Research and Development of Ammonia Emission Inventories for the Central States Regional Air Planning Association

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ABSTRACT

In support of the Central Regional Air Planning Association's (CENRAP) need to develop a regional haze plan, Sonoma Technology, Inc. (STI) developed a 2002 ammonia emission inventory for the nine-state CENRAP region, which includes Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota. The inventory was developed by applying the Carnegie Mellon University (CMU) ammonia emissions model, version 3.0, and by supplementing the model with updated activity data, emission factors, temporal profiles, and inventories of additional source categories. The most important source categories were estimated to be livestock and poultry, fertilizers, and biogenics. These three sources combined accounted for 87% of the annual ammonia emissions in the CENRAP region (see Figure 1). Emissions peaked in spring and fall (especially during the months of April and October)—times when manure and fertilizer are typically applied to croplands (see Figure 2).

Figure 1. 2002 NH_3 emissions by source category.

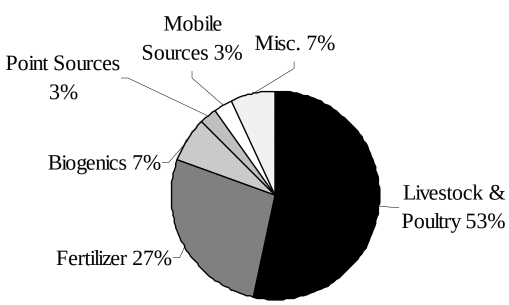
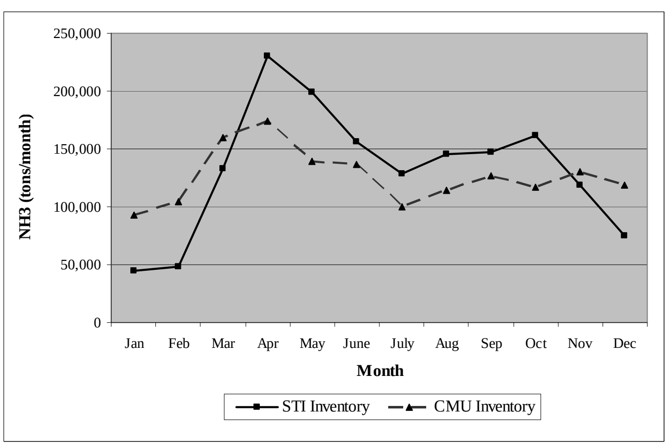


Figure 2. Monthly variation in total emissions (biogenic sources excluded).



INTRODUCTION

The Central Regional Air Planning Association (CENRAP) is responding to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas by researching visibility-related issues and developing a regional haze plan for the CENRAP region, which includes the states of Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota. An understanding of ammonia emissions is vital to the CENRAP because ammonia is a significant precursor to secondary particulate matter, which contributes significantly to episodes of low visibility. Visibility impairment is largely caused by particulate matter of aerodynamic diameter less than 2.5 microns ($PM_{2.5}$). $PM_{2.5}$ may be introduced directly into the atmosphere from sources such as fugitive dust and combustion soot (primary $PM_{2.5}$), or it may be the result of atmospheric chemical reactions (secondary $PM_{2.5}$). Atmospheric ammonia participates in secondary $PM_{2.5}$ formation by combining with nitrogen oxides (NO_x) or sulfur oxides (SO_x) to form ammonium nitrate and ammonium sulfate—a chemical reaction that tends to favor the formation of very tiny particles. Analysis of speciated $PM_{2.5}$ data in the CENRAP region indicates that at sites where sulfates and nitrates were measured, these secondary compounds together comprised approximately 30% to 60% of $PM_{2.5}$.

In support of its needs to understand ammonia emissions patterns, the CENRAP funded the development of a model-ready inventory of ammonia emissions to represent the year 2002. The project objectives were to identify and evaluate information resources that could be immediately applied to improve emissions estimates produced by version 3.0 of the Carnegie Mellon University (CMU) model—an ammonia emissions modeling tool and database system. The majority of these efforts focused on improving emission estimates for two types of emissions sources—livestock production and fertilizer use—while the remainder of the work was directed toward improving or incorporating emission estimates for other types of emissions sources (such as biogenics, off-road mobile sources, landfills, and industrial point sources).

TECHNICAL APPROACH

Ammonia emissions were calculated for 13 source categories using three basic approaches:

1) Use version 3.0 of the CMU ammonia model "as is" for relatively small source categories, such as publicly owned treatment works, human perspiration/respiration, domestic and wild animals, wildfires, and on-road mobile sources.
2) Update the CMU model's emission factors, activity data, and/or temporal profiles for significant source categories, such as livestock production, fertilizer application, and biogenic sources.
3) When necessary, prepare emission estimates for source categories not included in the CMU model, such as industrial point sources, landfills, ammonia refrigeration, and non-road mobile sources.

