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# TECHNICAL MEMORANDUM No. 8: AMMONIA SOURCE EMISSIONS

To: Tom Moore, Western Regional Air Partnership (WRAP)

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Subject: Ammonia Source emissions, including livestock and fertilizer sources, for the WestJumpAQMS 2008 Photochemical Modeling

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## INTRODUCTION

ENVIRON International Corporation (ENVIRON), Alpine Geophysics, LLC (Alpine) and the University of North Carolina (UNC) at Chapel Hill Institute for Environment are performing the West-wide Jump Start Air Quality Modeling Study (WestJumpAQMS) managed by the Western Governors' Association (WGA) for the Western Regional Air Partnership (WRAP). WestJumpAQMS is setting up the CAMx photochemical grid model for the 2008 calendar year (plus spin up days for the end of December 2007) on a 36 km CONUS, 12 km WESTUS and several 4 km Inter-Mountain West domains. The WestJumpAQMS Team is currently compiling emissions to be used for the 2008 base case modeling, with the 2008 National Emissions Inventory (NEI) being a major data source, and is preparing 13 Technical Memorandums discussing the sources of the 2008 emissions by major source sector:

1. Point Sources including Electricity Generating Units (EGUs) and Non-EGUs;
2. Area plus Non-Road Mobile Sources;
3. On-Road Mobile Sources that will be based on MOVES;
4. Oil and Gas Sources (5 installments);
5. Fires Emissions including wildfire, prescribed burns and agricultural burning;
6. Fugitive Dust Sources;
7. Off-Shore Shipping Sources;
8. Ammonia Emissions;
9. Biogenic Emissions;
10. Eastern USA Emissions;

11. Mexico/Canada;

12. Sea Salt and Lightning Emissions; and

13. Emissions Modeling Parameters including spatial surrogates, temporal adjustment parameters and chemical (VOC and PM) speciation profiles.

This document is Technical Memorandum Number 8 that discusses the approach and data sources to be used for developing 2008 emissions for the Ammonia ($NH_3$) source sector.

## 2008 NEI V2.0 OVERVIEW

The U.S. Environmental Protection Agency (EPA) develops and maintains the National Emissions Inventory (NEI). The NEI is a comprehensive and detailed estimate of air emissions of both Criteria and Hazardous air pollutants from all air emissions sources in the United States. The NEI is prepared every three years by the EPA and is based primarily upon emission estimates and emission model inputs provided by State, Local, and Tribal air agencies for sources in their jurisdictions, and supplemented by data developed by the EPA. The most current version of the NEI is Version 2 of the 2008 NEI (2008 NEIv2[1]) that we obtained from EPA at the end of February 2012[2]. The Eastern Regional Technical Advisory Committee (ERTAC), which is made up of emission inventory experts from state agencies, was created to coordinate emission inventory development and to provide a technically driven process for improving the 2008 NEI[3]. The EPA and ERTAC coordinated on the development of the non-point inventory category for the 2008 NEIv2 that includes most ammonia emission sources. Ammonia emissions in the 2008 NEIv2 were estimated using an ammonia emissions model developed at Carnegie Mellon University (CMU[4]).

## AGRICULTURAL AMMONA SOURCE EMISSIONS

The NEI non-point data inventory category contains emission estimates for sources that are inventoried at the county level. A broad category of many different types of emission sources, the non-point sector contains two agricultural sources that are significant emitters of $NH_3$. Livestock (aglv) and fertilizer (agft) sources are included in the non-point inventory and represent the majority of the $NH_3$ emissions in the NEI. Livestock refers to domesticated animals intentionally reared for the production of food, fiber, or other goods or for the use of their labor. The definition of livestock in this category includes beef cattle, dairy cattle, ducks, geese, goats, horses, poultry, sheep, and swine. Fertilizer refers to ammonia emissions emitted after the application of fertilizer to croplands.

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1 http://www.epa.gov/ttnchie1/net/2008inventory.html
2 http://www.epa.gov/ttnchie1/net/2008inventory.html
3 Dorn, J., F.Divita, R. Huntley, M. Janssen. 2010. Implementing a Collaborative Process to Improve the Consistency, Transparency, and Accessibility of the Nonpoint Source Emission Estimates in the 2008 National Emissions Inventory. Presented at the 19th Annual International Emission Inventory Conference. San Antonio, TX.
4 http://www.cmu.edu/ammonia/

As with most non-point sources, emissions in the agricultural $NH_3$ inventory is calculated as

$$E_{i,s} = A_{i,s} * F_s$$

Where $E_{i,s}$ = Emissions in county *i* for source *s*
$A_{i,s}$ = Activity in county *i* for source s
$F_s$ = Emission factor for source *s*

For livestock sources, the activity (A) is the population of a particular animal per county and the emission factor (F) is the emitted mass (kg) of $NH_3$ per animal per month. For fertilizer sources, A is the mass (kg) of fertilizer consumed per county and F is the percent of nitrogen in the fertilizer volatilized as $NH_3$.

ERTAC documented the sources of the data and calculations used to estimate emissions from the livestock[5] and fertilizer[6] components of the agricultural ammonia inventory. The livestock emissions are also discussed in Section 3.4 of the 2008 NEIv Technical Support Document (TSD[7]). The sections "Livestock Ammonia Emissions" and "Fertilizer Ammonia Emissions" are taken directly from the ERTAC or NEI TSD documentation for these source categories.

## Livestock Ammonia Emissions

The approach to calculating emissions for livestock $NH_3$ sources consisted of the following four general steps:

- Determining county-level population of animals for 2007.
- For beef, dairy, poultry, and swine, apportioning animal populations to a manure management train (MMT) for each county. Animal populations for ducks, geese, goats, horses, and sheep were not apportioned to MMTs.
- Modifying the emission factor files provided with the CMU Ammonia Model v. 3.6 to ensure that every county had an assigned emission factor[8].
- Using the CMU Ammonia Model v. 3.6 to calculate ammonia emissions based on the updated county-level animal populations and emission factors.

Table 1 is a listing of the Source Classification Codes (SCCs) assigned to the livestock $NH_3$ sources in the NEI08v2.

5 ftp://ftp.epa.gov/EmisInventory/2008_nei/nonpoint/animal_husbandry_epa_data.zip
6 ftp://ftp.epa.gov/EmisInventory/2008_nei/nonpoint/fertilizer_application_epa_data.zip
7 http://www.epa.gov/ttn/chief/net/2008neiv2/2008_neiv2_tsd_draft.pdf
8 Cliff Davidson, Peter Adams, Ross Strader, Rob Pinder, Natalie Anderson, Marian Goebes, and Josh Ayers. The Environmental Institute, Carnegie Mellon University, *CMU Ammonia Model v.3.6.*, 2004, at http://www.cmu.edu/ammonia/, accessed 25 April 2009.

**Table 1. Livestock Ammonia SCCs in the NEI08v2.**

| SCC | Descriptor 2 | Descriptor 4 | Descriptor 7 | Descriptor 8 |
|---|---|---|---|---|
| 2805001100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Beef cattle - finishing operations on feedlots (drylots) | Confinement |
| 2805001200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Beef cattle - finishing operations on feedlots (drylots) | Manure handling and storage |
| 2805001300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Beef cattle - finishing operations on feedlots (drylots) | Land application of manure |
| 2805002000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Beef cattle production composite | Not Elsewhere Classified |
| 2805003100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Beef cattle - finishing operations on pasture/range | Confinement |
| 2805007100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - layers with dry manure management systems | Confinement |
| 2805007300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - layers with dry manure management systems | Land application of manure |
| 2805008100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - layers with wet manure management systems | Confinement |
| 2805008200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - layers with wet manure management systems | Manure handling and storage |
| 2805008300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - layers with wet manure management systems | Land application of manure |
| 2805009100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - broilers | Confinement |
| 2805009200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - broilers | Manure handling and storage |
| 2805009300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - broilers | Land application of manure |
| 2805010100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - turkeys | Confinement |

| | | | | |
|---|---|---|---|---|
| 2805010200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - turkeys | Manure handling and storage |
| 2805010300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - turkeys | Land application of manure |
| 2805018000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle composite | Not Elsewhere Classified |
| 2805019100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - flush dairy | Confinement |
| 2805019200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - flush dairy | Manure handling and storage |
| 2805019300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - flush dairy | Land application of manure |
| 2805021100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - scrape dairy | Confinement |
| 2805021200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - scrape dairy | Manure handling and storage |
| 2805021300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - scrape dairy | Land application of manure |
| 2805022100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - deep pit dairy | Confinement |
| 2805022200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - deep pit dairy | Manure handling and storage |
| 2805022300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - deep pit dairy | Land application of manure |
| 2805023100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - drylot/pasture dairy | Confinement |
| 2805023200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - drylot/pasture dairy | Manure handling and storage |
| 2805023300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle - drylot/pasture dairy | Land application of manure |
| 2805025000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production composite | Not Elsewhere Classified (see also 28-05-039, -047, -053) |
| 2805030000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry Waste Emissions | Not Elsewhere Classified (see also 28-05-007, -008, -009) |

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|---|---|---|---|---|
| 2805030007 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry Waste Emissions | Ducks |
| 2805030008 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry Waste Emissions | Geese |
| 2805035000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Horses and Ponies Waste Emissions | Not Elsewhere Classified |
| 2805039100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production - operations with lagoons (unspecified animal age) | Confinement |
| 2805039200 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production - operations with lagoons (unspecified animal age) | Manure handling and storage |
| 2805039300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production - operations with lagoons (unspecified animal age) | Land application of manure |
| 2805040000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Sheep and Lambs Waste Emissions | Total |
| 2805045000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Goats Waste Emissions | Not Elsewhere Classified |
| 2805047100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production - deep-pit house operations (unspecified animal age) | Confinement |
| 2805047300 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production - deep-pit house operations (unspecified animal age) | Land application of manure |
| 2805053100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production - outdoor operations (unspecified animal age) | Confinement |

**Activity Data**

County-level animal numbers for 2007 were obtained from the U.S. Department of Agriculture's 2007 Census of Agriculture report[9]. For Virginia, the county-level census data include animal populations from Virginia's 39 independent cities. For some counties and states, census data were withheld to avoid disclosing data for individual farms. However, the total national-level animal numbers and most state-level animal numbers for each livestock type reported in the Census include those animal numbers not disclosed at the county-level. When available, state-level animal numbers from the USDA NASS online database were used for states with undisclosed animal numbers in the 2007 Census of Agriculture[10]. To determine the total number of undisclosed animals, disclosed county-level animal numbers for each livestock type were summed and subtracted from the total state animal numbers. The total undisclosed animal population for a specific livestock type was then allocated to those counties reporting undisclosed data based on the number of farms raising that livestock in each county[11]. If the state-level data were undisclosed and not available in the NASS database, then national animal numbers were used to determine undisclosed state numbers. The disclosed county-level data were then summed and subtracted from the state-level data to determine animal numbers not disclosed at the county-level. These numbers were then allocated to those counties reporting undisclosed data based on the number of farms raising that livestock in each county.

