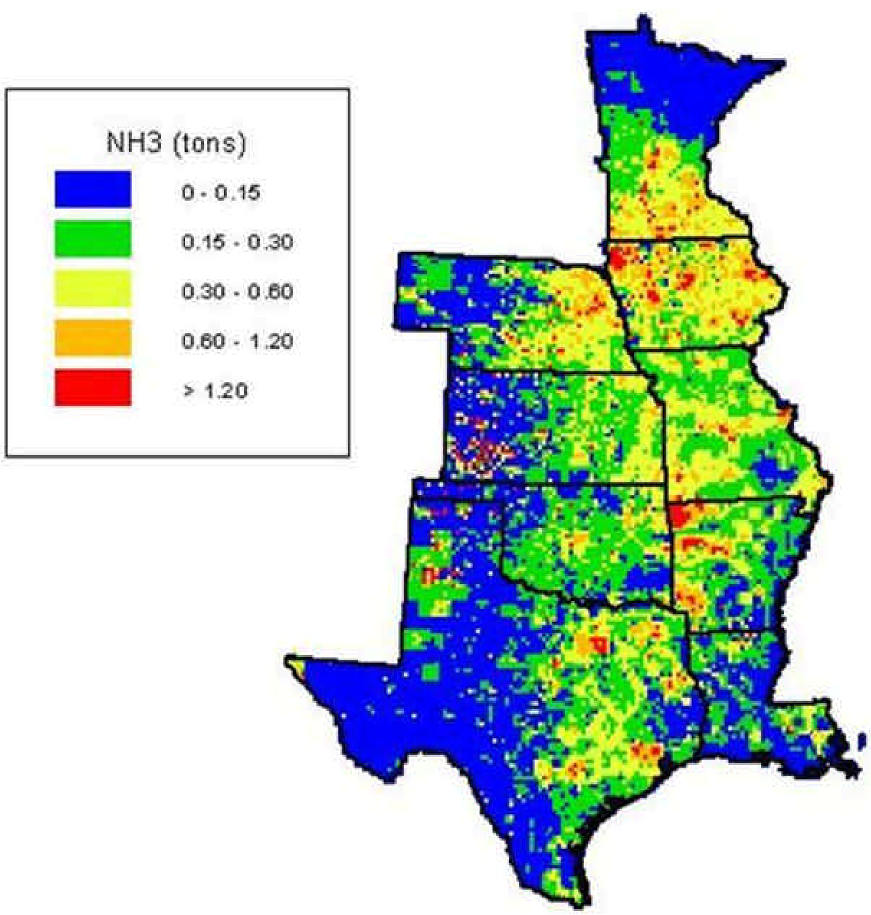

Figure 1-10. Geographic map of emissions densities for the CENRAP region, July 10, 2002.

2. SUMMARY AND ASSESSMENT OF THE INVENTORY

STI calculated emissions as detailed in Appendix A—Ammonia Emission Estimation Methods for the CENRAP Ammonia Emission Inventory. (Results are tabulated in Appendix B—Tabulation of Ammonia Emissions Estimates for the CENRAP Region.) In addition, STI carried out quality assurance procedures as provided in the Quality Assurance Plan and as detailed in this section. In summary, the most important source categories are estimated to be livestock and poultry, fertilizers, and biogenics, all three of which are also considered to contribute the greatest sources of uncertainty in the overall inventory. Total emissions vary seasonally by a factor of 3 to 8, with peaks occurring in the spring or fall. Total emissions vary geographically across the CENRAP region from <0.0.003 to >2 metric tons per day per square kilometer.

2.1 EMISSIONS FROM LIVESTOCK AND POULTRY

2.1.1 Summary of Emissions from Livestock and Poultry

Emissions estimates were generated for several types of livestock and poultry, including beef cattle, milk cows, hogs/pigs, sheep, goats, horses, broilers, layers, pullets, turkeys, geese, and ducks. The population of each of these animal types housed in concentrated animal feeding operations (CAFOs) was determined so that emissions from these facilities could be treated as point sources, with emissions from the remaining "free range" animals being treated as area sources. It was determined that emissions from livestock and poultry contribute 53% to total estimated emissions for the CENRAP region, ranging from 23% to 63% of total emissions from state to state (see **Table 2-1**). Emissions associated with concentrated animal feeding operations (CAFOs) were especially high for Iowa and Kansas, exceeding emissions associated with "free range" livestock for those two states. **Figure 2-1** shows the relative importance of each animal type in each state. The most important animal types are beef cattle (especially in the states of Texas, Kansas, and Nebraska), hogs and pigs (especially in the states of Iowa and Minnesota), and poultry (especially in the state of Arkansas).

The seasonal variability of livestock emissions follows a bimodal pattern, with peaks in spring and fall when manure is typically applied on croplands as fertilizer. **Figure 2-2** illustrates the seasonal variability in livestock emissions for each state.

Table 2-1. Livestock and poultry emissions by state.

State	NH_3 Emissions (tons/year)			% of State Inventory
	CAFOs[1]	Free range[2]	Total	
Arkansas	4,096.0	81,978.6	86,074.6	56.5%
Iowa	88,722.5	69,713.6	158,436.1	63.3%
Kansas	57,611.1	33,455.9	91,067.0	52.1%
Louisiana	82.4	15,837.5	15,919.9	23.1%
Minnesota	25,518.0	72,562.1	98,080.1	49.8%
Missouri	24,685.5	68,925.6	93,611.1	56.6%
Nebraska	30,240.0	66,743.0	96,983.0	53.9%
Oklahoma	19,864.6	60,016.8	79,881.4	60.1%
Texas	45,650.0	143,115.0	188,765.0	49.2%

[1]Includes emissions from all animal types housed at CAFOs in each state.
[2]Includes emissions from all non-CAFO animals in each state.

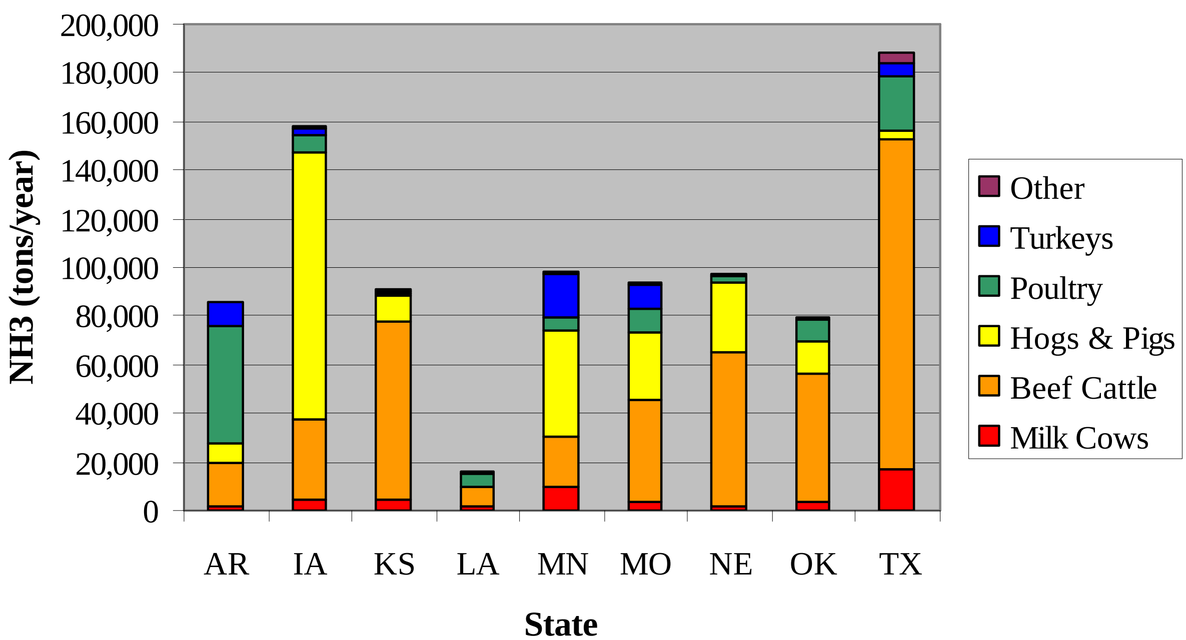

Figure 2-1. Livestock and poultry emissions by state and animal type.

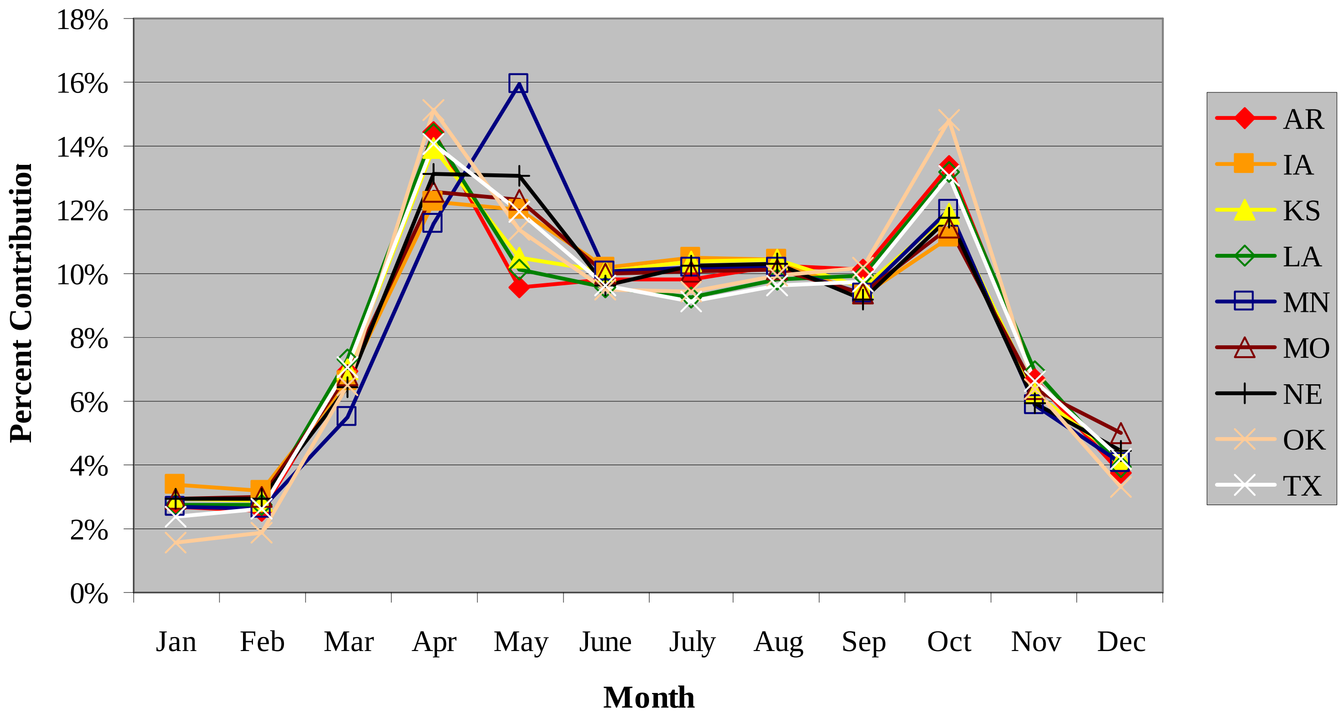

Figure 2-2. Seasonal variabilities in emissions from livestock and poultry by state.

2.1.2 Assessment of Emissions from Livestock and Poultry

This category (livestock and poultry) was the largest source of ammonia emissions in the inventory, which is to be expected for large Midwestern states recognized for their livestock production. (Louisiana is an exception.) To check the reasonableness of the emissions presented above, state totals were compared with results obtained by running the CMU model with no alteration in livestock population estimates (see **Figure 2-3** and Appendix C). Each state's total was within 5% of the CMU result with the exception of Kansas, where our emissions estimate was 14% higher. This difference is due to the fact that we estimate a greater population of beef cattle in Kansas based on National Agricultural Statistics Service (NASS) and CAFO data than is reported in the 1997 Census of Agriculture.