The following sections describe the techniques and data sources that were used to generate emission estimates for the source categories listed under approaches 2 and 3 above.

Livestock Production

Emission calculations for livestock and poultry production were based on county-level animal population estimates. Where possible, 2002 National Agricultural Statistics Service (NASS) data were substituted for the older population data from the 1997 USDA Agricultural Census used by the CMU model. Also, data on animal populations at confined animal feeding operations (CAFOs) were gathered from state agricultural and environmental agencies and subtracted from NASS estimates to prevent double counting. These methods and data sources are reasonably similar to those recently applied by the EPA[1] to estimate livestock and poultry populations. However, the EPA's population estimates differ significantly from those estimated for the CENRAP. The reasons for the differences are subjects of areas of ongoing discussion and investigation.

Updated population estimates were used in conjunction with the CMU model's existing emission factors to generate emission estimates for all livestock types except dairy cattle. For dairy cattle, ammonia emission estimates produced by a recently developed dairy farm model [2] were incorporated into the inventory.

Emissions were spatially allocated using two methods. Individual CAFO facilities were treated as point sources, with emissions from those facilities allocated according to specific location coordinates. Other emissions from livestock and poultry were treated as area sources and spatially allocated according to the distribution of rangeland in each county (as defined by the EPA's Biogenic Emissions Landcover Database [BELD]).

Emissions were temporally distributed according to county-specific seasonal allocation factors derived from the Pinder dairy farm model, which takes local climate and husbandry practices into account. (Emission estimates for livestock production produced by the CMU model are unvarying from month to month.) Diurnal allocation factors for CAFOs were derived from a European study of ammonia emissions from swine houses.[3] For "free range" animals, manure and urine depositions are spread over a much larger area than would be the case with animals housed at feedlots. Therefore, a diurnal profile based on nitric oxide fluxes from soil[4] was used.

Fertilizer Application

Emissions from fertilizer application were calculated by applying appropriate emission factors to county-level estimates of the amounts of fertilizers consumed in 2002. 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 types of fertilizers, including those that emit ammonia. A fertilizer sales database prepared from 2002 AAPFCO data was substituted for the 1995 AAPFCO data that were included in version 3.0 of the CMU model.

Version 3.0 of the CMU model makes use of European emission factors[5] that vary by fertilizer type, soil type, and climate. These 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.

The CMU model assigns whole states to one of the groupings listed above; five of the nine CENRAP states are classified as Group II. However, because emission factors for some fertilizer types vary by as much as 200% among the three classifications, greater refinement of emission factors by geography was preferable. Therefore, the European approach was more fully implemented through the use of soil type databases and geographic information systems (GIS). The NRCS State Soil Geographic database (STATSGO) was used to identify the dominant soil type (calcareous or acidic) in each county so that emission factors could be selected at a more local level.

Emissions from fertilizer application were spatially allocated to cropland areas in the EPA's BELD database. Emissions were seasonally allocated by using county-specific crop acreages published by NASS and the crop calendars and fertilizer timing rates employed by the CMU model. Because nitric oxide fluxes arise from analogous biological processes but are better quantified than ammonia fluxes, a diurnal profile based on nitric oxide fluxes from soil[4] was used for emissions from fertilizer.

Biogenic Sources

Biogenic (or "soil") emission 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.[6,7] Preliminary CMU model runs for the CENRAP region indicated that emissions from soil accounted for 50% of the total annual ammonia inventory. This result seemed unlikely; therefore, a literature search was performed to seek improved emission factors. STI chose to apply emission factors selected for use by Battye et al.,[8] which were based on factors reviewed or published by Schlesinger and Hartley,[9] Buowman et al.,[10] Kinnee et al,[11] and Van Der Hoek.[12]

The result of altering the CMU model's emission factors was a 93% reduction in biogenic emissions across the CENRAP domain. Thus, biogenic emissions were estimated to account for 7% of the total CENRAP ammonia inventory. Battye et al.[8] calculated similar percent contributions—about 6.6% and 6.3%—for emission inventories in North Carolina and California's San Joaquin Valley.

Other Sources

In addition to the three source categories described above (and the six sources for which the CMU model was run without alteration), emission estimates were prepared independently of the model for four other sources: landfills, ammonia refrigeration, non-road mobile sources, and industrial point sources.

For landfills, emission estimates were based on waste-in-place (WIP) data obtained from state agencies and the EPA's Landfill Methane Outreach Program (LMOP) database. Emissions from ammonia refrigeration systems used at food processing facilities were based on county-level employment estimates for industries that commonly employ such systems. Emissions from non-road mobile and industrial point sources were taken from existing inventories. County-level ammonia emission estimates from the 1999 National Emission Inventory (NEI) were used for non-road mobile sources, and 1999 NEI point source data were used in conjunction with 2001 Toxic Release Inventory (TRI) data for industrial point sources. Point source emissions were spatially allocated according to the location coordinates of individual facilities. (The CMU model contains only county-level point source emission estimates derived from the 1995 TRI).