County-level animal numbers were then apportioned to manure management trains (MMTs). An MMT consists of an animal confinement area (e.g., drylot, pasture, flush, scrape); components used to store, process, or stabilize the manure (e.g., anaerobic lagoons, deep pits); and a land application site where manure is used as a fertilizer source[12]. Apportioning emissions to MMTs was based on county-level MMT percentages derived from the CMU Ammonia Model. For each livestock type, the county-level number of animals in each MMT was divided by the total county-level animal population for that livestock type to calculate the percentage of total animals managed by each MMT. In cases where the county-level numbers were zero in the 2002 CMU Ammonia Model input files, the county was assigned state-level MMT percentages. The county-level animal population for each livestock type from the 2007 Census of Agriculture was multiplied by the MMT percentages to determine the total number of animals in each MMT in 2007. Animal populations for ducks, geese, goats, horses, and sheep were not apportioned to MMTs.

Cattle reported as "Other Cattle" in the 2007 Census of Agriculture were divided between dairy cattle and beef cattle at the county-level using percent allocations derived from county-level dairy and beef cattle reported in the 2007 Census of Agriculture and corrected for undisclosed data. The animal numbers from "Other Cattle" apportioned to dairy and beef cattle were used

9 U.S. Department of Agriculture, *2007 Census of Agriculture*, at http://www.agcensus.usda.gov/, accessed 30 April 2009

10 U.S. Department of Agriculture, National Agricultural Statistics Service, at http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/, accessed 28 January 2010.

11 USDA, 2007

12 U.S. Environmental Protection Agency, *National Emission Inventory – Ammonia Emissions from Animal Agricultural Operations*, Revised Draft Report, 22 April 2005, p. 4-6, at http://www.epa.gov/ttn/chief/net/2002inventory.html, accessed 5 May 2009

to create the Dairy Cattle – Composite and Beef Cattle – Composite activity input files for the CMU Ammonia Model.

County-level pullet numbers reported in the 2007 Census of Agriculture were used to create the Poultry – Composite activity input file for the CMU Ammonia Model.

**Emission Factors**

The emission factor for the poultry composite categories was obtained from an EPA report and is reported in Table 2 below[13]. The county-level emission factors for the beef composite and dairy composite categories were developed using beef and dairy cattle emission factors provided with the 2002 CMU Model. Specifically, weighted average emission factors were calculated based on the number of beef or dairy cattle in each MMT from the 2002 CMU Model activity files and the emission factor assigned to each MMT. All other emission factors were provided with the CMU Ammonia Model v.3.6. The emission factors for some counties in the CMU Ammonia Model files were zero. To ensure that all counties with animal populations were assigned emissions factors, the emission factor input files provided with the CMU Ammonia Model were modified. For all counties with an emission factor of zero, the emission factor was replaced with the state average emission factor. If all counties in the state had emission factors of zero, then the county emission factor was replaced with the national average emission factor. The state average emission factor was calculated by summing the counties with non-zero emission factors in the state and dividing the total by the number of counties in that state with non-zero emission factors. The national average emission factor was calculated by summing the counties with non-zero emission factors in the nation and dividing the total by the number of counties in the nation with non-zero emission factors.

13 Ibid

**Table 2: Emission factors for $NH_3$ emissions used for 2008 NEI's agricultural livestock data**

| Description | Emission Factor | Emission Factor Unit | Ref. |
|---|---|---|---|
| Beef Cattle – Composite | county | kg $NH_3$/cow/month | 2 |
| Beef Cattle – Drylot Operation – Confinement | 9.45E-01 | kg $NH_3$/cow/month | 1 |
| Beef Cattle – Drylot Operation – Land Application | state | kg $NH_3$/cow/month | 1 |
| Beef Cattle – Drylot Operation – Manure Storage | 3.78E-04 | kg $NH_3$/cow/month | 1 |
| Beef Cattle – Pasture Operation – Confinement | county | kg $NH_3$/cow/month | 1 |
| Dairy Cattle – Composite | county | kg $NH_3$/cow/month | 2 |
| Dairy Cattle – Deep Pit Dairy Confinement | 2.42E+00 | kg $NH_3$/cow/month | 1 |
| Dairy Cattle – Deep Pit Dairy Land Application | state | kg $NH_3$/cow/month | 1 |
| Dairy Cattle – Deep Pit Dairy Manure Storage | 1.13E-01 | kg $NH_3$/cow/month | 1 |
| Dairy Cattle – Drylot Dairy Confinement | state | kg $NH_3$/cow/month | 1 |
| Dairy Cattle – Drylot Dairy Land Application | state | kg $NH_3$/cow/month | 1 |
| Dairy Cattle – Drylot Dairy Manure Storage | state | kg NH3/cow/month | 1 |
| Dairy Cattle – Flush Dairy Confinement | 2.00E+00 | kg NH3/cow/month | 1 |
| Dairy Cattle – Flush Dairy Land Application | state | kg NH3/cow/month | 1 |
| Dairy Cattle – Flush Dairy Manure Storage | state | kg NH3/cow/month | 1 |
| Dairy Cattle – Scrape Dairy Confinement | state | kg NH3/cow/month | 1 |
| Dairy Cattle – Scrape Dairy Land Application | state | kg NH3/cow/month | 1 |
| Dairy Cattle – Scrape Dairy Manure Storage | state | kg NH3/cow/month | 1 |
| Ducks | 7.67E-02 | kg NH3/duck/month | 1 |
| Geese | 7.67E-02 | kg NH3/goose/month | 1 |
| Goats | 5.29E-01 | kg NH3/goat/month | 1 |
| Horses | 1.02E+00 | kg NH3/horse/month | 1 |
| Poultry – Broiler Operation – Confinement | 8.32E-03 | kg NH3/bird/month | 1 |
| Poultry – Broiler Operation – Land Application | 6.80E-03 | kg NH3/bird/month | 1 |
| Poultry – Broiler Operation – Manure Storage | 1.51E-03 | kg NH3/bird/month | 1 |
| Poultry – Composite | 2.00E-02 | kg NH3/bird/month | 3 |
| Poultry – Layers – Dry Manure Operation – Confinement | 3.36E-02 | kg NH3/bird/month | 1 |
| Poultry – Layers – Dry Manure Operation – Land Application | county | kg NH3/bird/month | 1 |
| Poultry – Layers – Wet Manure Operation – Confinement | 9.45E-03 | kg NH3/bird/month | 1 |
| Poultry – Layers – Wet Manure Operation – Land Application | county | kg NH3/bird/month | 1 |
| Poultry – Layers – Wet Manure Operation – Manure Storage | county | kg NH3/bird/month | 1 |
| Poultry – Turkey Operation – Confinement | 3.78E-02 | kg NH3/bird/month | 1 |
| Poultry – Turkey Operation – Land Application | 3.40E-02 | kg NH3/bird/month | 1 |
| Poultry – Turkey Operation – Storage | 6.80E-03 | kg NH3/bird/month | 1 |
| Sheep | 2.65E-01 | kg NH3/sheep/month | 1 |
| Swine – Composite | county | kg NH3/pig/month | 1 |
| Swine – Deep Pit Operation – Confinement | 2.65E-01 | kg NH3/pig/month | 1 |
| Swine – Deep Pit Operation – Land Application | county | kg NH3/pig/month | 1 |
| Swine – Lagoon Operation – Confinement | 2.27E-01 | kg NH3/pig/month | 1 |
| Swine – Lagoon Operation – Land Application | county | kg NH3/pig/month | 1 |
| Swine – Lagoon Operation – Manure Storage | county | kg NH3/pig/month | 1 |
| Swine – Outdoor Operation – Confinement | county | kg NH3/pig/month | 1 |

References:


1. Cliff Davidson, Peter Adams, Ross Strader, Rob Pinder, Natalie Anderson, Marian Goebes, and Josh Ayers. The Environmental Institute, Carnegie Mellon University, *CMU Ammonia Model v.3.6.*, 2004, at http://www.cmu.edu/ammonia/, accessed 25 April 2009
2. Jonathan Dorn, E.H. Pechan & Associates. 2009. A weighted average emission factor calculated using data from the 2002 CMU Ammonia Model v.3.6
3. U.S. Environmental Protection Agency, *National Emission Inventory – Ammonia Emissions from Animal Agricultural Operations*, Revised Draft Report, 22 April 2005, p. 4-6, at http://www.epa.gov/ttn/chief/net/2002inventory.html, accessed 5 May 2009.

**Emissions**

The livestock activity files that were provided with the CMU Ammonia Model v.3.6 were replaced with the updated county-level animal population files and modified emissions files. County-level ammonia emissions were then calculated by running the model.

**Sample Calculations**

*Allocation of Undisclosed Data*

From the 2007 Census of Agriculture, the total national number of beef cattle in Alabama is 678,949. The total number of beef cattle disclosed at the county-level is 388,827.