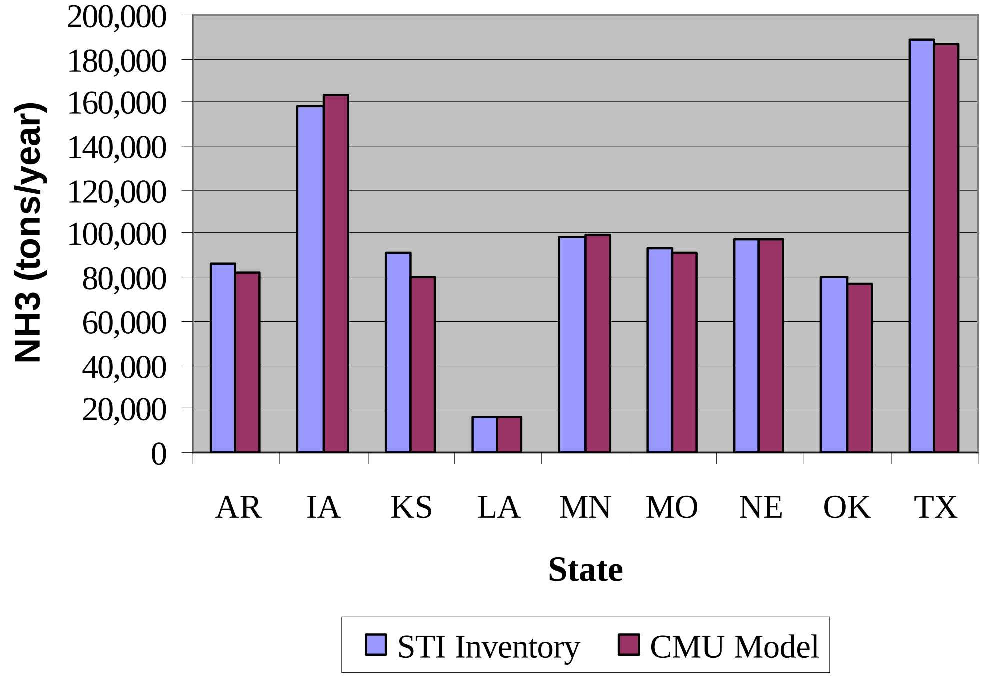

Figure 2-3. Comparison of livestock emission totals.

A second quality assurance step taken was the production of an emissions density plot showing only the point source portion of the inventory, which largely consists of CAFOs (14,000 point sources were included in the inventory, of which 80% were CAFOs). **Figure 2-4** shows a band of sources across northern Texas, western Kansas, central Nebraska, all of Iowa, and southern Minnesota, a distribution that can also be seen in an animal population density map for confined livestock produced by the U.S. Department of Agriculture for 1997 (see **Figure 2-5)**.

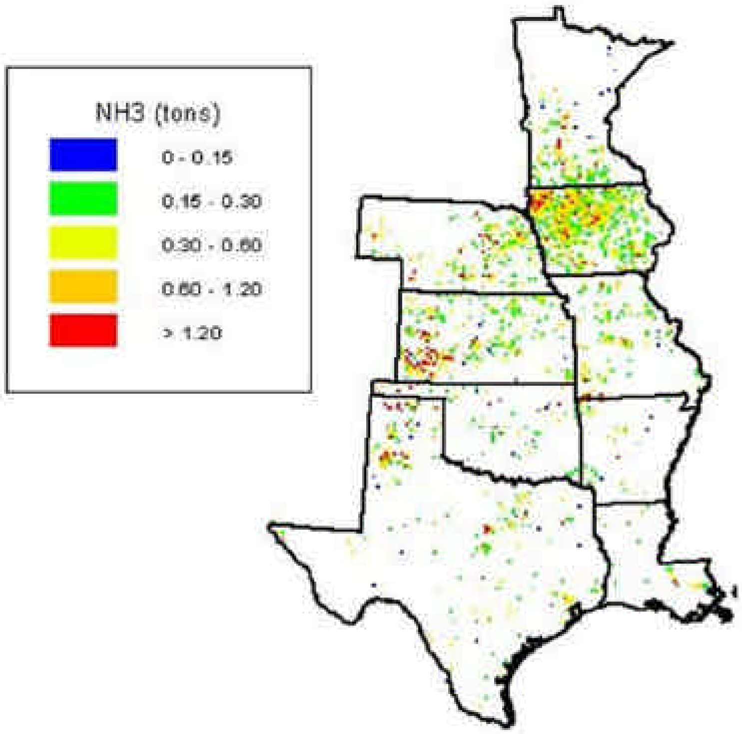

Figure 2-4.   Point source emissions for July 10, 2002.

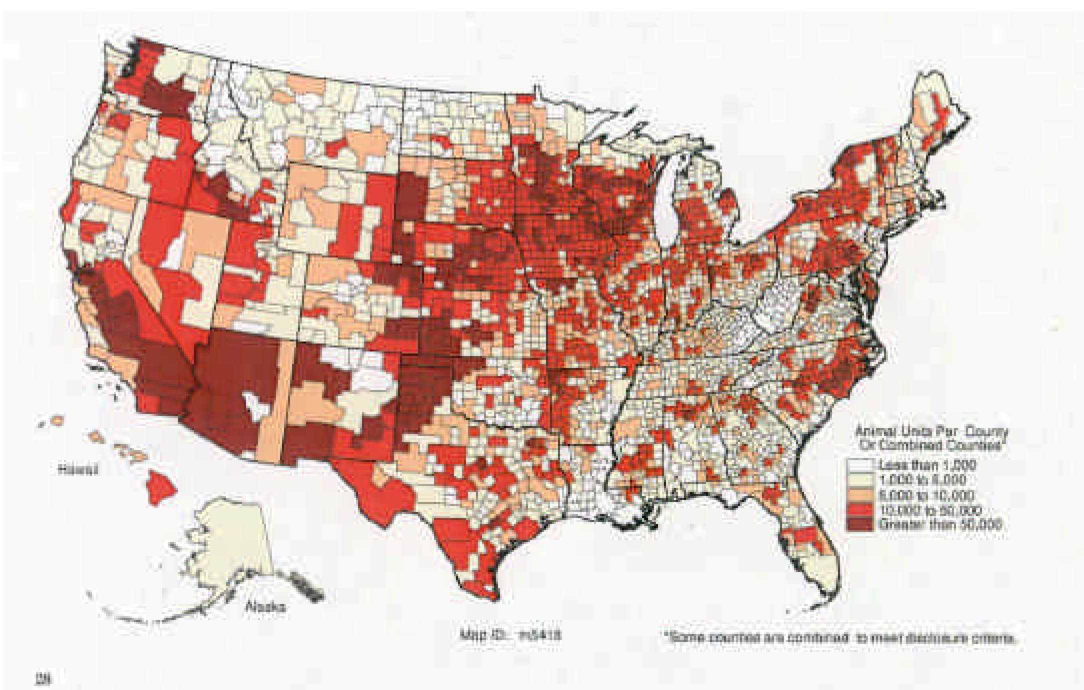

Figure 2-5.   Animal population density map for confined livestock, 1997 (Kellogg et al., 2000).

2.2 EMISSIONS FROM FERTILIZER APPLICATION

2.2.1 Summary of Emissions from Fertilizer Application

Emissions from fertilizer application contribute 27% to total estimated emissions for the CENRAP region, ranging from 20% to 37% of total emissions from state to state. The most important fertilizer types are urea (especially in the states of Minnesota, Texas, and Arkansas), nitrogen solutions (especially in the states of Texas, Nebraska, and Iowa), and anhydrous ammonia (especially in the states of Iowa, Nebraska, and Kansas). **Figure 2-6** illustrates the relative importance of each fertilizer type in each state.

Similar to emissions from livestock and poultry, emissions from fertilizer application follow a bimodal pattern of seasonal variability, with peaks in the spring and fall (see **Figure 2-7**). Some states exhibit particularly pronounced emission spikes in certain months due to the types of crops that dominate in the state. Iowa, for example, is dominated by corn growers and does not produce as wide a variety of crops as other CENRAP states. Thus, in Iowa 40% of all emissions from fertilizer application occur in the month of April. Oklahoma and Kansas, on the other hand, produce a great deal of winter wheat and, therefore, have unusually high emission rates in August and September.

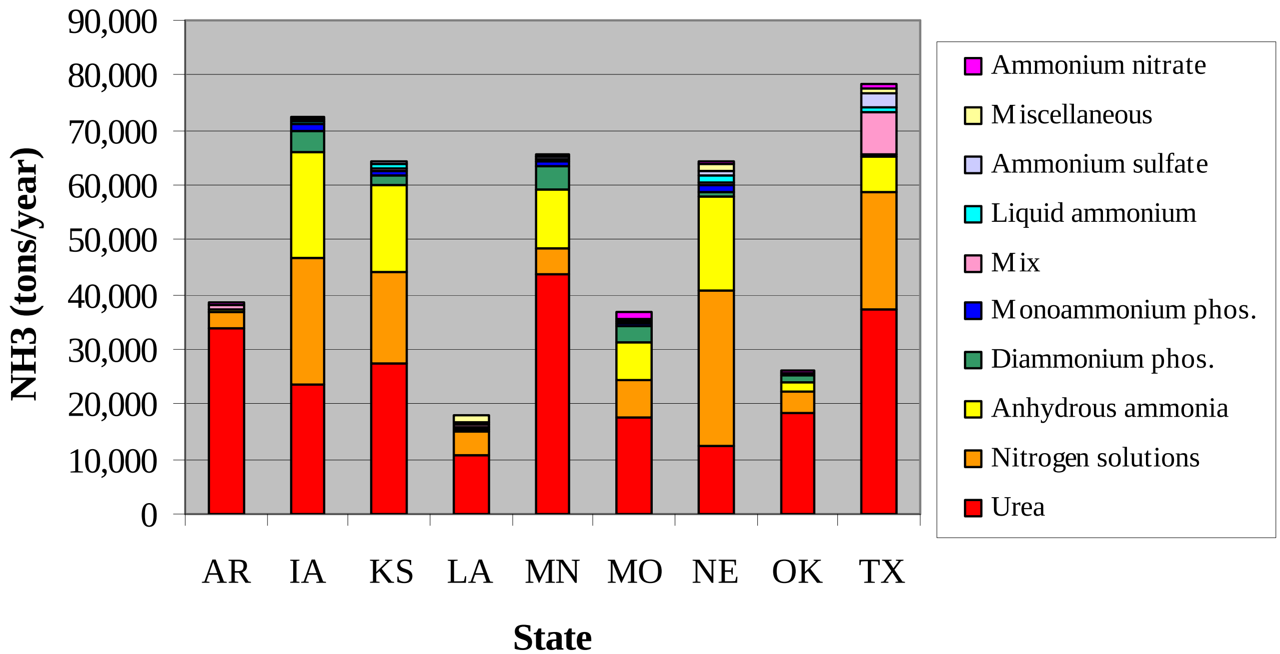

Figure 2-6. Emissions by fertilizer type for each state of the CENRAP region.

