**Methodology for Estimating NH3 and VOC Emissions from Livestock**

Source Category Description

Animal waste from livestock results in emissions of both NH3 (ammonia) and Volatile Organic Compounds (VOCs). VOCs emitted by livestock can be defined as any compound of carbon (excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate) that may participate in atmospheric photochemical reactions and is emitted by livestock. Livestock are domesticated farm animals raised in an agricultural setting for home use or profit. Following the work of CMU, the following livestock were evaluated: dairy cattle, beef cattle, swine, and poultry (layers and broilers).

The general approach to calculating NH3 emissions due to livestock is to multiply the emission factor (in kg per year per animal) by the number of animals in the county. VOC emissions were estimated by multiplying a national VOC/NH3 emissions ratio by the county NH3 emissions.

For this source category, the following SCCs were assigned:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **SCC** | **Descriptor 2** | **Descriptor 4** | **Descriptor 7** | **Descriptor 8** |
| 2805002000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Beef cattle production composite | Not Elsewhere Classified |
| 2805018000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Dairy cattle composite | Not Elsewhere Classified |
| 2805025000 | Miscellaneous Area Sources | Agriculture Production - Livestock | Swine production composite | Not Elsewhere Classified |
| 2805007100 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry production - layers with dry manure management systems | Confinement |
| 2805030004 | Miscellaneous Area Sources | Agriculture Production - Livestock | Poultry Waste Emissions | Broilers |

Activity Data

The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Quick Stats program (<https://quickstats.nass.usda.gov>) was utilized to obtain the activity data. The 2014 USDA Survey was used to obtain the livestock count for as many counties as possible across the United States. Because the survey did not cover the entire country, the USDA 2012 Census was used to fill in much of the remaining entities. However, the 2012 Census and the 2014 Survey were not spatially complete when combined, so it was necessary to calculate the missing county data using the methods described below. Table 1 outlines the use of the 2012 Census and 2014 Survey in the creation of the livestock populations.

**Table 1. Summary of Use of 2014 Survey or 2012 Census Animal Populations**

|  |  |
| --- | --- |
| **Animal Type** | **Source** |
| Broilers | There is no 2014 data in the Survey on Broiler Inventory at either the county or state level. Therefore, the inventory reflects the 2012 state level totals. 2014 NEI v2 county level populations were adjusted to ensure that the county totals match the 2012 state level totals. |
| Layers | For Layers, the 2014 NEI v2 animal populations are based on 2012 state level inventories, with a few exceptions. These inventories have been updated to reflect the 2014 state level inventories where 2014 data was available. There were 30 states with 2014 state level layer population data, and a growth factor was applied to 2012 county level populations to reflect the change in population between 2012 and 2014 state level totals. |
| Hogs | For hogs, there were four states in the NEI 2014v1 dataset that had 2014 county level data (MT, NC, ND, OK). No update is needed for those four. The other 46 states were updated to reflect the 2014 state level total. The county populations were multiplied by the growth factor between the NASS 2012 and 2014 state level data. This allows all 50 states to have the sum of their county inventories match the 2014 NASS State level data. |
| Dairy Cattle | No update was provided to the NEI 2014v1 dataset, except for a few states with error corrections. The sum of all county level data for each state matches the NASS state inventory totals. |
| Beef Cattle | No update was provided to the NEI 2014v1 dataset. The sum of all county level data for each state matches the NASS state inventory totals. |

**For Swine and Poultry**: For missing counties, the total value for the counties present is added up and then subtracted from the statewide reported value. This will result in the missing number of animals from the state. From there, the number of counties reporting (D – Did not report) are counted and the total missing animals is divided by the number of counties that did not report. This resulting number is then allocated to each county that reported a (D) value. The counties skipped in the survey are given a value of 0.