Total number of beef cattle undisclosed at the county-level = 678,949 - 338,827 = 340,122

From the 2007 Census of Agriculture, the total number of farms in Alabama not disclosing beef cattle numbers is 10,518.

Average beef cattle per farm not disclosing data = 340,122 / 10,518 = 32.3

For 2007, Baldwin County, Alabama beef cattle data were not disclosed. The total number of farms with beef cattle in Baldwin County is 343.

Estimated number of beef cattle in Baldwin County = 32.3 x 343 = 11,092

*Manure Management Train*

From the 2002 CMU Ammonia Model input files, Chilton County, Alabama had 79 beef cattle under drylot management and 18,900 beef cattle under pasture management in 2002.

Total beef cattle = 79 + 18,900 = 18,979
% of beef cattle under drylot management = 79 / 18,979 = 0.42
% of beef cattle under pasture management = 18,900 / 18,979 = 99.58

The total number of beef cattle for Chilton County reported in the 2007 Census of Agriculture is 7,939.

Number of beef cattle under drylot management in 2007 = 7,939 x 0.0042 = 33
Number of beef cattle under pasture management in 2007 = 7,939 x 0.9958 = 7,906

*"Other Cattle"*

For Clay County, Alabama, the 2007 Census of Agriculture reports the number of "Other Cattle" as 5,471, the number of dairy cattle as 216, and the number of beef cattle as 9,096.

Total beef and dairy cattle reported = 216 + 9,096 = 9,312
% of other cattle assigned to beef cattle = (9,096/9,312)*100 = 97.68

% of other cattle assigned to dairy cattle = (216/9,312)*100 = 2.32
Other cattle allocated to beef cattle = 5,471 x .9768 = 5,344
Other cattle allocated to dairy cattle = 5,471 x 0.0232 = 127

## Fertilizer Ammonia Emissions

Fertilizer in this category refers to any nitrogen-based compound, or mixture containing such a compound, that is applied to land to improve plant fitness.

The approach to calculating emissions for fertilizer $NH_3$ sources consisted of three general steps, as follows:

- Calculating the percent change in county-level fertilizer quantities applied between 2002 and 2007.
- Using the percent change in applied fertilizer quantity to grow the fertilizer activity files provided with the CMU Ammonia Model v.3.6[14].
- Running the CMU Ammonia Model to calculate ammonia emissions based on the updated county-level fertilizer quantities.

Table 3 is a listing of the SCCs assigned to the fertilizer $NH_3$ sources in the NEI08v2.

14 . Davidson et al., 2009

**Table 3. Fertilizer Ammonia SCCs in the 2008 NEIv2.**

| SCC | Descriptor 2 | Descriptor 4 | Descriptor 5 | Descriptor 10 |
|---|---|---|---|---|
| 2801700001 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Anhydrous Ammonia |
| 2801700002 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Aqueous Ammonia |
| 2801700003 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Nitrogen Solutions |
| 2801700004 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Urea |
| 2801700005 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Ammonium Nitrate |
| 2801700006 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Ammonium Sulfate |
| 2801700007 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Ammonium Thiosulfate |
| 2801700010 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | N-P-K (multi-grade nutrient fertilizers) |
| 2801700011 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Calcium Ammonium Nitrate |
| 2801700012 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Potassium Nitrate |
| 2801700013 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Diammonium Phosphate |
| 2801700014 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Monoammonium Phosphate |
| 2801700015 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Liquid Ammonium Polyphosphate |
| 2801700099 | Miscellaneous Area Sources | Agriculture Production - Crops | Fertilizer Application | Miscellaneous Fertilizers |

**Activity Data**

County-level fertilizer consumption data for 2002 and 2007 were obtained from the Fertilizer Institute's Commercial Fertilizers 2002 and 2007 reports[15]. The consumption data include total fertilizer sales or shipments for farm and non-farm use and are reported semi-annually for the fiscal year. To make the fertilizer types listed in the Commercial Fertilizers reports match the activity input files from the CMU Ammonia Model, the fertilizer types were grouped according to Table 4. For any state in 2002 reporting fertilizer quantities from unknown counties, the quantities were apportioned to every county in the state based on cropland area obtained from the U.S. Department of Agriculture's 2002 Census of Agriculture[16]. Similarly for 2007, fertilizer quantities from unknown counties were apportioned based on cropland area reported in the 2007 Census of Agriculture[17]. For each fertilizer group, the percent difference in fertilizer consumption between 2002 and 2007 was calculated for each county. These percentages were used to grow the 2002 county-level nitrogen quantities from the fertilizer activity files provided with the CMU Ammonia Model v.3.6.

The average nitrogen content for each fertilizer group, reported in Table 5, was calculated by summing the county-level fertilizer quantities for all counties from the CMU Ammonia Model activity files to generate total nitrogen applied. For each fertilizer group, the total nitrogen applied was then divided by the 2002 fertilizer consumption data from the 2002 Commercial Fertilizers report to obtain the percent nitrogen content for each fertilizer group. For any county with fertilizer consumption in 2007, but not in 2002, the fertilizer quantity obtained from the 2007 Commercial Fertilizer's report was multiplied by the percent nitrogen content of each fertilizer group to determine tons of nitrogen. The tons of nitrogen were then converted to kilograms and allocated temporally by month according to the state-level percentage of total fertilizer in that group applied each month. The state-level percentage was calculated using data in the CMU Ammonia Model input files.

**Emission Factors**

Emission factors for each fertilizer group were provided with the CMU Ammonia Model and are reported in Table 6.[12]

15 Association of American Plant Food Control Officials in partnership with The Fertilizer Institute, *Commercial Fertilizers 2002* and *Commercial Fertilizers 2007*, at http://www.aapfco.org/aapfcopubs.html, accessed 2 May 2009
16 U.S. Department of Agriculture, *2002 Census of Agriculture*, at http://www.agcensus.usda.gov/, accessed 30 April 2009
17 USDA, 2007.

**Table 4. Fertilizers Assigned to Fertilizer Groups**

| CMU Ammonia Model Fertilizer Group | Commercial Fertilizers Report - Fertilizer Code | Description 1 | Description 2 |
|---|---|---|---|
| Ammonium Nitrate | 10 | Ammonium Nitrate | Ammoniumnitrate |
| Ammonium Sulfate | 24 | Ammonium Sulfate | Ammoniumsulfate |
| Ammonium Thiosulfate | 31 | Ammonium Thiosulfate | Ammoniumthiosul |
| Anhydrous Ammonia | 2 | Anhydrous Ammonia | Anhy Ammonia |
| Aqueous Ammonia | 6 | Aqua Ammonia | Aqua Ammonia |
| Calcium Ammonium Nitrate | 35 | Calcium Ammonium Nit | Calcium Amm Nit |
| Diammonium Phosphate | 203 | Diammonium Phosphate | DAP |
| Liquid Ammonium Polyphosphate | 249 | Liquid Ammonium Poly | Liq Amm Poly |
| Miscellaneous | 12 | Ammonium Nitrate Sol | Amm Nit Solution |
| | 13 | Ammonium Nitrate-Lim | Amm Nit Lime Mix |
| | 16 | Ammonium Nitrate-Sul | Ammoniumnit-Sul |
| | 20 | Ammonium Polysulfide | Ammoniumpolysulf |
| | 25 | Ammonium Sulfate Sol | Amm Sul Solution |
| | 27 | Ammonium Sulfate-Nit | Ammoniumsul-Nit |
| | 29 | Ammonium Sulfate-Ure | Ammoniumsul-Urea |
| | 46 | Calcium Nitrate-Urea | Calcium Nit-Urea |
| | 52 | Magnesium Nitrate | Magnesium Nit |
| | 54 | Nitric Acid | Nitric Acid |
| | 62 | Sodium Nitrate | Sodium Nitrate |
| | 64 | Sulfur Coated Urea | Sul Ctd Urea |
| | 67 | Urea Solution | Urea Solution |
| | 68 | Urea-Formaldehyde | Urea-Form |
| | 97 | Nitrogen Product - C | Nitrogen No Code |
| | 98 | Nitrogen Product - C | Nitrogen No Id |
| | 201 | Ammonium Metaphospha | Ammoniummetaphos |
| | 202 | Ammonium Phosphate | Ammoniumphos |
| | 204 | Ammonium Polyphospha | Ammoniumpoly |
| | 206 | Ammonium Phosphate N | Amm Phosnitrate |
| | 207 | Ammonium Phosphate S | Amm Phossulfate |
| | 241 | Nitric Phosphate | Nitric Phos |
| | 413 | Manure Salts | Manure Salts |
| | 458 | Potassium-Sodium Nit | Pot-Sod Nitrate |
| | 617 | Fish Scrap | Fish Scrap |
| | 629 | Guano | Guano |
| | 649 | Manure | Manure |
| | 652 | Peat | Peat |
| | 661 | Sewage Sludge, Activ | Act Sew Sludge |
| | 663 | Sewage Sludge, Diges | Dig Sew Sludge |
| | 665 | Sewage Sludge, Heat | Ht Driedsew Slge |
| | 667 | Sewage Sludge, Other | Oth Sew Sludge |
| | 671 | Soybean Meal | Soybean Meal |
| | 673 | Tankage, Animal | Animal Tankage |
| | 675 | Tankage, Process | Process Tankage |
| | 697 | Natural Organic Prod | Nat Org No Code |
| | 698 | Nat Organic Product | Nat Org No Id |

| CMU Ammonia Model Fertilizer Group | Commercial Fertilizers Report - Fertilizer Code | Description 1 | Description 2 |
|---|---|---|---|
| | 764 | Soil Amendment | Soil Amendmnt |
| | 766 | Soil Conditioner | Soil Cond |
| | 767 | Potting Soil | Potting Soil |
| | 797 | Sec./Micronut. - Cod | Sec/Mic No Code |
| | 798 | Sec./Micronut. - Cod | Sec/Mic No Id |
| | 978 | Fertilizer Product - | Fert No Id |
| | 988 | Single Nutrient - Co | Sgle-Nu No Id |
| Mix | 0 | Identified By Grade | Ident. By Grade |
| | 998 | Multiple Nutrient - | Mult-Nut No Grade |
| Monoammonium Phosphate | 209 | Monoammonium Phosphate | Monoamm Phos |
| Nitrogen Solutions | 56 | Nitrogen Solution <28% | Nitrogensol <28% |
| | 58 | Nitrogen Solution 28% | Nitrogensol 28% |
| | 59 | Nitrogen Solution 30% | Nitrogensol 30% |
| | 60 | Nitrogen Solution 32% | Nitrogensol 32% |
| | 61 | Nitrogen Solution >32% | Nitrogensol >32% |
| Potassium Nitrate | 453 | Potassium Nitrate | Pot Nitrate |
| Urea | 66 | Urea | Urea |