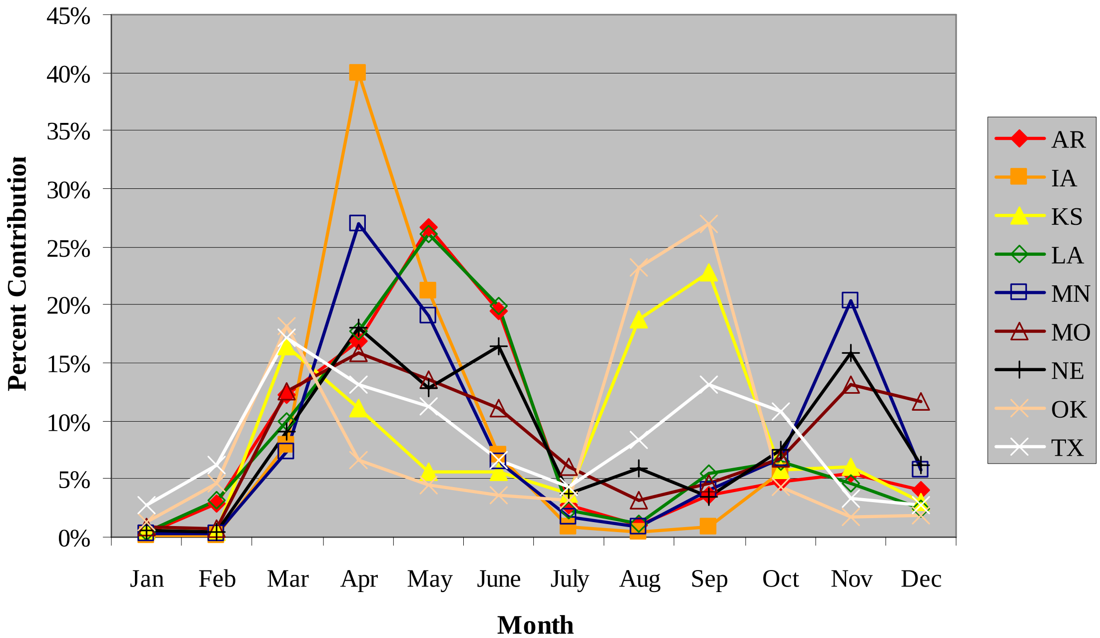

Figure 2-7. Seasonal variabilities in emissions from fertilizer application for each state of the CENRAP region.

2.2.2 Assessment of Emissions from Fertilizer Application

As expected, this category was the second largest source of ammonia emissions in the inventory. To check the reasonableness of the emissions presented above, state totals were again compared with results obtained by running the CMU model with no alteration in fertilizer activity data or emission factors (see **Figure 2-8** and Appendix C). The emissions totals for five states were within 5% of the CMU result, while the emissions for three states (Nebraska, Missouri and Louisiana) were 10% - 27% higher than the totals produced by the CMU model. Only one state, Kansas, proved to have significantly lower emissions (-8%) than those predicted by the CMU model.

These differences are largely due to changes in activity data and emission factors. First, we replaced the 1995 Association of American Plant Food Control Officials (AAPFCO) fertilizer usage data used in the CMU model with 2002 AAPFCO data, resulting in significant changes in activity data for some states. For example, total fertilizer usage in Kansas dropped 25% from 1995 to 2002, resulting in a significant emission reduction. On the other hand, fertilizer usage in Nebraska increased by 15% over the same time period, resulting in a 27% increase in emissions.

Additionally, we updated the emission factors used by the model. These emission factors were developed by the European Environment Agency (2001) and are dependent on soil type and climate. The European factors can be grouped according to the following classification system:

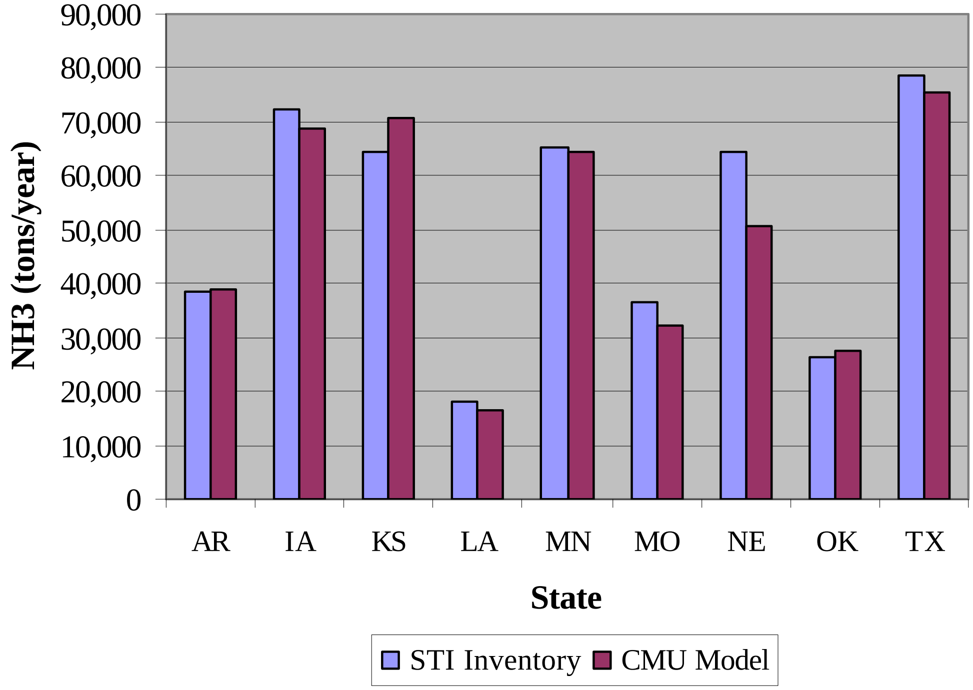

Figure 2-8. Comparison of emission totals from fertilizer application.

- Group I – Warm, temperate areas with a large proportion of calcareous soils.
- Group II – Temperate and warm-temperate areas with some calcareous soils (or managed with soil pH>7), but with large areas of acidic soils.
- Group III – Temperate and cool-temperate areas with largely acidic soils.

While the CMU model assigns whole states to one of the groupings listed above, we made these assignments at the county level based on the average soil pH in a given county (as reported by the National Resources Conservation Service (1994). Thus, for example, while the CMU model assigns all Nebraska counties to Group III, we assigned the majority of the state's counties to Group II, a classification with higher emission factors than Group III.

2.3 BIOGENIC EMISSIONS

2.3.1 Summary of Biogenic Emissions

Biogenic emissions (often called "natural soil" emissions) are especially uncertain because emission rates and the character of the natural environment as a source or a sink of ammonia are not studied as extensively as they are for other source categories. We estimated that biogenic emissions contribute 7% to total estimated emissions for the CENRAP region, ranging from 2% to 15% of total emissions from state to state. The most important land cover types are croplands and pasture (especially in the states of Texas, Iowa, and Kansas), deciduous forests (especially in the states of Missouri, Oklahoma, and Texas), and mixed forests (especially in the states of Texas, Minnesota, and Arkansas). **Figure 2-9** illustrates the relative importance of each land cover type in each state. No information about seasonal variabilities was available; therefore, no monthly temporal profiles have been assigned.

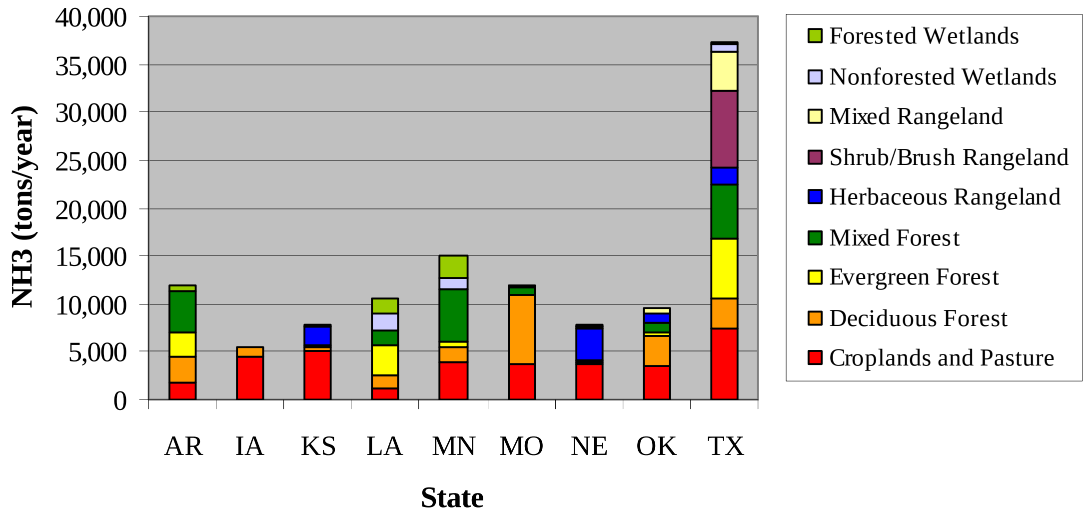

Figure 2-9. Biogenic emissions by land cover type for each state of the CENRAP region.

2.3.2 Assessment of Biogenic Emissions

Emissions estimates for this source category are *highly uncertain*. Initial estimates calculated using the CMU model's activity data and emission factors resulted in biogenic emission totals that accounted for half the total ammonia inventory in the CENRAP region. After a literature search, we chose to apply emission factors that were selected for use by Battye et al. (2003), which were based on factors reviewed or published by Schlesinger and Hartley (1992), Buowman et al. (1997), Kinnee et al (1997), and Van Der Hoek (1998). Use of these emission factors reduced biogenic emissions by 93% overall (see **Figure 2-10**), with the result that biogenic emissions accounted for 7% of the total CENRAP ammonia inventory. Battye et al. (2003) calculated similar percent contributions—about 6.6% and 6.3%—for emission inventories in North Carolina and California's San Joaquin Valley. When the CENRAP inventory is used for modeling sensitivity runs, it will be important to consider a wide range of uncertainty in the estimates of biogenic emissions.

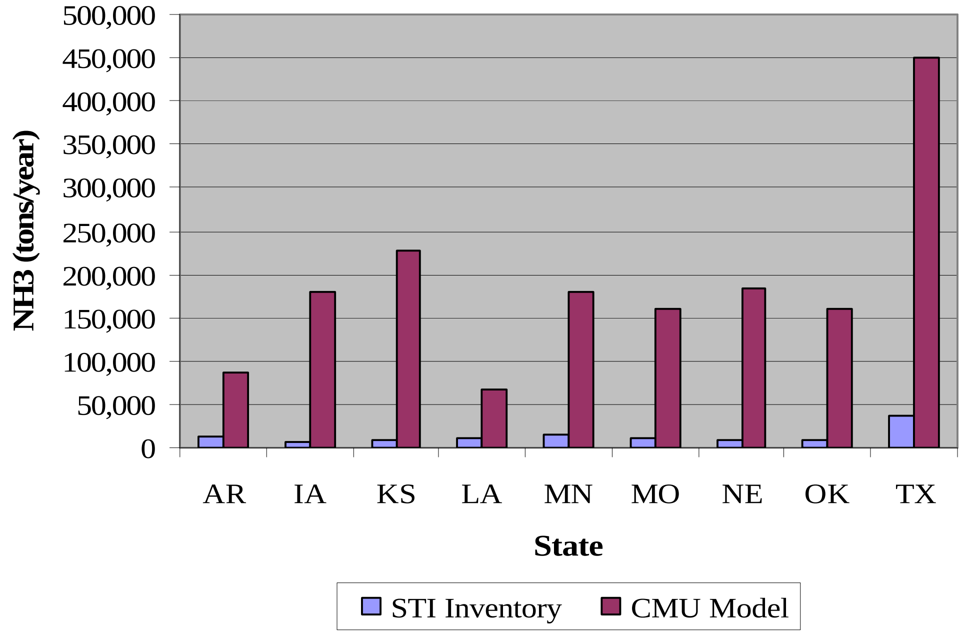

Figure 2-10. Comparison of biogenic emission totals.

2.4 EMISSIONS FROM OTHER SOURCE CATEGORIES

2.4.1 Summary of Emissions from Other Source Categories

All other source categories contributed 13% to total estimated emissions for the CENRAP region, ranging from 5% to 35% of total emissions from state to state. These included publicly owned treatment works (POTWs), wildfires, on-road mobile sources, non-road mobile sources, industrial point sources, landfills, ammonia refrigeration, and miscellaneous sources (domestic animals, human respiration, and wild animals). The most important of these source types are wild animals (especially in the states of Texas, Louisiana, and Arkansas), domestic animals (especially in the states of Texas, Missouri, and Oklahoma), and on-road mobile sources (especially in the states of Texas, Minnesota, and Missouri).

2.4.2 Assessment of Emissions from Other Source Categories

Because these source categories were relatively unimportant in comparison with livestock and fertilizer application, simple methods were employed to estimate the ammonia emissions associated with them. Emissions from six of these source categories (POTWs, wildfires, on-road mobile sources, domestic animals, wild animals, and human respiration) were taken directly from the CMU model with no updated activity data or emission factors.