*Example:*

County 1: 20

County 2: 45

County 3: (D)

County 4: 5

County 5: (D)

State total: 100

1. Calculate sum of all counties: 20 + 45 + 5 = 70
2. Calculate number of cattle missing from counties: 100 – 70 = 30
3. Since 2 states did not report values: 30/2 =15
4. Allocate 15 animals to County 3 and 15 animals to County 5

Therefore the county animal totals are as follows:

County 1: 20

County 2: 45

County 3: 15

County 4: 5

County 5: 15

**For Cattle:** Following the work of CMU, the total beef cattle is equal to the total cattle (including calves) minus the dairy cattle. In order to get the correct number of total cattle, a method similar to what is described above is used. For the counties missing data, the total value for the counties present is added up and then subtracted from the statewide reported value. This number is then divided by the total number of states that did not report the total number of cattle. The dairy cattle missing in each county are calculated using the formula:

# Dairy Cattle = # Dairy Cattle missing in county\*(Total Cattle (incl. calves) in county/sum of Total Cattle in all counties missing data)

Then, finally, the beef cattle can be calculated using the formula:

# Beef Cattle = Total # Cattle - # Dairy Cattle

Example:

|  |  |  |  |
| --- | --- | --- | --- |
| County | Total Cattle  (including calves) | Beef Cattle | Dairy Cattle |
| 1 | 30 |  | 20 |
| 2 | 100 |  | 30 |
| 3 | 20 |  | (D) |
| 4 | (D) |  | (D) |
| 5 | (D) |  | 10 |

Total State Cattle: 250

Total Dairy Cattle: 100

1. Get total cattle: 30+100+20 = 150

Total missing cattle: 100, therefore 50 cattle goes to county

|  |  |  |  |
| --- | --- | --- | --- |
| County | Total Cattle  (including calves) | Beef Cattle | Dairy Cattle |
| 1 | 30 |  | 20 |
| 2 | 100 |  | 30 |
| 3 | 20 |  | (D) |
| 4 | 50 |  | (D) |
| 5 | 50 |  | 10 |

1. Get total dairy cattle:

Missing number of dairy cattle: 100 – 20 – 30 – 10 = 40

Total number of cattle in counties missing dairy: 20 + 50 = 70

# dairy/county = 40\* (total number of cattle in missing county/70)

Therefore, the number of dairy cattle in:

County 3 = 40\*(20/70) = ~11

County 4 = 40\*(50/70) = ~29

|  |  |  |  |
| --- | --- | --- | --- |
| County | Total Cattle  (including calves) | Beef Cattle | Dairy Cattle |
| 1 | 30 |  | 20 |
| 2 | 100 |  | 30 |
| 3 | 20 |  | 11 |
| 4 | 50 |  | 29 |
| 5 | 50 |  | 10 |

1. Calculate total beef by subtracting dairy cattle from total cattle.\*

|  |  |  |  |
| --- | --- | --- | --- |
| County | Total Cattle  (including calves) | Beef Cattle | Dairy Cattle |
| 1 | 30 | 10 | 20 |
| 2 | 100 | 70 | 30 |
| 3 | 20 | 9 | 11 |
| 4 | 50 | 21 | 29 |
| 5 | 50 | 40 | 10 |
| **Sum** | **250** | **150** | **100** |

\*It is important to note that the total beef cattle obtained from the census is the actual total for beef cattle in each county. However, the procedures listed above were followed for the census data when data wasn’t given.

Emission Factors

CMU developed a model to estimate NH3 emissions from livestock (McQuilling and Adams, 2015). This model produces daily-resolved, climate level emissions factors for a particular distribution of management practices for each county and animal type, as expressed as emissions/animal. These county level emissions factors are then combined together to create a state level emissions factor for each animal type. These state level emissions factors were back calculated from the CMU model using statewide emissions divided by statewide animal totals, and those are the emissions factors used in this analysis. Thus, the CMU model provides a state specific NH3 emissions/head emission factor for each animal type.

VOC emission factors come from the ratio of NH3 to VOC emissions in counties which provided an estimate of both pollutants in NEI 2014 v1. There were 106 counties which provided emissions for both pollutants, and the average ratio was 0.08 tons of VOC for every ton of NH3. This ratio is multiplied by all county level NH3 emissions in NEI 2014 v2 to estimate VOC emissions for each county. This ratio does not vary by state or animal type.