**Table 5. Fertilizer Nitrogen Content**

| Fertilizer | Nitrogen Content (percent) |
|---|---|
| Ammonium Nitrate | 36 |
| Ammonium Sulfate | 22 |
| Ammonium Thiosulfate | 12 |
| Anhydrous Ammonia | 82 |
| Aqueous Ammonia | 21 |
| Calcium Ammonium Nitrate | 17 |
| Diammonium Phosphate | 18 |
| Liquid Ammonium Polyphosphate | 10 |
| Miscellaneous | 8 |
| Mix | 12 |
| Monoammonium Phosphate | 11 |
| Nitrogen Solutions | 29 |
| Potassium Nitrate | 14 |
| Urea | 46 |

**Table 6. Fertilizer Emission Factors**

| Fertilizer Description | Pollutant Code | Emission Factor (varies by county for some fertilizers) | | | Emission Factor Unit | Emission Factor Reference* |
|---|---|---|---|---|---|---|
| | | Min | Max | Average | | |
| Ammonium Nitrate | NH3 | 1.0 | 3.0 | 1.91 | % N volatilized as NH3 | CMUv3.6 |
| Ammonium Sulfate | NH3 | 5.0 | 15.0 | 9.53 | % N volatilized as NH3 | CMUv3.6 |
| Ammonium Thiosulfate | NH3 | 2.5 | 2.5 | 2.5 | % N volatilized as NH3 | CMUv3.6 |
| Anhydrous Ammonia | NH3 | 4.0 | 4.0 | 4.0 | % N volatilized as NH3 | CMUv3.6 |
| Aqueous Ammonia | NH3 | 4.0 | 4.0 | 4.0 | % N volatilized as NH3 | CMUv3.6 |
| Calcium Ammonium Nitrate | NH3 | 1.0 | 3.0 | 1.91 | % N volatilized as NH3 | CMUv3.6 |
| Diammonium Phosphate | NH3 | 5.0 | 5.0 | 5.0 | % N volatilized as NH3 | CMUv3.6 |
| Liquid Ammonium Polyphosphate | NH3 | 5.0 | 5.0 | 5.0 | % N volatilized as NH3 | CMUv3.6 |
| Miscellaneous Fertilizers | NH3 | 6.0 | 8.0 | 6.59 | % N volatilized as NH3 | CMUv3.6 |
| Monoammonium Phosphate | NH3 | 5.0 | 5.0 | 5.0 | % N volatilized as NH3 | CMUv3.6 |
| Nitrogen Solutions | NH3 | 8.0 | 8.0 | 8.0 | % N volatilized as NH3 | CMUv3.6 |
| N-P-K (multi-grade nutrient fertilizers) | NH3 | 1.0 | 3.0 | 1.91 | % N volatilized as NH3 | CMUv3.6 |
| Potassium Nitrate | NH3 | 2.0 | 2.0 | 2.0 | % N volatilized as NH3 | CMUv3.6 |
| Urea | NH3 | 15.0 | 20.0 | 15.8 | % N volatilized as NH3 | CMUv3.6 |

* Cliff Davidson, Peter Adams, Ross Strader, Rob Pinder, Natalie Anderson, Marian Goebes, and Josh Ayers. The Environmental Institute, Carnegie Mellon University, *CMU Ammonia Model v.3.6.*, 2004, at http://www.cmu.edu/ammonia/, accessed 25 April 2009

## Emissions

The fertilizer activity files provided with the CMU Ammonia Model v.3.6 were replaced with the updated county-level fertilizer files. County-level ammonia emissions were then calculated by running the model. The model corrects for the difference in mass between nitrogen and ammonia.

N applied x % N volatilized as $NH_3$ x 17 g /14 g = $NH_3$ emissions

**Sample Calculations**

*Allocation of Fertilizer Quantities from Unknown Counties*

From the 2007 Commercial Fertilizers report, Colorado reported 4,774,000 kg of ammonium nitrate from unknown counties for January through June of 2007. This quantity was distributed to counties based on the percent of cropland in the state located in each county. For example, Colorado has 11,484,000 acres of cropland. Adams County, Colorado has 547,000 acres of cropland.

Percent of cropland in CO located in Adams County = (547,000 / 11,484,000) x 100 = 4.76

Ammonium nitrate allocated to Adams County = 4,774,000 kg x .0476 = 227,240 kg

*Growing the CMU Ammonia Model Input Files*

After allocating fertilizer data from unknown counties for 2002 and 2007, the county-level percent difference between fertilizer quantity applied in 2002 and 2007 was used to grow the data in the activity files provided with the CMU Ammonia Model. For example, Autauga County, Alabama applied 473,180 kg of ammonium nitrate from July 2001 through December 2001 and 516,240 kg from July 2006 through December 2006.

Percent change in ammonium nitrate applied = (516,240 kg / 473,180 kg) x 100 = 109

The quantity of nitrogen, in the form of ammonium nitrate, applied per month from July through December 2002 in Autauga County was extracted from the CMU Ammonia Model activity files and multiplied by the percent change.

| | |
|---|---|
| July: | 3,250 kg x 1.09 = 3,543 kg N |
| August: | 3,210 kg x 1.09 = 3,499 kg N |
| September: | 9,640 kg x 1.09 = 10,508 kg N |
| October: | 6,320 kg x 1.09 = 6,889 kg N |
| November: | 2,600 kg x 1.09 = 2,834 kg N |
| December: | 1,380 kg x 1.09 = 1,504 kg N |

*Calculation of Nitrogen Content in a Fertilizer Group*

The sum of all nitrogen applied in the form of ammonium nitrate from the CMU Ammonia Model ammonium nitrate activity file was 508,000,000 kg. From the 2002 Commercial Fertilizers report, the total quantity of ammonium nitrate applied in 2002 was 1,420,000,000 kg.

N content of ammonium nitrate = (508,000,000 kg / 1,420,000,000 kg) x 100 = 36 %

*County Where Fertilizer was Applied in 2007, but not in 2002*

In Meade County, Kentucky, there was no ammonium nitrate applied from January to June of 2002, but there were 356,705 kg applied from January to June of 2007. To convert to kg of nitrogen, the quantity of ammonium nitrate applied in 2007 was multiplied by the nitrogen content of ammonium nitrate.

N applied = 356,705 kg x 0.36 = 128,414 kg

The quantity of nitrogen was then allocated temporally by month from January to June based on the state-level distribution of nitrogen applied in the form of ammonium nitrate from the CMU Ammonia Model ammonium nitrate activity file. Total nitrogen in the form of ammonium nitrate applied in Kentucky from January through June of 2002 was 17,000,000 kg. The total for January was 289,000 kg. The total for February was 745,000 kg.

January: (289,000 kg / 17,000,000 kg) x 128,414 kg = 2,183 kg N applied in Meade County
February: (745,000 kg / 17,000,000 kg) x 128,414 kg = 5,600 kg N applied in Meade County
March – June: calculated same as above

# EMISSIONS PROCESSING

The fertilizer and livestock non-point source emissions were processed for the WestJumpAQMS using the Sparse Matrix Operator Kernel Emissions (SMOKE[18]) modeling system. The SCCs for these sources were extracted from the general NEI08v2 non-point inventory into separate fertilizer (agft) and livestock (aglv) inventory files. Separating these inventory components to explicit processing sectors facilitates source attribution modeling and special treatment of these sources for air quality modeling. As non-point sources, these sectors were simulated as county total, annual inventories. Details of the processing steps used to prepare these sources for air quality modeling are included in the following sections. Additional details of the ancillary data files used in these processing steps are contained in Technical Memorandum 13: Emissions Modeling Parameters and Ancillary Data for the WestJumpAQMS 2008 Photochemical Modeling.

## Spatial Allocation

Spatial allocation of the ammonia sources to the WestJumpAQMS modeling domains is accomplished using spatial surrogates. Spatial surrogates map county polygons to the uniformly spaced grid cells of a modeling domain. All of the fertilizer emissions are allocated to the modeling grids using the Total Agriculture surrogate, which uses the 2001 National Landcover Database (NCLD)[19] attributes Pasture/Hay, Grains, Row Crops, Fallow Land, and Orchards/Vineyards to characterize the spatial distribution of these sources. All livestock sources outside of Colorado also use the NLCD Total Agriculture surrogate for mapping the county level emissions to the modeling grids. Within the state of Colorado we used a dataset of

18 http://www.smoke-model.org/index.cfm
19 Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDriel, J.N., and Wickham, J. 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States. *Photogrammetric Engineering and Remote Sensing*, Vol. 73, No. 4, pp 337-341

confined animal feeding operation (CAFO) locations for cattle, horses, sheep, poultry, and goats provided by Colorado State University to allocate the 2008 NEIv2 livestock $NH_3$ emissions to the WestJumpAQMS modeling grids. The CAFO dataset includes the number of each type of animal at latitude/longitude coordinates throughout Colorado. We assigned animal-specific emissions factors to calculate the $NH_3$ emissions at each CAFO and then calculated spatial surrogates that are weighted by the annual tonnage of emissions at each CAFO. Figure 1 is a map of the underlying CAFO data used to compute the livestock emissions spatial surrogate for the state of CO. Figure 1 shows the total $NH_3$ emissions for all CAFOs in the dataset. The actual spatial surrogates used to prepare emissions for the WestJumpAQMS use spatial distributions for the five animal types listed above.