Three other source categories (non-road mobile sources, landfills, and ammonia refrigeration) were omitted from the CMU model, so we independently prepared emissions estimates for these categories. Emissions from non-road mobile sources were taken directly from the 1999 NEI, emissions from landfills were calculated from facility-specific, waste-in-place estimates, and emissions from ammonia refrigeration were estimated on an employment-based emission factor of 187 kg NH_3/employee reported by Battye et al. (1994). As the latter estimate is the most uncertain, we verified the scale of the emission factor by determining that annual production of ammonia for refrigeration uses in the United States is between 270,000 Mg and 350,000 Mg (Battye et al., 1994; International Institute of Ammonia Refrigeration, 2003). For the food-production industries that commonly use ammonia refrigeration, total United States employment equals approximately 1 million employees (U.S. Census Bureau, 2003). Thus, these figures yield a factor of 270 to 350 kg NH_3/employee-yr, which is on the same order of magnitude as the factor estimated by Battye et al. (1994), although it is 44% to 87% larger.

Finally, for industrial point sources, county-level emissions data from the EPA's 1995 Toxics Release Inventory (TRI), which was loaded into the CMU model, were replaced with data from the 2001 TRI and 1999 NEI point source inventory. Emissions reported in the more recent TRI data were selected for facilities with emissions records in both data sets, and emissions for several "supersized" ammonia sources (those with emissions greater than 5 tons/summer day) in the 1999 NEI were altered or eliminated based on guidance received from individual states (Sabo, 2003).

2.5 SOURCE CATEGORIES OMITTED FROM THE INVENTORY

We considered, but omitted, several source categories from the final inventory, including biomass burning, composting, geothermal emissions, ammonia injection for NO_x control, and biosolids (sewage sludges). These categories were excluded for the following reasons:

- *Biomass Burning.* The CMU model estimates ammonia emissions from wildfires, but not planned burning. However, because a planned burning emissions inventory, which will include ammonia, is being developed by STI under a different work assignment, this source category will be addressed through that separate project.
- *Composting*. Ammonia is released during the degradation of organic waste at composting operations. A 2000 inventory of ammonia emissions prepared by AVES for California's South Coast Air Basin (Botsford et al., 1999) utilized an emission factor of 2.755 pounds of ammonia per ton of material processed to estimate emissions from this source. In that inventory, composting operations accounted for 5.25% of the total inventory. However, this estimate was based on an annual throughput of 2,445,600 tons of waste in the South Coast Air Basin alone. By comparison, the only CENRAP states for which composting activity data were readily available—Iowa and Minnesota—report statewide annual throughputs of only 628,000 tons and 462,000 tons, respectively. Based on this indication that composting efforts are not likely to be widespread in the CENRAP region and a lack of easily accessible data for the seven other states, we excluded this source category.
- *Geothermal Emissions.* Geothermal power-generation facilities release significant ammonia emissions from cooling towers. However, the *Renewable Energy Annual 1996* (Energy Information Administration, 1997) indicates that "known geothermal resource

areas in the United States with resource conditions sufficient to generate electricity are rare, occurring domestically only in the Western United States and Hawaii."

- *Ammonia Injection for NO_x Control.* One technology for controlling NO_x emissions from stack gases is the injection of ammonia into the exhaust of boilers or gas turbines—an approach that is primarily used at power generation facilities. Excess ammonia that does not react with NO_x is emitted to the atmosphere and is referred to as "ammonia slip."

  In an attempt to determine whether any facilities in the CENRAP states use this technology, we searched control codes contained in the 1999 NEI database. No facilities reported the use of ammonia injection in the NEI. A telephone survey of power generation facilities would be necessary to confirm the absence of these controls. However, such a survey was beyond the scope of the current project; therefore, this source category was omitted.

- *Biosolids.* Our recent review of the CMU Ammonia Model identified biosolids (or sewage sludges) as a source of potentially significant emissions on local scales, but also a source for which emission factors and activity data were insufficient to generate an emission inventory (Chinkin et al., 2003). The effort required to develop the necessary information through measurement programs and facility surveys is beyond the scope of the current project; therefore, this source category was omitted.

3. RECOMMENDATIONS FOR FURTHER RESEARCH

In this report, we have identified the following significant sources of uncertainty (roughly in order of importance): emission factors and temporal profiles for biogenic emissions, livestock emissions, and fertilizer emissions. Research is currently progressing into improved emissions models in each of these three areas. In general, we recommend keeping current with the latest published findings as they are released; from these, identifying the governing parameters that influence emission rates; and setting goals and planning research efforts to gather and track the activity data that will be needed as inputs for the next generations of emissions models. In addition, we have identified two source categories that lack sufficient information to generate emissions estimates for the CENRAP region: ammonia injection for NO_x control and biosolids.

3.1 RECOMMENDATIONS FOR BIOGENIC SOURCES

The largest degree of uncertainty in total emissions is associated with the biogenic source category. Depending on the choice of currently available emission factors, biogenics may be estimated to contribute more than 50% of total annual emissions in the CENRAP region (10 to 15 times more than we estimated), or plant-soil systems may be considered to behave as a net sink of ambient ammonia. In addition, ammonia fluxes for plant-soil systems have been shown to change direction—from net source to net sink—at different times of the year and at different times of the day (Sutton et al., 2002). However, we were unable to identify information that would readily translate into seasonal or diurnal temporal profiles.

Additionally, a lack of clarity currently exists regarding assignment of ammonia emissions to the biogenics category versus the livestock or fertilizer categories. Application of fertilizers or manures to grasslands and cutting of grass have been shown to greatly increase the release of ammonia from living plants (Sutton et al., 2002). However, an argument can be made that because the excess emissions are driven by anthropogenic processes, they are more appropriately assigned to an anthropogenic source category (such as fertilizer use, livestock, or land management).

At this time, the best prospect for improving biogenic emissions estimates for the CENRAP region is the application of research findings from recent and ongoing projects that focus on measurements and modeling of ammonia fluxes from European grasslands: the GRassland-AMmonia INteractions Across Europe (GRAMINAE) and the Emissions and Deposition programs, which have been conducted in partnership with the Coordinated Ammonia Research Activities (CARA) program of the Centre for Ecology and Hydrology (CEH), Edinburgh Research Station, United Kingdom. (Information about CARA, GRAMINAE, and the Emissions and Deposition research programs may be found at http://www.nbu.ac.uk/cara/nh3home.htm.) Recent publications have presented models of ammonia exchange with grassland ecosystems (Flechard et al., 1999; Nemitz et al., 2001; Spindler et al., 2001). In order to apply these models and generate improved estimates of biogenic emissions for the CENRAP region, research should be undertaken to validate their applicability to the CENRAP region, to acquire activity data that the models use as inputs (such as land use information, climatological data, and levels of agricultural nitrogen inputs), and to modify the models for application to the CENRAP region. Such a research effort would be significant in scope; however, the payoff is likely to be worth the expense.

3.2 RECOMMENDATIONS FOR LIVESTOCK

3.2.1 Address Next-Generation Emissions Models

The degree of uncertainty in livestock emissions is also large. Battye et al. (2003), who applied methods similar to ours, recently estimated uncertainties of roughly ±35% for annual emission inventories that were prepared for regions of North Carolina and California. Emission factors and models for livestock and poultry are an area of active research. Researchers are developing emission factors and models that take into account weather and soil conditions, manure management practices, animal diets, and animal housing configurations. Recent peer-reviewed publications include Huijsmans et al. (2003), Battye et al. (2003), Mathur and Dennis (2003), Gilliland et al. (2003), and Riedo et al. (2002). Journals in which research is often published include *Environmental Pollution*; *Atmospheric Environment*; *Water, Air, and Soil Pollution*; *Journal of Agricultural Engineering Research*; *Nutrient Cycling in Agroecosystems*; *Agriculture, Ecosystems and Environment*; and *Plant and Soil*.

In order to take advantage of the research results that have been recently published and will be published over the next few years, productive research efforts could be directed toward the study and acquisition of the activity parameters that are likely to be needed for the emission models under development, such as thorough surveys of manure management practices, manure disposal methods, land application methods, and typical weather conditions experienced at various stages of the manure handling cycle.

3.2.2 Refine Animal Population Estimates

Though the 1997 Census of Agriculture livestock population data used by the CMU model was updated with more current NASS data and state-provided CAFO population data, some uncertainties still exist, particularly in reference to the CAFO data. During this process of updating livestock populations, it was noticed that for several counties the CAFO-reported animal populations greatly exceeded the county totals found in the NASS and/or Census data. For example, the 1997 Census of Agriculture reports 8.3 million broilers (a type of poultry) in Barry County, Missouri, whereas the CAFO data received from the Missouri Department of Natural Resources shows 12 million broilers in the county.

Investigation revealed that for CAFO permitting purposes, facilities report maximum capacities rather than actual animal populations. While it can be assumed that most CAFOs attempt to operate near their capacity, there are situations where this does not appear to be the case, or where facilities are reporting an annual throughput rather than a one-time population figure (we discovered the latter to be the case with a large livestock auction yard in Canadian County, Oklahoma, for example). Because of such anomalies, CAFO data for some counties were scaled down to ensure that total animal population counts remained comparable with data reported in NASS estimates and the 1997 Agricultural Census. For future efforts, uncertainties could be reduced by conducting a survey of large CAFOs in selected counties to determine how closely they operate to their reported maximum capacities.

3.3 RECOMMENDATIONS FOR FERTILIZERS

Uncertainties in the emissions estimates for fertilizers carry similar significance for the CENRAP inventory as the uncertainties for livestock emissions—roughly 20% or so of the total inventory. As is the case for livestock, emission factors and models for fertilizers are an area of active research. Researchers are developing emissions models that take into account weather and soil conditions, land application methods, and fertilizer quality. Research is frequently published in the same journals listed for livestock: *Environmental Pollution*; *Atmospheric Environment*; *Water, Air, and Soil Pollution*; *Journal of Agricultural Engineering Research*; *Nutrient Cycling in Agroecosystems*; *Agriculture, Ecosystems and Environment*; and *Plant and Soil*. In order to apply the next-generation models that are likely to become available over the next several years, it would be useful to develop research strategies to acquire the activity data that will be needed to support emissions modeling, such as thorough surveys of application practices, typical weather conditions, and fertilizer quality.

3.4 RECOMMENDATIONS OTHER SOURCE CATEGORIES

Information was insufficient to develop emissions estimates for ammonia injection for NO_x control and biosolids, sources which may be significant on local geographic scales. We recommend a survey of power plants in the CENRAP region in order to identify facilities that use the ammonia-injection control technology and to assess the potential importance of this source category for the CENRAP inventory.

Development of an inventory for biosolids is more complicated. Suitable emission factors and models are currently unavailable for use, and we have not identified any ongoing research projects related to this area. Should an emissions model be developed at a future date, it will likely be necessary to gather activity data that are not currently tracked: facility-specific estimates of sludge quantities produced, sludge management and disposal practices, ammoniacal contents of produced sludges, and weather conditions.

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APPENDIX A

AMMONIA EMISSION ESTIMATION METHODS FOR THE CENRAP AMMONIA EMISSION INVENTORY

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AMMONIA EMISSION ESTIMATION METHODS FOR THE CENRAP AMMONIA EMISSION INVENTORY

Methods Document
STI-902502-2386-MD2

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October 30, 2003

QUALITY ASSURANCE STATEMENT

This report was reviewed and approved by the project Quality Assurance (QA) Officer or his delegated representative, as provided in the project QA plan.

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Project QA Officer

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1. INTRODUCTION

In support of the Central States Regional Air Planning Association's (CENRAP) need to develop a regional haze plan, Sonoma Technology, Inc. (STI) developed an ammonia emission inventory for the region. This Methods Document presents the techniques applied to develop the inventory. In summary, we used the Carnegie Mellon University (CMU) model—an ammonia emissions modeling tool—and supplemental emissions estimation techniques for miscellaneous source categories that were omitted from the CMU model.

Inventory development began with the identification and evaluation of information resources to enhance version 3.0 of the CMU model. STI previously evaluated an earlier version (2.0) of the CMU model as part of a study for the Lake Michigan Air Directors Consortium (LADCO) (Chinkin et al., 2003), and CMU incorporated many of STI's recommendations in the most recent version of the model (version 3.0), which was released in April 2003. This Methods Document identifies further revisions that were made to improve the CMU model outputs for the CENRAP region, including revisions to the emission factors and updates of the activity data.