Emissions

A general method to calculate the emissions per county for a given pollutant can be calculated by multiplying the emission factor for the given livestock type by the animal activity in a given county.

Sample Calculations:

*Back Calculating the Emissions Factors from the CMU Model*

The Emissions estimates in NEI 2014 v1 came from the CMU model. These emissions were then divided by the model’s animal population figures to estimate the statewide NH3 emission factor. In Cochise County, AZ, there were 925 head of swine. Those accounted for 9370 kg of NH3.

State NH3 Emissions Factor = Emissions / Number of Animals

= 9370 / 925

= 10.13 kg NH3/head

Note that this EF is the same for all counties in Arizona. Pima County had 5744 kg of NH3and 567 head of swine, or 10.13 kg NH3/head.

*NH3 Emission due to Livestock*

Emissions are calculated by multiplying the state specific NH3 emission factor (in NH3/head) by the number of animals in a given county. For example, in Calhoun County, AL, there were 7,400 head of beef cattle in 2014. The Alabama emission factor for beef cattle from the CMU model was 3.68 kg of NH3/head/year.

Calculate the emissions:

Beef Cattle NH3 Emissions = Emission Factor \* Number of Animals

= 3.68 \* 7,400

= 27,224 kg NH3

*VOC Emission due to Livestock*

VOC emissions are calculated using the ratio of VOC to NH3 emissions from livestock. That ratio is 0.08 kg of VOC for every kg of NH3. Therefore, the VOC emissions from beef cattle in Calhoun County, AL would be calculated as follows:

Beef Cattle VOC Emissions = VOC/NH3 ratio \* NH3 Emissions

= 0.08 \* 27,224 kg NH3

= 2,186 kg VOC

Possible Errors in 2014 v1 Estimates

The animal populations used in NEI 2014 v1 had several consistent problems which have been corrected.  In many cases, the total animal population of all counties is significantly different from the NASS state population total for either 2012 or 2014.  For example, the NEI 2014 v1 had a total swine population of 109,000, which does not match the state total in the NASS for either 2012 or 2014.  This has been corrected so that the total swine inventory in Arizona counties equals the 2014 NASS state total of 139,000.  This type of error occurs in other animal datasets as well.  For broilers, there were no 2014 state level NASS animal populations, so the data should reflect the 2012 state level census data. NEI 2014 v1 showed a broiler population of 13,402 in Rhode Island, while the 2012 dataset shows a population of 18,396.  Matching the NEI 2014v2 dataset with the most recently available state level totals (either 2012 or 2014) ensures an improved animal population dataset than that seen in NEI 2014 v1.

Estimation of Hazardous Air Pollutants (HAPs) for Livestock

HAPs for this sector were estimated by multiplying county-specific VOC emissions by speciation factors that are animal-specific as shown in Table 2 below. All of the HAP VOC fractions were obtained from EPA’s SPECIATE database (the reader is referred to the reference below on SPECIATE for further details). As per the availability in SPECIATE, there are total of 6 VOC HAPs estimated for beef cattle, 5 VOC HAPs for dairy cattle, 4 VOC HAPs for swine, and 14 (same) VOC HAPs for layers and broilers (poultry).