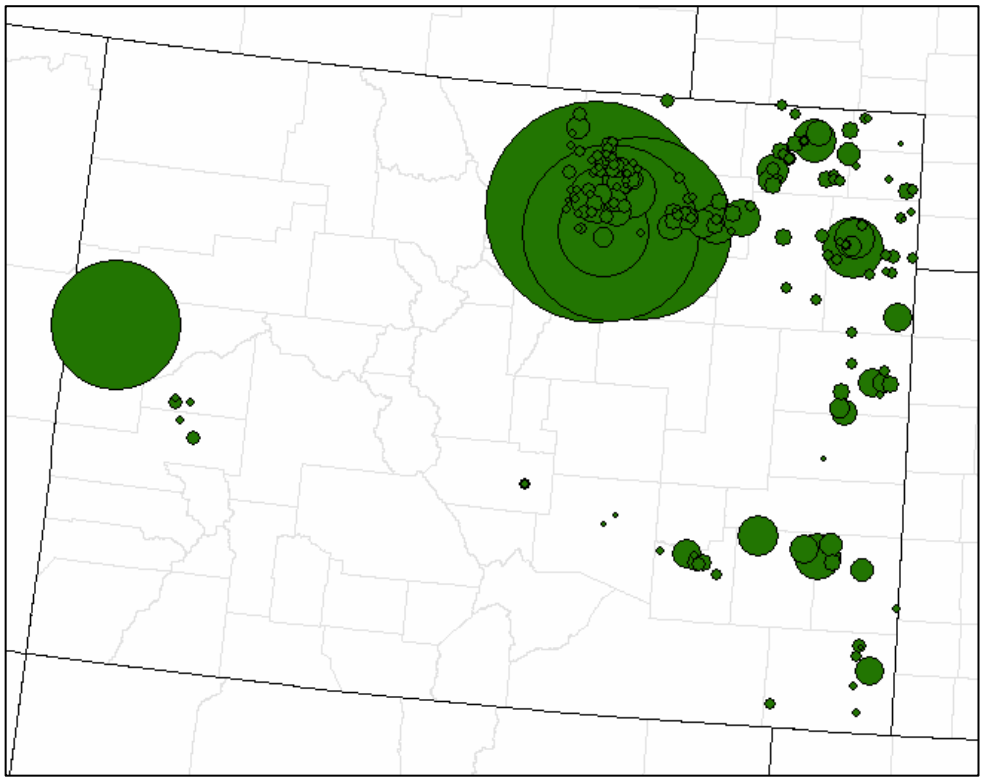

**Figure 1. Colorado Livestock $NH_3$ Sources**

## Temporal Allocation

EPA provided temporal allocation factors for use with the 2008 NEIv2 datasets. The monthly temporal profiles available for livestock sources are either state-specific that are based on process-based[20] modeling, or they are national that are based on inverse[21] modeling studies. Figure 2 shows the monthly temporal profiles available from the EPA for livestock sources in the western U.S. While state-specific profiles are available, they are not being used in the

20 Pinder, R.W., Ross Strader, Cliff I Davidson, Peter J Adams, A temporally and spatially resolved ammonia emission inventory for dairy cows in the United States, Atmospheric Environment, Volume 38, Issue 23, July 2004

21 Gilliland, A. B., K. W. Appel, R. W. Pinder, and R. L. Dennis (2006), Seasonal $NH_3$ emissions: Inverse model estimation and evaluation, Atmos. Environ., 40, 4986–4998.

WestJumpAQMS modeling as these data have not necessarily been fully vetted, thus are potentially subject to significant error, hence, incorporation of such data is beyond the resources of this project. All of the livestock sources in the 2008 NEIv2 were prepared using the Gilliland and Pinder/Gilliland profiles shown in Figure 2, which are based on either inverse modeling or a combination of inverse and process-based modeling, respectively. All livestock sources use a flat weekly profile, meaning the emissions are the same for each day of the week, and the diurnal profile shown in Figure 3.

The origin of the EPA temporal profiles for fertilizer sources is not clear, although they are state-specific. Figure 4 shows the monthly temporal profiles available from EPA for fertilizer sources in the western U.S. Like livestock, all fertilizer sources use a flat weekly profile and the diurnal profile shown in Figure 3.