Consistent with the project goals presented in the Work Plan (Coe, 2003), this Methods Document primarily discusses emission estimation techniques for two source categories: livestock production and fertilizer use. In addition, it provides a cursory treatment of emissions sources that are omitted from version 3.0 of the CMU model, such as landfills, non-road mobile sources, and ammonia refrigeration.

1.1 SUMMARY OF RECOMMENDED METHODS

We estimated ammonia emissions for thirteen source categories listed in **Table 1-1**. For livestock production, fertilizer application, and biogenic sources (soil), we used the CMU model to estimate emissions, but only after the model's emission factors and activity data were revised and/or updated as summarized in **Table 1-2**. We also used the CMU model to estimate emissions for six other categories, including publicly owned treatment works (POTWs) and on-road mobile sources. For these categories, we simply used the version 3.0 model outputs without modification. In addition, we adopted existing emission inventories for point sources. Lastly, we estimated emissions for three source categories omitted from the CMU model: landfills, non-road mobile sources, and ammonia refrigeration.

Table 1-2 briefly identifies recommended sources of emission factors and activity data. **Tables 1-3 and 1-4** list recommended temporal profiles and spatial allocation surrogates by source category. The diurnal profile for livestock house at feedlots was derived from a study of ammonia emissions from swine operations (Aarnink, 1997). The diurnal profile for fertilizer application and free-range livestock was based on a study of nitric oxide fluxes from soil (Anderson and Levine, 1987). The diurnal profile for emissions from soil was derived from a recent European research project conducted on grasslands (Sutton et al., 2002). Diurnal allocations for other categories were based on default profiles assigned by the Sparse Matrix Operator Kernal Emissions Modeling System (SMOKE). The subsequent chapters of this Methods Document provide many more details about the information summarized in Tables 1-2 through 1-4.

Table 1-1. Summary of approaches to estimate ammonia emissions.

Source Category	Emissions Estimation Approach		
	Use CMU Model		Generate or Adopt Estimates Independently from CMU Model
	Without Revisions	With Revisions	
Included in CMU model:			
Livestock		✓	
Fertilizer		✓	
POTWs	✓		
Human perspiration and respiration	✓		
Domestic animals	✓		
Wild animals	✓		
Wildfires	✓		
On-road mobile sources	✓		
Industrial point sources			✓
Biogenic sources (“soil”)		✓	
Not included in CMU model:			
Landfills			✓
Ammonia refrigeration			✓
Non-road mobile sources			✓

Table 1-2. Summary of emission factors and activity data sources.

Source Category	Emission Factor(s)	Activity Data	Comments
Livestock production	Retain factors from CMU Model 3.0 (Region-specific characteristics will be applied through temporal and spatial allocations).	Existing 1997 USDA Agricultural Census data will be improved with 2002 NASS population data and data for confined animal feeding operations (CAFO), which will be obtained from individual states.	Emissions from CAFOs will be treated as point sources.
Fertilizer application	Refine factors from CMU model to make them more specific to climate and soil types in the CENRAP.	2002 fertilizer usage data from the Association of American Plant Food Control Officials (AAPFCO) will be used with additional data from state agencies.	The CMU model currently uses 1995 AAPFCO data.
Landfills	Use equations published in the Emission Inventory Improvement Plan (EIIP) Volume VIII and a published ratio of methane to ammonia emissions.	Obtain waste in place (WIP) data from EPA's Landfill Methane Outreach Program (LMOP) database and use with additional data from state agencies.	The EIIP methodology generates methane emissions, which are then converted to ammonia.
Ammonia refrigeration	Apply an employment-based emission factor.	Use county-level employment data published by the U.S. Census Bureau.	Emissions estimates are based on employment in specific food processing industries.
Non-road mobile sources	N/A	N/A	Emissions will be taken directly from the 1999 National Emission Inventory (NEI) non-road inventory.
Point sources	N/A	N/A	Emissions will be taken directly from the 2001 Toxics Release Inventory (TRI) and 1999 NEI inventories.
Biogenic sources (soil)	Replace factors used in the CMU model with those recently published by Battye et al. (2003).	Use soil-type data from the CMU model with no revisions.	Emissions estimates from this source category are highly uncertain.

Table 1-3. Summary of seasonal profiles and spatial surrogates.

Source Category	Source of Information for Seasonal Profiles	Source of Information for Spatial Surrogates
Livestock Production	Use monthly allocation factors published by Pinder et al (2003).	Rangeland landuse category from the EPA's Biogenic Emissions Landcover Database (BELD).
Fertilizer Application	Develop new seasonal profiles.	Cropland landuse category from the EPA's BELD data.
Landfills	Use SMOKE default temporal profiles assigned by Source Category Code (SCC).	Facility-reported coordinates, addresses, or centroid of zip codes.
Point Sources		
Ammonia Refrigeration	Use SMOKE default temporal profiles assigned by Source Category Code (SCC).	County area.
Non-road Mobile Sources		
Biogenics (soil)	Use diurnal profile from recent European study (Sutton et al., 2002).	County area.

Table 1-4. Summary of diurnal profiles.

Hour of Day	Proportion of Total Daily Emissions (%)		
	Livestock Housed at Feedlots	Fertilizer/Free-range Livestock	Soil
Midnight-1 a.m.	3.9%	2.0%	3.9%
1-2 a.m.	4.0%	2.0%	3.1%
2-3 a.m.	4.0%	2.0%	2.3%
3-4 a.m.	4.1%	2.0%	1.6%
4-5 a.m.	4.1%	2.0%	1.1%
5-6 a.m.	4.2%	2.1%	0.8%
6-7 a.m.	4.2%	2.8%	0.7%
7-8 a.m.	4.2%	4.1%	0.9%
8-9 a.m.	4.2%	7.0%	1.5%
9-10 a.m.	4.3%	7.4%	2.3%
10-11 a.m.	4.3%	8.2%	3.4%
11 a.m.-Noon	4.3%	8.2%	4.5%
Noon-1 p.m.	4.3%	8.1%	5.5%
1-2 p.m.	4.3%	7.8%	6.4%
2-3 p.m.	4.3%	6.5%	6.9%
3-4 p.m.	4.3%	4.1%	7.1%
4-5 p.m.	4.2%	4.1%	7.1%
5-6 p.m.	4.2%	3.1%	6.9%
6-7 p.m.	4.2%	2.9%	6.7%
7-8 p.m.	4.2%	2.9%	6.4%
8-9 p.m.	4.1%	2.9%	6.0%
9-10 p.m.	4.1%	2.9%	5.5%
10-11 p.m.	4.0%	2.9%	5.0%
11 p.m.-Midnight	4.0%	2.0%	4.5%

1.2 IMPORTANT PREMISES AND ASSUMPTIONS

The methods that we selected for use were based on several important premises or assumptions:

- For livestock populations, the grounds for selecting 2002 county-level National Agricultural Statistics Service (NASS) data—which are based on local surveys—is that we gauged them to be an improvement over the older population data reported in the 1997 USDA Agricultural Census (which is the latest version of the Agricultural Census available).
- We assumed that temporal allocation factors for dairy cows (seasonal) and swine (diurnal) are reasonably similar to those of other types of livestock.
- For fertilizer application, emission factors developed by the European Environment Agency (2001) for similar climate zones and similar types of fertilizers were presumed to be applicable to fertilizers used in the United States.
- Natural Resources Conservation Service (NRCS) classifications of soil types were presumed to be representative and indicative of the fertilizer emission factors that are most applicable to each county in the CENRAP region.
- We assumed that diurnal patterns of nitric oxide flux from soil emissions observed by Anderson and Levine (1987) can be used to approximate diurnal patterns of ammonia emissions from fertilizer application (Chinkin et al., 2003).
- For landfills, the U.S. Environmental Protection Agency's (EPA) Landfill Methane Outreach Program (LMOP) is assumed to be sufficiently complete for those states where other data is unavailable.
- For point sources, a combination of ammonia emissions data contained in the 2001 Toxics Release Inventory (TRI) and 1999 National Emissions Inventory (NEI) are expected to be sufficiently complete for the purposes of this inventory.
- We expected that the emission factors and activity data contained in version 3.0 of the CMU model were sufficient to characterize ammonia emissions from POTWs, human beings, domestic animals, wild animals, wildfires, and on-road mobile sources. In addition, we assumed that the hidden algorithms in version 3.0 of the CMU model function correctly and as reported in the model documentation for these sources.

2. LIVESTOCK PRODUCTION

2.1 OVERVIEW

For other inventories, livestock and poultry operations have been estimated to be the most significant sources of ammonia emissions nationwide (U.S. Environmental Protection Agency, 2000). Nationally, the EPA estimated that ammonia emissions from commercial animal husbandry in the United States were dominated by calves and cattle (78%), followed by hogs and pigs (19%). The other 3% of emissions came from chickens (2%) and sheep (1%).

In order to estimate the magnitude of livestock and poultry emissions for a given state or county, local animal populations are needed, as well as emission factors that quantify pounds of ammonia emissions per head of livestock. Ideally, emission factors also should vary with weather conditions, animal management practices, and manure management practices. However, emission factors with this level of detail generally are unavailable. To compensate, we used a new study recently published by Pinder et al. (2003) and discussed in Section 2.4 to generate an inventory for livestock that reasonably represents region-specific temporal patterns.

2.2 LIVESTOCK AND POULTRY EMISSION FACTORS

A wide variation in livestock emissions is reported in different studies in the United States and Europe. Version 2.0 of the CMU model—previously evaluated by STI for the LADCO project—made use of composite emission factors compiled by Battye et al. (1994) for each U.S. Department of Agriculture (USDA) category. The Battye report recommended European animal waste ammonia factors, which were developed by Asman (1992) on the basis of measurements collected in the 1980s in Europe, for use in the United States. However, STI concluded that these factors might not be well-suited for estimating emissions in the United States because of differences in both animal waste management practices and animal husbandry practices between Europe and the United States. For example, animal waste in the United States is commonly stored in lagoons, and ranches are generally larger in size and enable wider cattle grazing activity. Confined cattle with diets high in nitrogen, as are more common in Europe, tend to emit more ammonia so that European emission factors may over-represent cattle emissions in the United States.

Version 3.0 of the CMU model utilizes emission factors recommended by the EPA's Office of Research and Development (ORD) (U.S. Environmental Protection Agency, 2002b). The original source of the ORD factors were Bouwman and Van der Hoek (1997). Although these, too, are European emission factors, the ORD considered them to be more representative of U.S. agricultural practices on the basis of a detailed mass balance. In addition, these emission factors equate to roughly 25% of excreted nitrogen, which is more in line with current thinking. Therefore, we used the ORD-recommended emission factors as they exist in version 3.0 of the CMU ammonia model.

2.3 LIVESTOCK AND POULTRY ACTIVITY DATA

Version 3.0 of the CMU model, like its predecessor, relies exclusively on the 1997 USDA Agricultural Census as its source of livestock and poultry activity data. This census is conducted every five years, and data for the 2002 study will not be released until spring of 2004. Therefore, STI will supplement the 1997 data with estimates from the NASS, which are generated annually. Each January and July, the NASS conducts surveys of a sample group of livestock producers, taking steps to ensure statistically representative coverage of all livestock operations in each state. These surveys are then used to produce an estimated livestock inventory by county. The vintages of the NASS agricultural surveys vary somewhat by state, so we will use the most current estimates available for each. **Table 2-1** shows the vintages of all available NASS estimates more current than 1997.

Table 2-1. Vintages of most current NASS estimates by state.

State	NASS Livestock Types			
	Beef Cattle	Milk Cows	Hogs & Pigs	Sheep/ Goats
Arkansas	2002	2000	2000	N/A
Iowa	2002	2002	N/A	N/A
Kansas	2002	2002	N/A	2001
Louisiana	2002	2002	N/A	N/A
Minnesota	2002	2002	N/A	2002
Missouri	2002	2002	N/A	2002
Nebraska	2002	2001	N/A	2002
Oklahoma	2002	2002	1999	2002
Texas	2002	2002	N/A	2000

Note: N/A indicates none available from NASS or that data pre-date the 1997 Agricultural Census. For these cases, 1997 Agricultural Census data will be used.