**Table 2: VOC speciation fractions used to estimate HAP Emissions for the Livestock Sector**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SCC | Animal Type | HAP | Fraction of VOC | SPECIATE Profile Number |
| 280500200 | Beef Cattle | 1,4-Dichlorobenzene | 0.0013 | 95240 |
| 280500200 | Beef Cattle | Methyl isobutyl Ketone | 0.0008 |
| 280500200 | Beef Cattle | Toluene | 0.011 |
| 280500200 | Beef Cattle | Chlorobenzene | 0.0001 |
| 280500200 | Beef Cattle | Phenol | 0.0006 |
| 280500200 | Beef Cattle | Benzene | 0.0001 |
| 2805007100 | Poultry---Layers | Methyl isobutyl ketone | 0.0169 | 95223 |
| 2805007100 | Poultry---Layers | Toluene | 0.0018 |
| 2805007100 | Poultry---Layers | Phenol | 0.0024 |
| 2805007100 | Poultry---Layers | N-hexane | 0.0111 |
| 2805007100 | Poultry---Layers | Chloroform | 0.0025 |
| 2805007100 | Poultry---Layers | Cresol/Cresylic Acid (mixed isomers) | 0.0048 |
| 2805007100 | Poultry---Layers | Acetamide | 0.0075 |
| 2805007100 | Poultry---Layers | Methanol | 0.0608 |
| 2805007100 | Poultry---Layers | Benzene | 0.0052 |
| 2805007100 | Poultry---Layers | Ethyl Chloride | 0.0031 |
| 2805007100 | Poultry---Layers | Acetonitrile | 0.0088 |
| 2805007100 | Poultry---Layers | Dichloromethane | 0.0002 |
| 2805007100 | Poultry---Layers | Carbon Disulfide | 0.0034 |
| 2805007100 | Poultry---Layers | 2-Methyl Napthalene | 0.0006 |
| 2805009100 | Poultry-Broilers | Methyl isobutyl ketone | 0.0169 | 95223 |
| 2805009100 | Poultry-Broilers | Toluene | 0.0018 |
| 2805009100 | Poultry-Broilers | Phenol | 0.0024 |
| 2805009100 | Poultry-Broilers | N-hexane | 0.0111 |
| 2805009100 | Poultry-Broilers | Chloroform | 0.0025 |
| 2805009100 | Poultry-Broilers | Cresol/Cresylic Acid (mixed isomers) | 0.0048 |
| 2805009100 | Poultry-Broilers | Acetamide | 0.0075 |
| 2805009100 | Poultry-Broilers | Methanol | 0.0608 |
| 2805009100 | Poultry-Broilers | Benzene | 0.0052 |
| 2805009100 | Poultry-Broilers | Ethyl Chloride | 0.0031 |
| 2805009100 | Poultry-Broilers | Acetonitrile | 0.0088 |
| 2805009100 | Poultry-Broilers | Dichloromethane | 0.0002 |
| 2805009100 | Poultry-Broilers | Carbon Disulfide | 0.0034 |
| 2805009100 | Poultry-Broilers | 2-Methyl Napthalene | 0.0006 |
| 2805018000 | Dairy Cattle | Toluene | 0.0018 | 8897 |
| 2805018000 | Dairy Cattle | Cresol/Cresylic Acid (mixed isomers) | 0.0276 |
| 2805018000 | Dairy Cattle | Xylenes (mixed isomers) | 0.0046 |
| 2805018000 | Dairy Cattle | Methanol | 0.3542 |
| 2805018000 | Dairy Cattle | Acetaldehyde | 0.0141 |
| 2805025000 | Swine | Toluene | 0.0047 | 95241 |
| 2805025000 | Swine | Phenol (Carbolic Acid) | 0.0179 |
| 2805025000 | Swine | Benzene | 0.0035 |
| 2805025000 | Swine | Acetaldehyde | 0.0155 |

References

McQuilling, A. M. & Adams, P. J. Semi-empirical process-based models for ammonia emissions from beef, swine, and poultry operations in the United States. *Atmos. Environ.* **120,** 127–136 (2015).

United States Department of Agriculture, 2012. "2012 Census Volume 1, Chapter 2: County Level." http://www.agcensus.usda.gov/Publications/2012/Full\_Report/Volume\_1,\_Chapter\_2\_County\_Level/

United States Department of Agriculture, 2015. “National Agricultural Statistics Service.”

<http://www.nass.usda.gov/Data_and_Statistics/County_Data_Files/Livestock_County_Estimates/>

EPA’s SPECIATE Database, 2016, available at: <https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-40>