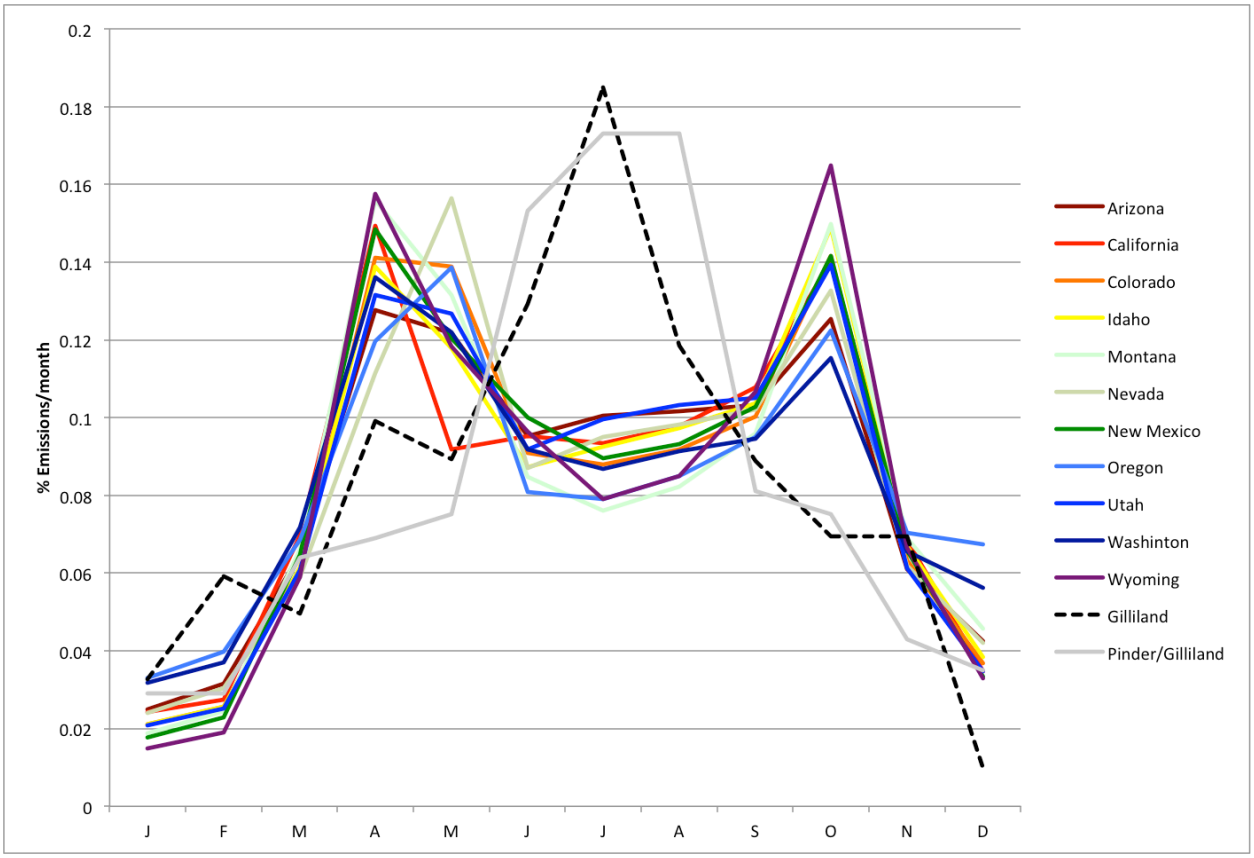


**Figure 2. Livestock Source Monthly Temporal Profiles**

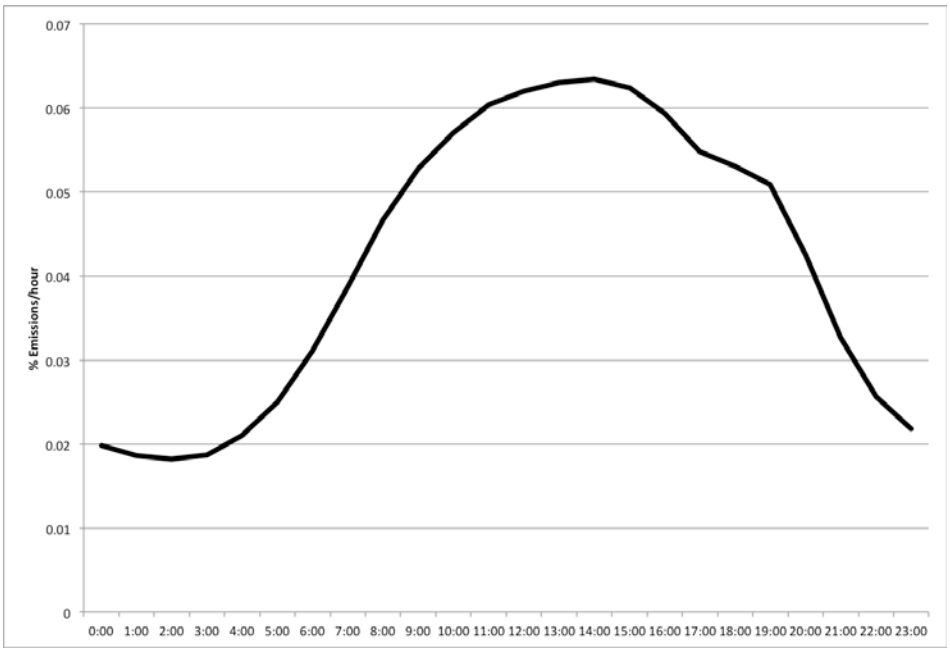


**Figure 3. Livestock and Fertilizer Source Hourly Temporal Profile**

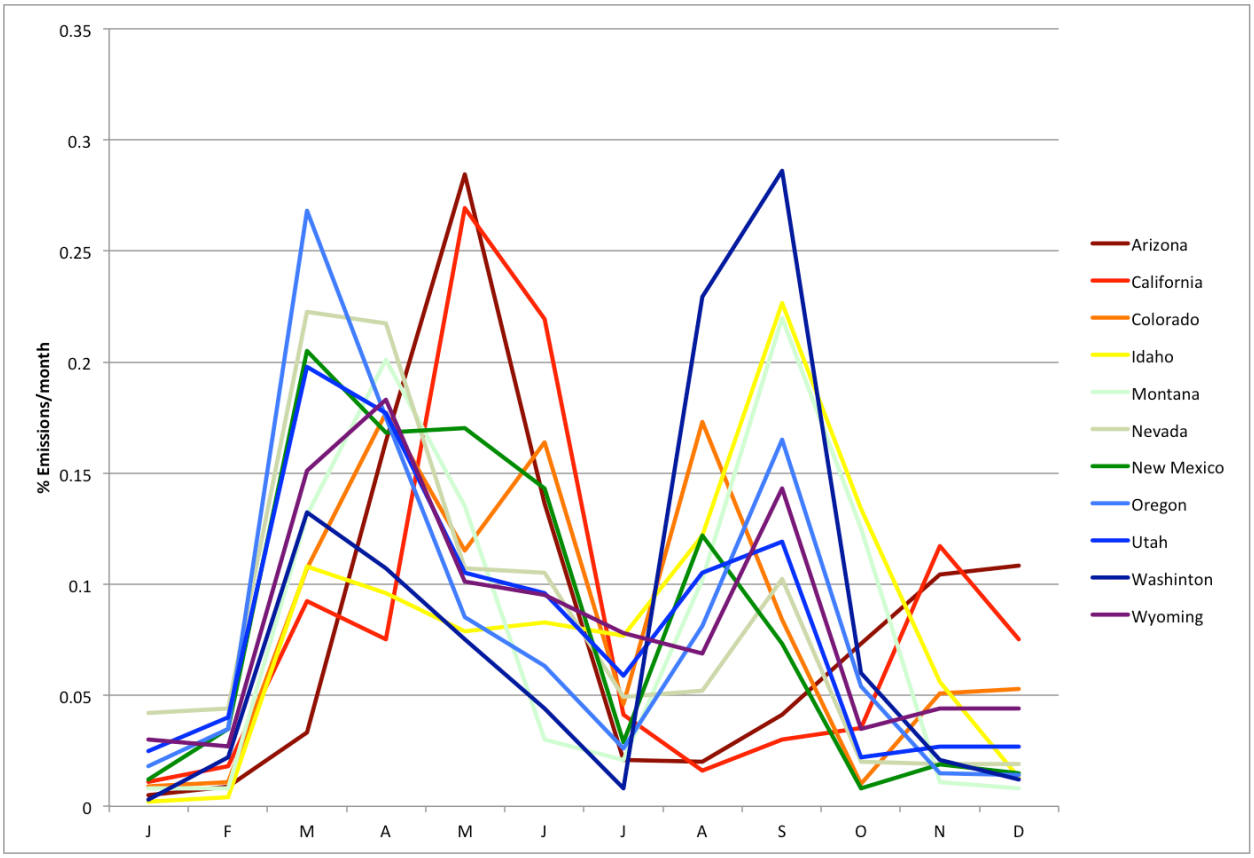


**Figure 4. Fertilizer Source Monthly Temporal Profile**

## Chemical Speciation

Ammonia does not require any chemical speciation and is passed through to the air quality model with no mass adjustments or chemical mapping. The only speciation process impacting the inventory $NH_3$ is the conversion from mass to molar units.

## Quality Assurance

Quality assurance (QA) will be performed following the emissions quality assurance protocol developed for the WRAP Regional Modeling Center (Adelman, 2004[22]). These procedures include systematic procedures for:

- Modeling QA – accuracy assurance and problem identification.
- System QA – software and data tracking.
- Documentation – tracking QA issues, recording the QA process and report writing.

An emissions QA checklist is developed that delineates each step of the QA process and allows a systematic approach to the QA process to assure critical steps are not overlooked. The completed QA checklists and templates include:

- Model configuration settings.
- Inventory file log.
- Ancillary input file log.
- Model execution log.

A series of QA products are produced that are compared to other studies and the expected outcomes:

- Spatial plots of emissions by source category.
- Annual time series plots of emissions for subregions.
- Diurnal time series plots.
- Daily vertical profile plots.

# AMMONIA EMISSIONS RESULTS

Table 7 shows the annual livestock, fertilizer and combined total agriculture ammonia emissions by state. Iowa (8.5%) has the most livestock $NH_3$ emissions followed by Texas (8.3%), California (7.9%), North Carolina (6.3%), Nebraska (4.6%) and Minnesota (4.6%). Iowa (7.6%) and Texas (7.3%) are also the two top emitting states for fertilizer $NH_3$ emissions follows by South Dakota (7.2%), Minnesota (6.1%), Illinois (5.9%), California (5.6%), Nebraska (5.5%) and North Dakota (5.4%). The highest emitting total agricultural ammonia emissions states are Iowa (8.2%) and Texas (8.0%) followed by California (7.1%), Minnesota (5.1%), Nebraska (4.9%) and North Carolina (4.7%).

22 http://www.epa.gov/ttnchie1/conference/ei13/qaqc/adelman_pres.pdf

**Table 7. 2008 NEIv2 total livestock and fertilizer source ammonia (NH3) emissions by state, annual emissions (Tons per Year, TPY); WRAP states highlighted**

| FIPS CODE | State | Livestock (TPY) | Fertilizer (TPY) | Total Ag (TPY) | Live-stock | Fertil-izer | Total Ag |
|---|---|---|---|---|---|---|---|
| 1000 | Alabama | 55443.5 | 6517.1 | 61960.6 | 2.3% | 0.6% | 1.7% |
| 4000 | Arizona | 22327.4 | 6355.7 | 28683.2 | 0.9% | 0.5% | 0.8% |
| 5000 | Arkansas | 77631.9 | 42570.0 | 120201.8 | 3.2% | 3.6% | 3.3% |
| 6000 | California | 192380.6 | 65915.4 | 258295.9 | 7.9% | 5.6% | 7.1% |
| 8000 | Colorado | 53939.7 | 14537.6 | 68477.3 | 2.2% | 1.2% | 1.9% |
| 9000 | Connecticut | 2059.5 | 427.9 | 2487.4 | 0.1% | 0.0% | 0.1% |
| 10000 | Delaware | 11135.8 | 1929.4 | 13065.2 | 0.5% | 0.2% | 0.4% |
| 12000 | Florida | 26179.3 | 7156.9 | 33336.2 | 1.1% | 0.6% | 0.9% |
| 13000 | Georgia | 74087.7 | 10568.9 | 84656.6 | 3.0% | 0.9% | 2.3% |
| 15000 | Hawaii | 3093.5 | 3804.0 | 6897.5 | 0.1% | 0.3% | 0.2% |
| 16000 | Idaho | 76040.5 | 25721.6 | 101762.0 | 3.1% | 2.2% | 2.8% |
| 17000 | Illinois | 46913.5 | 69612.8 | 116526.3 | 1.9% | 5.9% | 3.2% |
| 18000 | Indiana | 59126.4 | 42504.3 | 101630.6 | 2.4% | 3.6% | 2.8% |
| 19000 | Iowa | 206086.3 | 89461.5 | 295547.8 | 8.5% | 7.6% | 8.2% |
| 20000 | Kansas | 92100.5 | 59035.1 | 151135.6 | 3.8% | 5.0% | 4.2% |
| 21000 | Kentucky | 34003.0 | 17645.2 | 51648.2 | 1.4% | 1.5% | 1.4% |
| 22000 | Louisiana | 18048.2 | 18924.5 | 36972.7 | 0.7% | 1.6% | 1.0% |
| 23000 | Maine | 3032.5 | 1704.8 | 4737.3 | 0.1% | 0.1% | 0.1% |
| 24000 | Maryland | 21126.2 | 5895.1 | 27021.3 | 0.9% | 0.5% | 0.7% |
| 25000 | Massachusetts | 1423.1 | 730.0 | 2153.0 | 0.1% | 0.1% | 0.1% |
| 26000 | Michigan | 36521.9 | 24270.7 | 60792.6 | 1.5% | 2.1% | 1.7% |
| 27000 | Minnesota | 111054.9 | 72562.0 | 183616.9 | 4.6% | 6.1% | 5.1% |
| 28000 | Mississippi | 46081.3 | 13087.8 | 59169.1 | 1.9% | 1.1% | 1.6% |
| 29000 | Missouri | 79482.4 | 44847.6 | 124330.0 | 3.3% | 3.8% | 3.4% |
| 30000 | Montana | 21229.9 | 33715.1 | 54944.9 | 0.9% | 2.8% | 1.5% |
| 31000 | Nebraska | 111496.6 | 64674.4 | 176170.9 | 4.6% | 5.5% | 4.9% |
| 32000 | Nevada | 4584.4 | 786.1 | 5370.5 | 0.2% | 0.1% | 0.1% |
| 33000 | New Hampshire | 1035.1 | 113.1 | 1148.2 | 0.0% | 0.0% | 0.0% |
| 34000 | New Jersey | 1972.5 | 1362.1 | 3334.6 | 0.1% | 0.1% | 0.1% |
| 35000 | New Mexico | 31894.8 | 7050.0 | 38944.8 | 1.3% | 0.6% | 1.1% |
| 36000 | New York | 35657.2 | 4223.1 | 39880.3 | 1.5% | 0.4% | 1.1% |
| 37000 | North Carolina | 154187.0 | 14341.2 | 168528.2 | 6.3% | 1.2% | 4.7% |
| 38000 | North Dakota | 14742.0 | 63948.0 | 78690.0 | 0.6% | 5.4% | 2.2% |
| 39000 | Ohio | 52213.3 | 31317.7 | 83531.0 | 2.1% | 2.6% | 2.3% |
| 40000 | Oklahoma | 72131.3 | 25036.4 | 97167.7 | 3.0% | 2.1% | 2.7% |
| 41000 | Oregon | 17952.5 | 24687.1 | 42639.7 | 0.7% | 2.1% | 1.2% |
| 42000 | Pennsylvania | 61152.1 | 9548.0 | 70700.1 | 2.5% | 0.8% | 2.0% |
| 44000 | Rhode Island | 169.7 | 92.7 | 262.5 | 0.0% | 0.0% | 0.0% |
| 45000 | South Carolina | 24622.5 | 5181.2 | 29803.7 | 1.0% | 0.4% | 0.8% |
| 46000 | South Dakota | 46530.2 | 84902.7 | 131432.9 | 1.9% | 7.2% | 3.6% |
| 47000 | Tennessee | 25483.6 | 8395.4 | 33878.9 | 1.0% | 0.7% | 0.9% |