Some limitations are associated with the 1997 USDA Agricultural Census and the NASS data. First, these estimates do not reflect some factors that affect actual state cattle populations, such as seasonal import and export of animals to other states. Also, these data sources do not contain any information on the locations of concentrated animal feeding operations (CAFOs). Feedlots service thousands of animals in fairly confined spaces, such that emissions from the facilities are better treated as point sources. To address these limitations, we contacted agricultural and environmental agencies or departments in each state to request information about livestock populations and seasonal movements of herds, as well as data on CAFO animal populations which might be available from National Pollutant Discharge Elimination System (NPDES) records or other sources. Though no useful data was available on herd movements, we were able to obtain current permit data on CAFO locations and animal populations from all nine CENRAP states. This allowed us to subtract livestock populations at the various CAFOs from the CMU model's county-wide totals so that emissions from those facilities could be treated as point sources and allocated to specific CAFO locations.

During this process of updating livestock populations, it was noticed that for several counties the reported CAFO animal populations greatly exceeded the county totals found in the NASS and/or census data. Investigation revealed that for CAFO permitting purposes, facilities report maximum capacities rather than actual animal populations. While it can be assumed that most CAFOs attempt to operate near their capacity, there are situations where this does not appear to be the case, or where facilities are reporting an annual throughput rather than a one-time population figure. For example, an auction yard named OKC West Livestock Market in Canadian County, Oklahoma, reports a beef cattle population of 198,797 head, which turned out to be the total number of animals moved through the facility in one year (for comparison, the 1997 Agricultural Census identifies only 25,700 head of beef cattle in the entire county). Because of such anomalies, CAFO data for some counties were scaled down to ensure that total animal population counts remained comparable with data reported in NASS estimates and the 1997 Agricultural Census.

Finally, we utilized recent estimates of ammonia emissions from dairy farms published by Pinder et al. (2003) instead of estimates produced by the CMU model for this category. The estimates calculated by Pinder et al. (2003) were derived using a model that considers manure management practices and climatic conditions and, from these, calculates month-specific and region-specific emission factors for dairy cows. Pinder et al. (2003) applied these emission factors to dairy cow populations from the 1997 USDA Agricultural Census to produce a county-level emissions inventory for the entire United States.

2.4 LIVESTOCK AND POULTRY TEMPORAL ALLOCATION

2.4.1 Seasonal Allocation

The CMU model assumes a flat, unvarying rate for livestock emissions. Earlier, STI recommended (Chinkin et al., 2003) the use of a seasonal distribution proposed by Gilliland et al. (2002), which is based on modeled results. While there were concerns about the use of modeled outputs to adjust emission rates, a non-varying seasonal distribution seemed even less likely to reflect real-world conditions.

However, the recent dairy farm model developed by Pinder et al. (2003) is a new source of county-specific seasonal allocation factors that seem more representative of emissions from livestock. Side-by-side comparison shows that the seasonal variability in Pinder et al.'s aggregate national-scale inventory matches up somewhat comparably with the monthly allocation factors proposed by Gilliland et al. (see **Table 2-2 and Figure 2-1**), with some differences.

Table 2-2. Side-by-side comparison of monthly seasonal allocation factors (Proportions are relative to annual average emission rates).

Month	Gilliland Seasonal Allocation Factors	Pinder Seasonal Allocation Factors
January	67%	33%
February	75%	36%
March	75%	78%
April	82%	161%
May	126%	139%
June	164%	122%
July	183%	116%
August	154%	119%
September	115%	120%
October	73%	150%
November	51%	78%
December	51%	50%

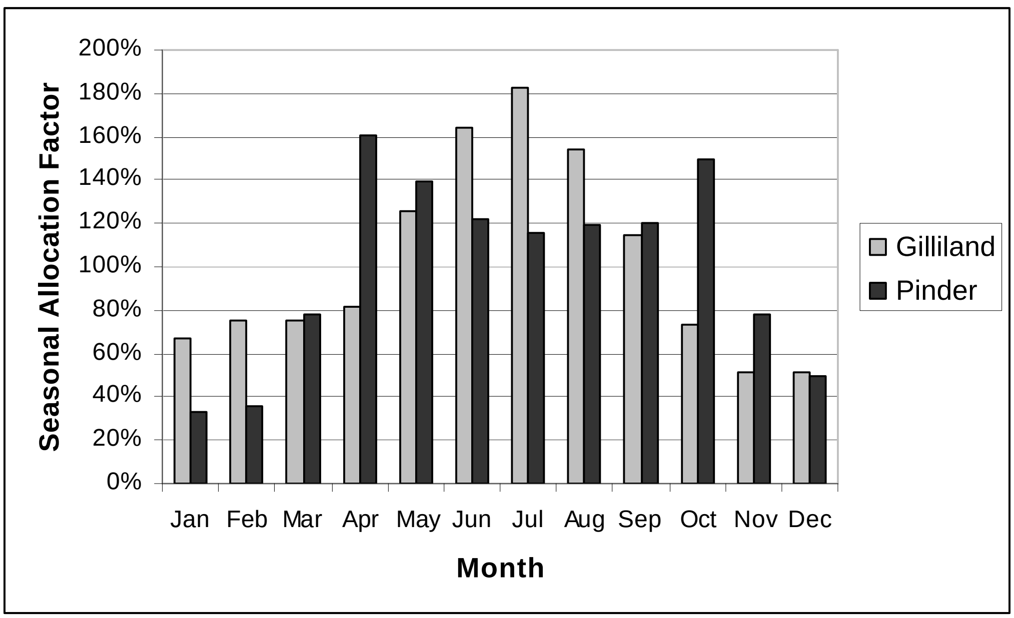


Figure 2-1. Graphical comparison of monthly seasonal allocation factors.

Though the Pinder et al. study was specifically related to dairy cattle, we expect that the allocation factors derived from this study are more representative of real-world conditions than Gilliland's reverse-modeling approach. Therefore, we will use Pinder et al.'s profiles to seasonally allocate emissions from all livestock. Because the Pinder et al. model takes local conditions into account (emission factors are generated for each county in the United States based on climate, husbandry practices, etc.), this approach will result in the development of county-specific seasonal allocation factors for this source category. (It should be noted that the national-level seasonal allocation shown in Table 2-2 is almost certainly weighted toward the colder northern states, which have the most dairies and would not be suitable for the entire CENRAP domain).

2.4.2 Diurnal Allocation

Aarnink (1997) reported that ammonia emissions from houses with rearing and fattening pigs had higher emissions during the day than during the night: +10% for rearing pigs and +7% for fattening pigs. For rearing pigs, emissions peaked in the morning, but for fattening pigs, they peaked in the afternoon. We used this information to develop the diurnal profile for ammonia emissions from pigs shown in Table 1-3 (Chinkin et al., 2003). Because information is currently unavailable to determine a diurnal profile of emissions from other types of livestock, we applied the swine diurnal profile to feedlot cattle, poultry, and other livestock that tend to be housed at close quarters.

For rangeland cattle, manure and urine depositions are spread out over a much larger area than would be the case with cattle housed at feedlots. It is our judgment that diurnal emissions patterns for such cattle are more likely to be consistent with emissions from fertilizer application than with emissions from housed swine. Therefore, we used a diurnal profile developed from nitric oxide fluxes from soil (Anderson and Levine, 1987) that is also being applied to emissions from fertilizer application (see Section 3.4.2).

2.5 LIVESTOCK AND POULTRY SPATIAL ALLOCATION

CAFOs were treated as point sources, with emissions from those facilities allocated according to specific reported coordinates. Other emissions from livestock and poultry will be spatially allocated according to the “rangeland” land type category, an aggregate of the “pasture” and “grassland” landuse categories available from the EPA’s Biogenic Emissions Landcover Database (BELD).

3. FERTILIZER APPLICATION

3.1 OVERVIEW

In other inventories, fertilizer application has been estimated as the second most abundant source of ammonia emissions nationwide (U.S. Environmental Protection Agency, 2000). Emissions from this source can be calculated by applying an appropriate emission factor to the amount of fertilizer applied. Emission factors vary by fertilizer type, application method, soil type, and climate.

3.2 FERTILIZER EMISSION FACTORS

Historically, the EPA recommended the use of Battye et al. (1994) emission factors—in part, because they were accompanied by supporting data and an explanation of factor development. These emission factors range from 24 lb to 264 lb of NH_3 emitted per ton of fertilizer nitrogen applied (or equivalently, 1% to 5% of NH_3 as nitrogen emitted per ton of fertilizer nitrogen applied). The emission factors in version 2.0 of the CMU model were similar to those recommended by EPA and reported by Battye et al. (1994)

Because ammonia emissions from fertilizer are a function not only of fertilizer type but also soil type and climate, STI recommended (Chinkin et al., 2003) the use of emission factors from the European Environment Agency (2001) which are fertilizer type-, soil type-, and climate-dependent. The European factors were developed according to the following classification system:

- Group I – Warm, temperate areas with a large proportion of calcareous soils.
- Group II – Temperate and warm-temperate areas with some calcareous soils (or managed with soil pH>7), but with large areas of acidic soils.
- Group III – Temperate and cool-temperate areas with largely acidic soils.

Version 3.0 of the CMU model makes use of these European emission factors, assigning whole states to one of the groupings listed above:

- Group I: Texas
- Group II: Arkansas, Kansas, Louisiana, and Missouri
- Group III: Iowa, Minnesota, and Nebraska

While this approach is an improvement over that used in the previous version of the CMU model, greater refinement of emission factors by geography is possible and preferable. As **Table 3-1** shows, emission factors for some fertilizer types vary widely among classifications. For ammonium sulfate-based fertilizers, for example, the Group I emission factor is 200% higher than the Group III factor and 50% higher than the Group II factor.

Table 3-1. Fertilizer emission factors used in CMU model version 3.0 (%N volatilized as NH_3).

State	EEA Group	Mix/ Ammonium Nitrate	Ammonium Sulfate	Calcium Ammonium Nitrate	Urea	Misc.
Texas	I	3	15	3	20	8
Arkansas	II	2	10	2	15	6
Kansas	II	2	10	2	15	6
Louisiana	II	2	10	2	15	6
Missouri	II	2	10	2	15	6
Oklahoma	II	2	10	2	15	6
Iowa	III	1	5	1	15	7
Minnesota	III	1	5	1	15	7
Nebraska	III	1	5	1	15	7

Because of these large differences, we more fully implemented the European approach through the use of an integrated geographic information system (GIS). The NRCS State Soil Geographic database (STATSGO) was used to identify the dominant soil type (calcareous or acidic) in each county so that the best possible emission factors could be applied. The emission factors in the CMU model were updated as necessary.

3.3 FERTILIZER ACTIVITY DATA

National fertilizer use data are available from the Association of American Plant Food Control Officials (AAPFCO). These data contain semi-annual sales distributions at a county-level for over 100 different types of fertilizers, including those that emit ammonia. Version 3.0 of the CMU model uses AAPFCO data from 1995; therefore, we prepared an updated fertilizer sales database from the 2002 AAPFCO data. State agricultural experts were contacted for further information on fertilization consumption, but no improvements to the AAPFCO data proved to be available.

3.4 FERTILIZER TEMPORAL ALLOCATION

3.4.1 Seasonal Allocation

In version 3.0 of the CMU model, six-month sales data from AAPFCO was broken down into a monthly resolution via an algorithm that incorporated fertilizer timing based on crop calendars and application rates. This algorithm operates on separate six-month intervals—first distributing spring sales data over the first six months of the year, then fall data over the second half of the year. Such a method assumes, of course, that all fertilizer purchased in a given semi-annual period is completely consumed during that time frame.

However, a survey of the AAPFCO data showed that a significant number of records report zero or negative values for fertilizer shipped during the fall cycle (second half of the year). This anomaly is due to returns of unused fertilizer in the fall to fertilizer sellers. While these anomalies tend to occur in counties with relatively small fertilizer sales, they do indicate that fertilizer is not always consumed in the season during which it was purchased. Therefore, they may be indicative of a larger scale, systematic bias throughout the inventory.