Sources considered but omitted from the final inventory included biomass burning, composting, geothermal emissions, ammonia injection for NO_x control, and biosolids (sewage sludges). Ammonia emissions from planned burning activities in the CENRAP region are the subject of another study, and the remaining categories were judged to be insignificant sources of ammonia (NH_3) or lacked the data needed to generate an inventory.

RESULTS

Year 2002 NH_3 emissions for the CENRAP region were estimated to be 1.7 million tons, almost 50% less than the 3.2 million tons predicted by the CMU model without alteration. This significant difference is mostly the result of different approaches to biogenic sources (in fact, when biogenic sources are excluded from both inventories, the remaining emissions are actually 5% higher in the STI inventory than those estimated with the CMU model). It was determined that emissions from livestock and poultry production contribute 53% to this total, ranging state to state from 23% (Louisiana) to 63% (Iowa). Fertilizer application was the second largest source, accounting for 27% of the total NH_3 emissions in the region and ranging state to state from 20% (Oklahoma) to 37% (Kansas). Other source categories contributed significantly to the NH_3 inventory in individual states. For example, industrial point sources were responsible for only about 3% of the NH_3 emissions in the CENRAP region as a whole, but made up over 13% of the inventory for Louisiana. (See Figure 3 for a breakdown of emissions by state and source category and Figure 4 for a map of emissions densities for the CENRAP region).

Figure 3. 2002 NH3 emissions by source category for each state of the CENRAP region.

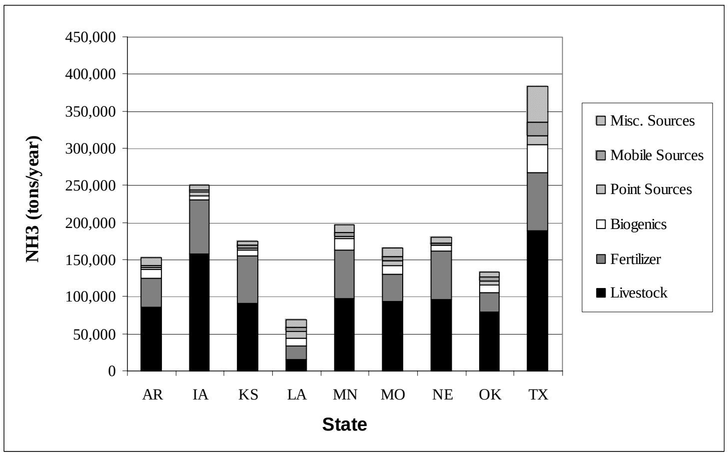
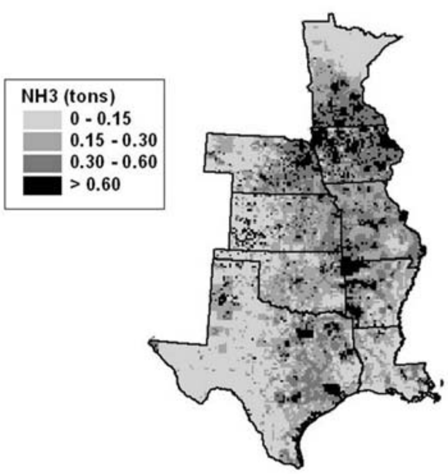


Figure 4. Geographic map of emissions densities for the CENRAP region, July 10, 2002.



The seasonal variability of NH_3 emissions follows a bimodal pattern, with a large spring peak in April and a smaller fall peak in October (see Figure 2). These peaks correspond to times when manure and fertilizer are typically applied to croplands. Emissions are lowest during the winter months of December, January, and February.

CONCLUSIONS

As anticipated, livestock production and fertilizer application were the most significant sources of NH_3 emissions in the CENRAP region, accounting for 80% of the total emissions in 2002. For the region as a whole, estimates for these two source categories were within 5% of the totals previously predicted by version 3.0 of the CMU model. However, differences from state to state and county to county are much more pronounced. For example, CENRAP's emissions from livestock and poultry production in Kansas and from fertilizer application in Nebraska are 14% and 27% higher, respectively, than predicted by the CMU model.

Similarly, temporal emission distributions are significantly different when the CENRAP and CMU model inventories are compared. As Figure 2 shows, CENRAP's emissions estimates are consistently higher than those from the CMU model inventory for spring, summer, and fall, but the reverse is true for winter. These significant changes in the geographic and temporal distribution of emissions are critical for modeling efforts, through which the impact of emission sources on Class I areas will be analyzed throughout the region.

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KEY WORDS

Ammonia
Emissions Inventories
Emission Inventory
Livestock
Fertilizer
CENRAP
Arkansas
Iowa
Kansas
Louisiana
Minnesota
Missouri
Nebraska
Oklahoma
Texas
CMU model