| FIPS CODE | State | Livestock (TPY) | Fertilizer (TPY) | Total Ag (TPY) | Live-stock | Fertil-izer | Total Ag |
|---|---|---|---|---|---|---|---|
| 48000 | Texas | 202031.2 | 86216.7 | 288247.8 | 8.3% | 7.3% | 8.0% |
| 49000 | Utah | 34104.9 | 1702.3 | 35807.2 | 1.4% | 0.1% | 1.0% |
| 50000 | Vermont | 6798.1 | 756.4 | 7554.6 | 0.3% | 0.1% | 0.2% |
| 51000 | Virginia | 33178.9 | 8414.0 | 41592.8 | 1.4% | 0.7% | 1.2% |
| 53000 | Washington | 24799.9 | 17919.7 | 42719.6 | 1.0% | 1.5% | 1.2% |
| 54000 | West Virginia | 8795.4 | 3630.9 | 12426.4 | 0.4% | 0.3% | 0.3% |
| 55000 | Wisconsin | 82453.5 | 32876.6 | 115330.1 | 3.4% | 2.8% | 3.2% |
| 56000 | Wyoming | 12381.5 | 6877.3 | 19258.9 | 0.5% | 0.6% | 0.5% |
| | Total | 2430918 | 1183554 | 3614471 | | | |

Figure 5 displays the agricultural livestock $NH_3$ emissions across the 36 km CONUS domain. The highest livestock NH3 emissions occur in the Midwest with high values also seen in the California Central Valley, North Carolina and several other locations. Figures 6 and 7 displays the spatial distribution of agricultural livestock and fertilizer ammonia emissions across the 12 km WESTUS and 4 km IMW domains, respectively. Within the 12 km WESTUS domain, high livestock $NH_3$ emissions are seen in the California Central Valley, northeastern Nebraska and adjacent areas in Iowa and Minnesota, southwestern Kansas and the Texas panhandle (Figure 6a). High fertilizer $NH_3$ emissions occur in the California Central Valley and eastern Nebraska and South Dakota (Figure 6b).

The monthly livestock ammonia emissions across the 4 km InterMountain West Domain (Figure 7a) exhibit seasonal variations as expected given the use of the Gilliland and Pinder/Gilliland monthly profiles in Figure 2. The highest livestock emissions occur in the Texas panhandle, Kansas, Nebraska and southern Idaho. The monthly fertilizer emissions in the 4 km domain exhibit a different seasonal variation (Figure 4) with the highest emissions in the spring and fall transition months and lowest in the winter (Figure 7b). Because of seasonal variations, different states have different fertilizer schedules. For example, North Dakota has essentially no fertilizer utilization in January while there is some fertilizer application in the warmer states (e.g., Texas). Fertilizer ammonia emissions for North Dakota are greatest in October.