Furthermore, the CMU model calculates a single temporal distribution for each state based on the total acreage of various crop types within the state. This approach does not take into account local variations in crop types, which can be considerable across the large states found within the CENRAP region.

To address these concerns, we generated revised temporal algorithms that summed the semi-annual sales data for each county and redistributed the annual total over the twelve months of the year by using county-specific crop acreages published by NASS and the crop calendars and fertilizer timing rates currently employed by the CMU model.

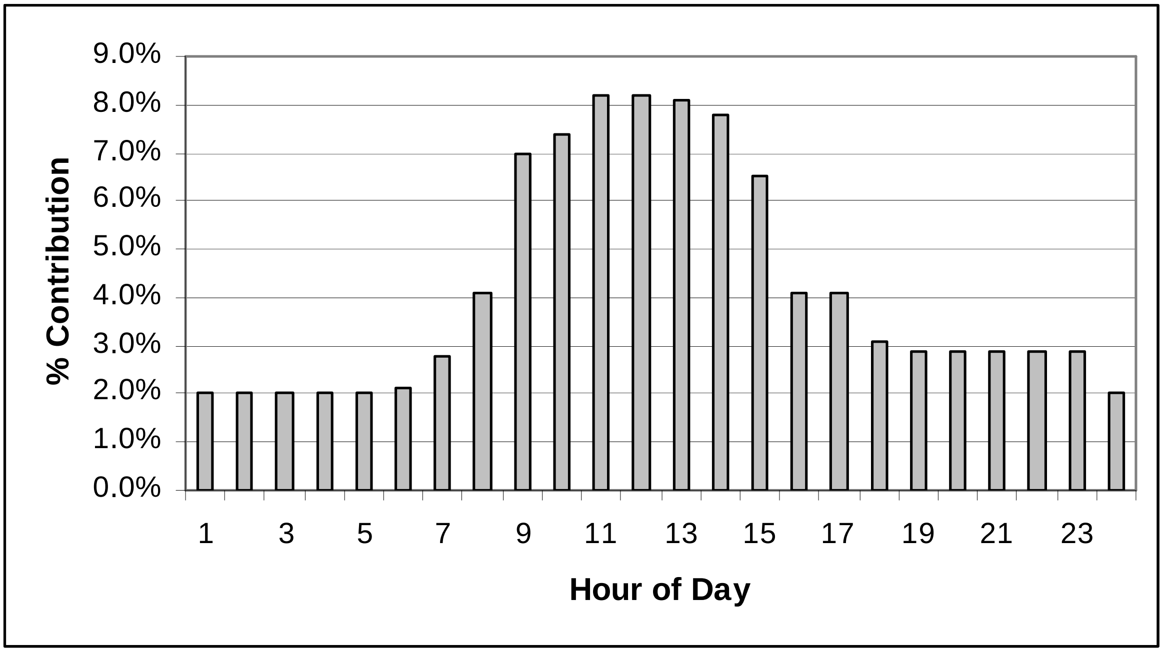
3.4.2 Diurnal Allocation

Midwest Research Institute (1998) found that hourly emission rates of ammonia from fertilizer applications exhibit diurnal patterns that follow temperature fluctuations. Anderson and Levine (1987) found a similar pattern in diurnal nitric oxide fluxes from soil. Because nitric oxide flux profiles are better quantified than ammonia flux profiles, we used them to create the diurnal profile shown in **Figure 3-1**. Although a profile that is directly based on good-quality ammonia emissions measurements would be preferable, we believe that, at present, the better quality of the nitrogen oxides data is a good rationale for its use (Chinkin et al., 2003).

3.5 FERTILIZER SPATIAL ALLOCATION

Emissions from fertilizer application will be spatially allocated to cropland areas available from EPA's BELD.

Figure 3-1. Diurnal ammonia emissions profile for fertilizer application (% of total daily emissions).



4. OTHER SOURCE CATEGORIES

4.1 OVERVIEW

Emissions from other source categories omitted from the CMU model were estimated in order to compile a complete inventory. However, because these sources were assigned a lesser priority than livestock and fertilizer application, we derived emissions estimates by using simple methods.

We considered several source categories for possible inclusion in the final inventory, including landfills, biomass burning, composting, ammonia refrigeration, non-road mobile sources, geothermal emissions, and ammonia injection for NO_x control. We concluded that emissions should be estimated for all of these except biomass burning, composting, geothermal sources, and ammonia injection for NO_x control. These categories were excluded for the following reasons:

- Biomass Burning. The CMU model estimates ammonia emissions from wildfires, but not planned burning. However, because a planned burning emissions inventory, which will include ammonia, is being developed by STI under a different work assignment, this source category will be addressed through that separate project.
- Composting. Ammonia is released during the degradation of organic waste at composting operations. A 2000 inventory of ammonia emissions prepared by AVES for California's South Coast Air Basin (Botsford et al., 1999) utilized an emission factor of 2.755 pounds of ammonia per ton of material processed to estimate emissions from this source. In that inventory, composting operations accounted for 9.7 tons per day of ammonia emissions, or 5.25% of the total inventory. However, this estimate was based on an annual throughput of 2,445,600 tons of waste in the South Coast Air Basin alone. By comparison, the only CENRAP states for which composting activity data were readily available—Iowa and Minnesota—report statewide annual throughputs of 628,000 tons and 462,000 tons, respectively. Based on this indication that composting efforts are not likely to be widespread in the CENRAP region and a lack of easily accessible data for seven states, it is recommended that this source category be excluded from the current inventory effort.
- Geothermal Emissions. Geothermal power-generation facilities release significant ammonia emissions from cooling towers. However, the *Renewable Energy Annual 1996* (Energy Information Administration, 1997) indicates that "known geothermal resource areas in the United States with resource conditions sufficient to generate electricity are rare, occurring domestically only in the Western United States and Hawaii."
- Ammonia Injection for NO_x Control. One technology for controlling NO_x emissions from stack gases is the injection of ammonia into the exhaust of boilers or gas turbines—an approach that is primarily used at power generation facilities. Excess ammonia that does not react with NO_x is emitted to the atmosphere and is referred to as "ammonia slip."

In an attempt to determine if any facilities in the CENRAP states use this technology, we searched control codes contained in the 1999 NEI database. No facilities reported the use of ammonia injection in the NEI. A telephone survey of power generation facilities would be necessary to confirm the absence of these controls. However, such a survey is beyond the scope of the current project.

The remainder of this chapter highlights emissions estimations methodologies for the new categories that were included in the final inventory, as well as two other source categories (point and biogenic sources) for which improvements were made to the CMU approach.

4.2 LANDFILLS

According to *EIIP Volume VIII: Estimating Greenhouse Gas Emissions* (Emission Inventory Improvement Program, 1999), methane emissions from landfills depend on three key factors: (1) total "waste in place" (WIP), which is defined as the sum of waste disposal over a 30-year period; (2) landfill size; and (3) location in an arid or non-arid climate. When WIP data is available for specific landfills within a state, the following equations can be used to estimate methane emissions:

<u>Small Landfills (less than 1.1 millions tons of waste in place)</u>

- Arid climate (less than 25 inches of rainfall per year):

$$CH_4 \text{ (tons/year)} = WIP_{tons} \text{ x } \frac{0.27 \text{ ft}^3\text{/day}}{\text{ton}} \text{ x } \frac{0.0077 \text{ tons } CH_4\text{/yr}}{\text{ft}^3\text{/day}} \qquad \textbf{(4-1)}$$

- Non-arid climate (25 inches or more of rainfall per year):

$$CH_4 \text{ (tons/year)} = WIP_{tons} \text{ x } \frac{0.35 \text{ ft}^3\text{/day}}{\text{ton}} \text{ x } \frac{0.0077 \text{ tons } CH_4\text{/yr}}{\text{ft}^3\text{/day}} \qquad \textbf{(4-2)}$$

<u>Large Landfills (over 1.1 millions tons of waste in place)</u>

- Arid climate (less than 25 inches of rainfall per year):

$$CH_4 \text{ (tons/year)} = [417{,}957 \text{ ft}^3\text{/day} + \frac{0.16 \text{ ft}^3\text{/day}}{\text{ton}} \text{ x } (WIP_{tons})] \text{ x } \frac{0.0077 \text{ tons } CH_4\text{/yr}}{\text{ft}^3\text{/day}} \qquad \textbf{(4-3)}$$

- Non-arid climate (25 inches or more of rainfall per year):

$$CH_4 \text{ (tons/year)} = [417{,}957 \text{ ft}^3\text{/day} + \frac{0.26 \text{ ft}^3\text{/day}}{\text{ton}} \text{ x } (WIP_{tons})] \text{ x } \frac{0.0077 \text{ tons } CH_4\text{/yr}}{\text{ft}^3\text{/day}} \qquad \textbf{(4-4)}$$

We have contacted state agencies to obtain landfill WIP estimates, and data has been obtained from Iowa, Kansas, Texas, and Minnesota. For the remaining CENRAP states, we utilized data available through EPA's LMOP database. This program is voluntary, and the

LMOP database only includes data for landfills that use gas recovery systems or have the potential to employ such systems in the future. Though the database is not likely to be exhaustive for any of the CENRAP states, it does contain records for 372 landfills within the CENRAP region, and only Arkansas appears to have data that are severely incomplete (with only three data records for that state).

We used the equations above to estimate methane emissions for each landfill for which we have WIP data, then calculated ammonia emissions by using a published ratio of 0.7% ammonia to methane (Eggleston, 1992). We apportioned landfill emissions to the best spatial data available—either the facility latitude/longitude (for state-specific data) or the centroid of the postal code area (ZIP) where each landfill is located (for facilities in the LMOP database).

For Arkansas, landfill emissions were treated as an area source, and a statewide estimate of ammonia emissions was calculated based on an alternative population-based method described in the EIIP documentation. This statewide emissions total was then disaggregated to the county level based on population.

4.3 AMMONIA REFRIGERATION

Ammonia is commonly used as a refrigerant at food processing facilities. The Occupational Safety & Healthy Administration (OSHA) of the U.S. Department of Labor has identified common industries that use ammonia refrigeration systems (Occupational Safety & Health Administration, 2002). These industries and their corresponding NAICS (North American Industry Classification System) number appear in **Table 4-1**.

Table 4-1. List of industries that use ammonia refrigeration.

Industry	NAICs
Meat, poultry, and fish processing facilities	31161, 31171
Dairy and ice cream plants	31151, 31152
Wineries and breweries	31212, 31213
Juice and soft drink processing facilities	31211
Cold storage warehouses	49312

To estimate emissions from this source, we applied an emission factor that was reported by Battye et al. (1994): 187 kg NH_3/employee. This factor is based on the assumption that annual production levels of ammonia refrigerants are roughly in material balance with fugitive losses from refrigeration systems. If a significant fraction of ammonia refrigerants is recovered for disposal, stabilization, or re-use in non-refrigeration applications, or if the demand for new refrigeration systems outstrips the demand for system recharges, then this emission factor should represent a conservatively high estimate.

We contacted the International Institute of Ammonia Refrigeration to determine the relative market demands for ammonia refrigerants (manufactures of new systems versus recharges of old systems) and to determine the likely environmental fates of manufactured ammonia refrigerants (fugitive losses, recovery, etc.). However, we were unable to acquire definitive information from this resource. Additionally, we are currently locating the latest issue of the serial, *Chemical Economics Handbook* by Stanford Research Institute, which includes a chapter of statistics and discussions about the ammonia manufacturing industry. Given the scheduled delivery of the ammonia emission inventory files, we were unable to review this resource in time for delivery. However, if the *Chemical Economics Handbook* contains relevant and useful information, then we will (at a later time) issue a revision memorandum to the CENRAP with simple instructions for updating the emissions estimates for ammonia refrigeration.

In order to verify the scale of the emission factor, we determined that annual production of ammonia for refrigeration uses in the United States is between 270,000 Mg and 350,000 Mg (Battye et al., 1994; International Institute of Ammonia Refrigeration, 2003). To prevent the possibility of significant double-counting, we confirmed that this figure is much larger than total air releases of ammonia reported by United States facilities in the food products industry (SIC 20) for the 2001 TRI (approximately 7400 Mg). For the industries listed in Table 4-1, total United States employment equals approximately 1 million employees (U.S. Census Bureau, 2003). Thus, these figures yield a factor of 270 to 350 kg NH_3/employee-yr, which is on the same order of magnitude as the factor estimated by Battye et al. (1994), although it is 44% to 87% larger.

4.4 NON-ROAD MOBILE SOURCES

NEI contains ammonia emissions from non-road mobile sources. These data will be extracted and incorporated into the final inventory. It should be noted that the most current NEI data are for 1999, or three years out of date. Because this is a minor category, we will consider 1999 emissions to be reasonably representative of 2002 emissions.

4.5 POINT SOURCES

To quantify ammonia emissions from industrial/point sources, the CMU model takes county-level emissions from the EPA's 1995 TRI and distributes these totals evenly over 12 months of the year for each county. It should be noted that the CMU model does not contain any location information on these sources, meaning that they cannot be treated as true "point sources".

However, we have evaluated the TRI to be incomplete for several types of point sources, such as power generation facilities. Reporting requirements for the TRI limit the inventory to specific industrial sectors such as manufacturing, mining, and petroleum processing (U.S. Environmental Protection Agency, 2002c). Our preliminary investigation showed that a number of ammonia sources included in the 1999 NEI do not appear in the TRI data, and there appears to be little overlap between these two inventories. For example, the 2001 TRI contains ammonia emissions data for 211 facilities in the state of Texas, which emit 2,603 tons per year of ammonia. The NEI contains emissions data for 87 facilities—mostly power generation plants, none of which are listed in the TRI—that emit 1,834 tons per year of ammonia.

In order to improve upon the CMU model output for point sources, we downloaded the most current TRI data available (year 2001), and we located the emissions as point sources according to the reported coordinates of each facility. In addition, we augmented the TRI point source inventory with point source emissions estimates and facility locations reported in the 1999 NEI.

To check this approach, we verified that emissions from an important source of ammonia emissions—fertilizer manufacturing—are adequately represented in the point source inventory. Kansas was examined as a sample state, and ammonia emissions in the NEI and TRI inventories from fertilizer manufacturing amounted to 12,400 tons. Using emission factors from AP-42 (U.S. Environmental Protection Agency, 2002a) and fertilizer sales data for Kansas contained in the CMU model, an emissions estimate of 14,650 tons of ammonia from fertilizer manufacturing was calculated. Though this calculation was crude, it does indicate that the data contained in the NEI and TRI inventories will provide a reasonable representation of emissions from this source.

4.6 BIOGENIC SOURCES

As the documentation provided with the CMU emissions model states, biogenic (or "soil") emissions estimates are highly uncertain. Literature sources indicate that the soil-plant canopy system can be a source of ammonia emissions under some conditions and a sink under other conditions (Strader et al., 2001; Sutton et al., 2002). The emission factors used in Version 3.0 of the CMU model were derived from a variety of sources, and activity data on soil types was obtained from the EPA's GIRAS land-use data set.

Preliminary CMU model runs indicated that emissions from soil accounted for 50% of the total annual ammonia inventory. This result seemed unlikely; therefore, we performed a literature search to seek improved emission factors. We chose to apply emission factors that were selected for use by Battye et al. (2003), which were based on factors reviewed or published by Schlesinger and Hartley (1992), Buowman et al. (1997), Kinnee et al (1997), and Van Der Hoek (1998). **Table 4-2** shows a comparison between the CMU model's emission factors and those selected for use.

The result of altering the CMU model's emission factors was a 93% reduction in biogenic emissions across the CENRAP domain. Thus, we estimated that biogenic emissions account for 7% of the total CENRAP ammonia inventory. Battye et al. (2003) calculated similar percent contributions—about 6.6% and 6.3%—for emission inventories in North Carolina and California's San Joaquin Valley.

However, it is important to note that these results are *highly uncertain*. Based on very recent research projects conducted on grasslands in Europe (Sutton et al., 2002), results continue to demonstrate that relatively undisturbed environments with low nitrogen inputs tend to absorb ammonia from the atmosphere, while lands with high nitrogen inputs—from fertilizer, decomposing plant matter, manure, large herds or flocks of wild animals, acid rain deposition, or other sources—tend to emit ammonia. Reported emission rates range from –590 kg/km^2/yr to +2600 kg/km^2/yr and areas may act as net sinks or net sources of ammonia at different times of the year and at different times of the day (Sutton et al., 2002). It will be very important to consider the uncertainties in the biogenic emissions estimates when evaluating air quality modeling sensitivities and uncertainties.

Table 4-2. Comparison of soil emission factors.

Soil Type	Emission Factor (kg/km^2/yr)	
	CMU Model	STI Update
Residential, Commercial, Industrial, Urban	160	10
Cropland, Pasture, Other Agricultural Land	1200	30
Orchards, Groves, Vineyards	1296	30
Rangeland	370	40
Forests	140	120
Wetlands	370	120
Dry Salt Flats	6.7	10
Transitional Areas	370	10
Mixed Barren Land	60	10
Unknown	370	10

5. PREPARATION OF DIGITAL FILE SYSTEMS

5.1 NATIONAL EMISSIONS INVENTORY INPUT FORMAT FILE CONVERSION

The CMU model creates output files in version 2.0 of the National Emissions Inventory Input Format (NIF), with the NIF 2.0 records containing ammonia emissions by county, source category code (SCC), and month. These output files were updated to the latest version of NIF (version 3.0).

5.2 SMOKE-COMPATIBLE FILE SYSTEMS

In order to process these emissions data through SMOKE, the NIF files were converted to Inventory Data Analyzer (IDA) format, which contains data fields for annual or average ozone season emissions data. A simple utility was written in FORTRAN to perform this conversion.

Also, seasonal and diurnal temporal profiles were created as necessary in order to apply the allocation factors recommended in earlier sections of this document. SMOKE cross-reference files were updated to access these new profiles for the appropriate source categories.

STI created all input files and scripts so that they are compatible with the most recent version of SMOKE (version 1.5), as we have been advised that CENRAP plans to use version 1.5 for its January and July 2002 modeling efforts.

5.3 DELIVERABLE FILES

The following files were delivered by STI upon completion of the ammonia emission inventory with accompanying documentation:

- Activity data files used as inputs to the CMU model
- Emission factor files used as inputs to the CMU model
- CMU output emission data files in latest NIF format
- Emission data files converted to IDA format and ready for input to SMOKE 1.5
- Temporal profile and cross-reference files for use by SMOKE
- Spatial surrogate and cross-reference files for use by SMOKE

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APPENDIX B

TABULATION OF AMMONIA EMISSIONS ESTIMATES FOR THE CENRAP REGION

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Table B-1. Annual ammonia emissions by state and source category.

Source Category	AR	IA	KS	LA	MN	MO	NE	OK	TX	Total
	Ammonia Emissions by State (tons/year)									
Livestock										
CAFOs	*4096.0*	*88722.5*	*57611.1*	*82.4*	*25518.0*	*24685.5*	*30240.0*	*19864.6*	*45650.0*	*296470.0*
Free-Range	*81978.6*	*69713.6*	*33455.9*	*15837.5*	*72562.1*	*68925.6*	*66743.0*	*60016.8*	*143115.0*	*612348.0*
Total Livestock:	86074.6	158436.1	91067.0	15919.9	98080.1	93611.1	96983.0	79881.4	188765.0	908818.0
Fertilizer Application	38547.1	72258.7	64577.0	18113.5	65407.0	36742.9	64442.5	26209.4	78665.2	464963.4
Biogenics (Soil)	11971.1	5574.4	7802.6	10645.6	14977.6	11886.7	7829.2	9643.0	37511.2	117841.3
Point Sources										
Industrial	*2845.2*	*3700.7*	*1882.7*	*7727.9*	*1362.2*	*4237.7*	*421.9*	*4599.9*	*4429.7*	*31207.8*
Landfills	*140.6*	*848.4*	*812.3*	*1165.2*	*959.7*	*2096.1*	*378.2*	*1181.2*	*7959.0*	*15540.8*
Total Point Sources:	2985.8	4549.1	2694.9	8893.1	2321.9	6333.8	800.1	5781.1	12388.7	46748.6
Mobile Sources										
On-road	*2557.5*	*2715.7*	*2407.3*	*3633.8*	*4898.4*	*4414.3*	*1520.8*	*3628.7*	*14104.9*	*39881.3*
Off-road	*389.9*	*578.1*	*577.1*	*1256.8*	*810.8*	*755.3*	*320.1*	*773.7*	*4330.7*	*9792.4*
Total Mobile Sources:	2947.3	3293.8	2984.4	4890.6	5709.2	5169.6	1840.9	4402.4	18435.6	49673.7
Misc. Sources										
Ammonia Refrigeration	*1799.7*	*1274.1*	*300.8*	*288.2*	*721.1*	*440.3*	*2440.0*	*90.7*	*4022.7*	*11377.5*
POTWs	*5.3*	*6.8*	*5.2*	*9.3*	*11.0*	*15.0*	*4.3*	*5.2*	*60.9*	*122.9*
Domestic Animals	*2520.1*	*2014.1*	*1998.2*	*2853.5*	*2599.6*	*4336.6*	*1296.7*	*3235.2*	*15940.5*	*36794.3*
Wild Animals	*4022.9*	*1499.9*	*747.8*	*5000.0*	*4587.1*	*3820.2*	*1255.1*	*1651.2*	*18014.3*	*40598.7*
Humans	*1229.3*	*1388.4*	*1253.9*	*2120.2*	*2277.1*	*2614.2*	*806.2*	*1611.5*	*9409.2*	*22710.0*
Wildfire	*260.5*	*25.0*	*1347.2*	*203.6*	*182.2*	*366.8*	*2109.5*	*428.8*	*176.7*	*5100.2*
Total Misc. Sources:	9837.8	6208.3	5653.0	10474.7	10378.0	11593.0	7911.8	7022.5	47624.4	116703.6
Total Emissions:	**152363.8**	**250320.4**	**174778.8**	**68937.4**	**196873.8**	**165337.1**	**179807.5**	**132939.8**	**383390.1**	**1704748.7**

APPENDIX C

TABULATION OF DIFFERENCES BETWEEN THE STI INVENTORY AND CMU MODEL OUTPUTS

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Table C-1. Comparison between the STI inventory and CMU model outputs for key sources.

Ammonia Emissions (tons/year)									
	Livestock & Poultry			Fertilizer			Biogenics		
State	STI	CMU	% Difference	STI	CMU	% Difference	STI	CMU	% Difference
AR	86,074.6	82,657.0	4.1%	38,547.1	38,877.8	-0.9%	11,971.1	86,009.7	-86.1%
IA	158,436.1	163,651.4	-3.2%	72,258.7	68,756.6	5.1%	5,574.4	178,752.5	-96.9%
KS	91,067.0	80,178.7	13.6%	64,577.0	70,575.3	-8.5%	7,802.6	227,338.2	-96.6%
LA	15,919.9	15,918.9	0.0%	18,113.5	16,402.3	10.4%	10,645.6	66,879.7	-84.1%
MN	98,080.1	99,245.3	-1.2%	65,407.0	64,604.6	1.2%	14,977.6	179,269.6	-91.6%
MO	93,611.1	91,717.7	2.1%	36,742.9	32,264.0	13.9%	11,886.7	160,992.1	-92.6%
NE	96,983.0	97,833.8	-0.9%	64,442.5	50,822.8	26.8%	7,829.2	184,292.2	-95.8%
OK	79,881.4	77,359.0	3.3%	26,209.4	27,506.2	-4.7%	9,643.0	160,003.9	-94.0%
TX	188,765.0	186,762.5	1.1%	78,665.2	75,327.6	4.4%	37,511.2	450,664.0	-91.7%
Total:	908,818.0	895,324.2	1.5%	464,963.4	445,137.2	4.5%	117,841.3	1,694,201.8	-93.0%