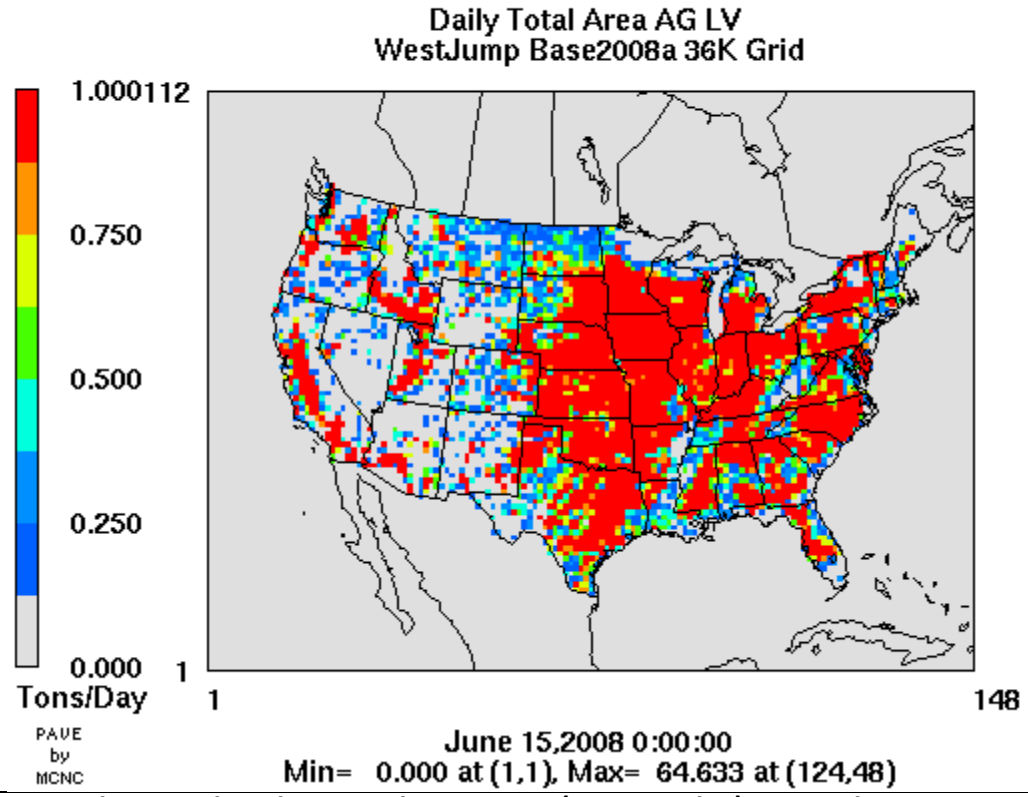


**Figure 5. Daily Agricultural Livestock emissions (tons per day) across the CONUS 36 km domain on June 15, 2008.**

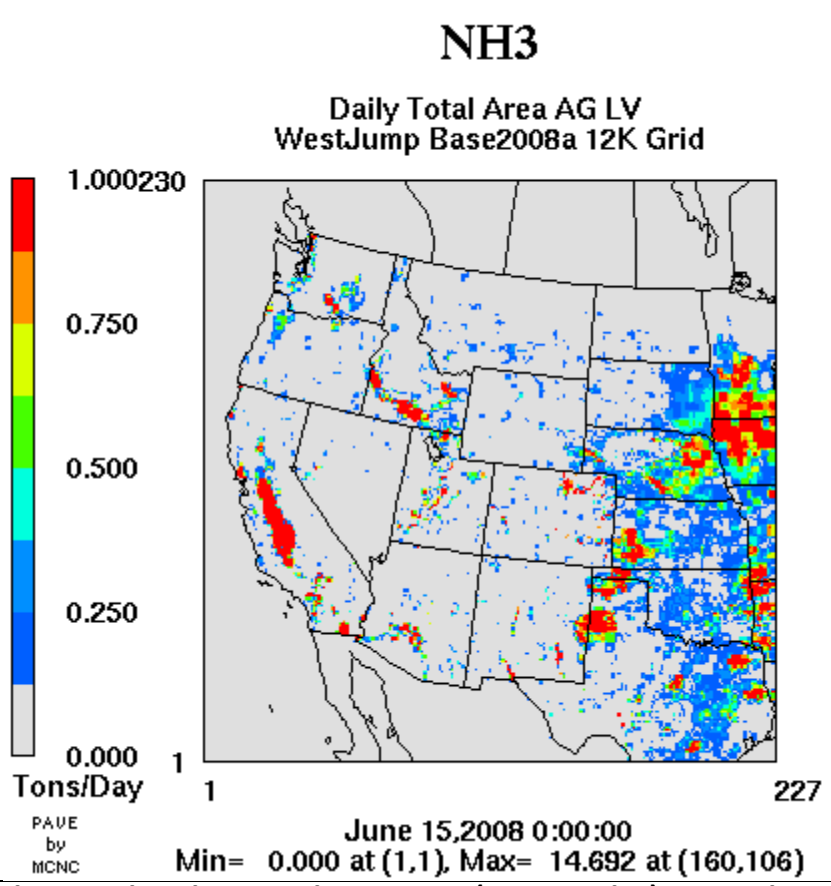


**Figure 6a. Daily Agricultural Livestock emissions (tons per day) across the WESTUS 12 km domain on June 15, 2008.**

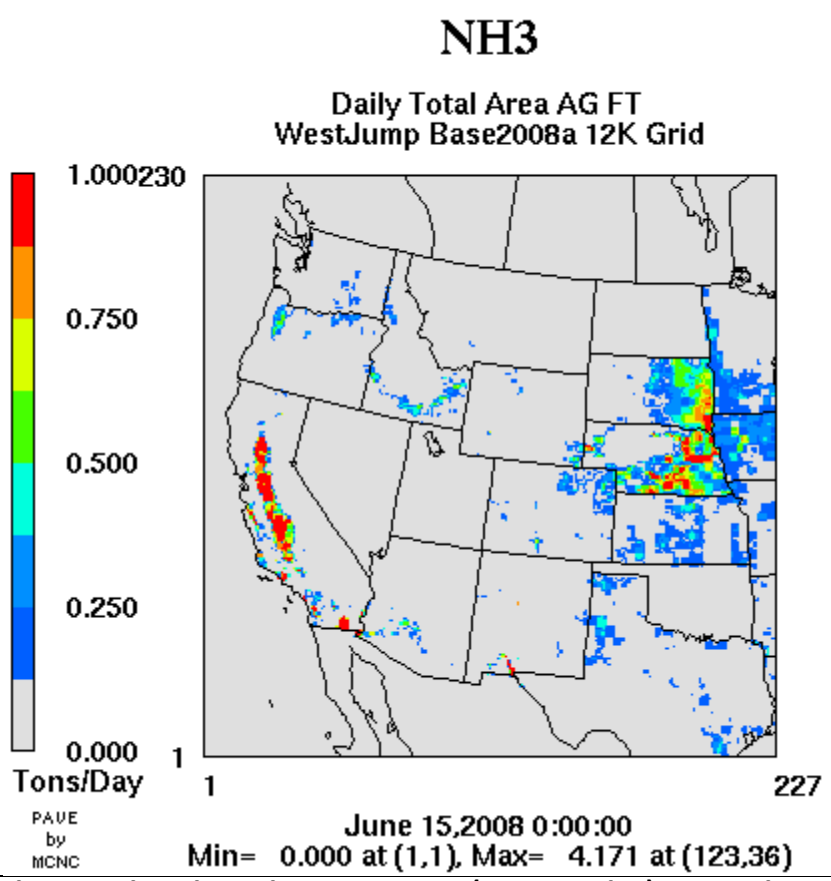


**Figure 6b. Daily Agricultural Fertilizer emissions (tons per day) across the WESTUS 12 km domain for June 15, 2008.**

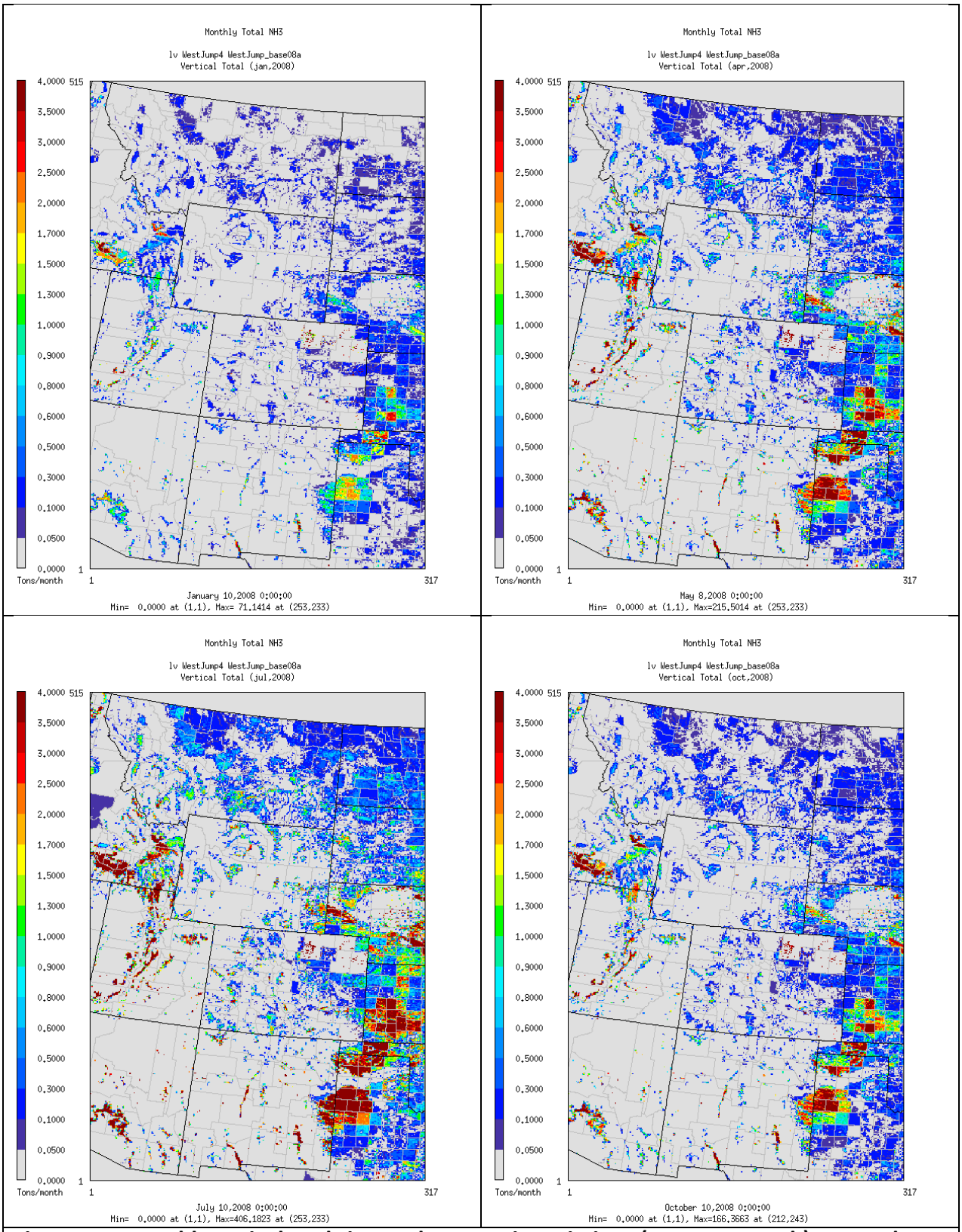


**Figure 7a. Monthly Agricultural Livestock ammonia emissions (tons per month) across the 4 km InterMountain West Domain for January (top left), April (top right), July (bottom left) and October (bottom right) 2008.**

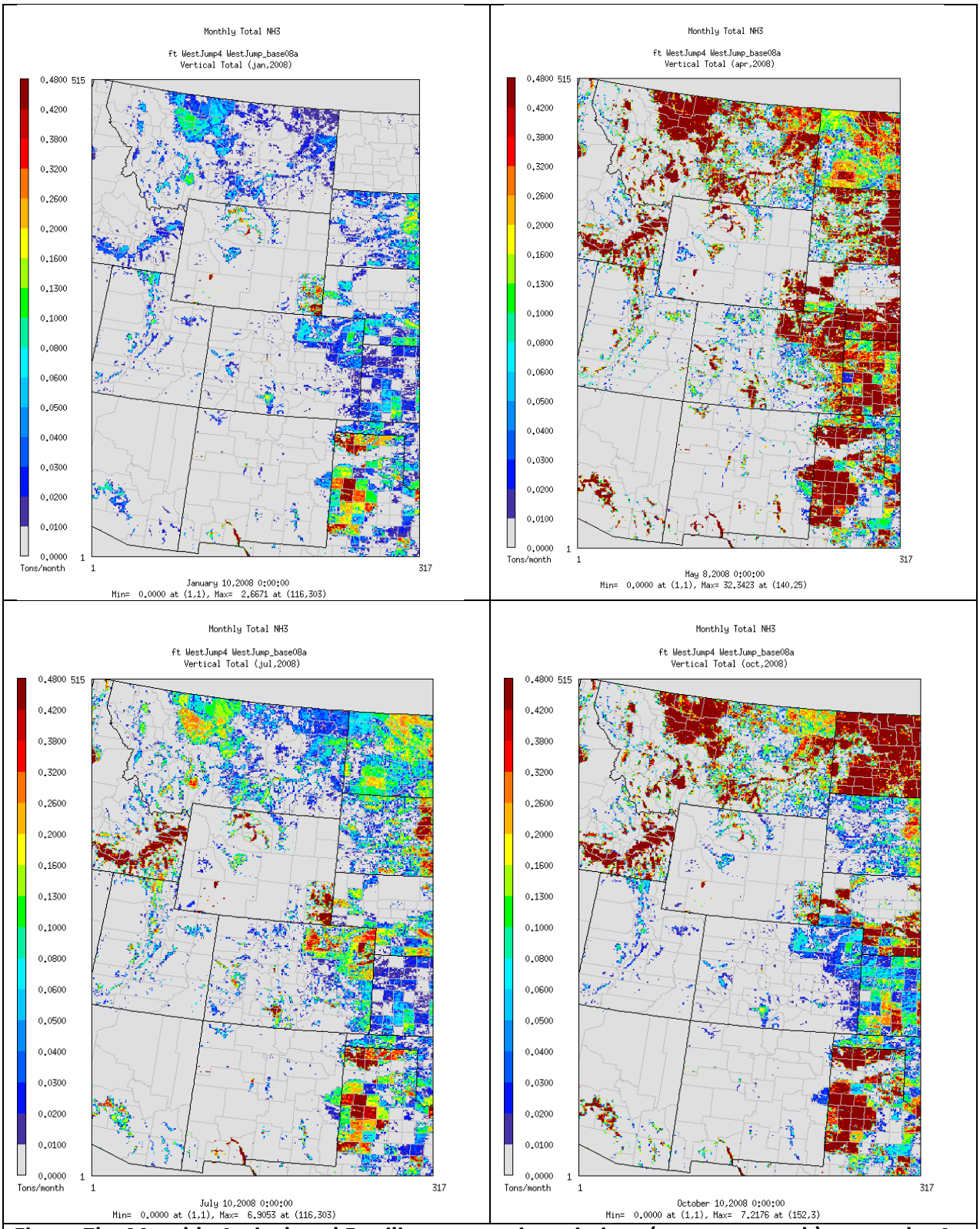


**Figure 7b. Monthly Agricultural Fertilizer ammonia emissions (tons per month) across the 4 km InterMountain West Domain for January (top left), April (top right), July (bottom left) and October (bottom right) 2008.**