2014 Livestock Ammonia Emissions Inventory: Data Sources and Methods Documentation

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**Animal Practice Documentation**

Ammonia emissions from livestock depend on two major factors—the management practices employed by the producers (i.e. what housing, storage and application methods are used) and the environmental conditions of location where the farm is situated (i.e. temperatures, wind speeds, precipitation). All of these factors have significant impacts on the conditions of the manure and waste (e.g. water content, total ammoniacal nitrogen concentration) and as a result can enhance or reduce the emissions of ammonia from these sources.

As stated, the model requires farm-type inputs which describe the type of animal housing, manure storage and application methods used for a particular location. Each location is expected to have some combination of practices; for example, in a single county, some of the swine farms may use deep-pit housing, lagoon storage, and irrigation application while other farms use shallow-pit housing with lagoon storage and injection application. In order to understand the differences in regional preferences for particular manure management strategies, information was extracted from the most recent National Animal Health Monitoring Surveys done by the USDA. The beef cattle NAHMS was completed in 2007 and feedlot beef in 2011; dairy cattle data was from 2002 and 2007; swine data were collected for 2006 and 2012, and the most recent poultry NAHMS was completed for 2010. The most recent data available had limited spatial resolution (compared to previous work[1], [2]), and so this work is only able to resolve large-scale regional differences in practices. For beef cow-calf systems, the United States was divided into four regions, but only two regions for beef housed on feedlots. For swine, the country was divided into three regions—Midwest, East, and South, and for layers, there were four regions—Northeast, Southeast, Central and West. An additional limitation in the data available for the characterization of the farm practices was that for some of the questions asked by the study, results were only reported in terms of percent of operations which used a particular practice. This may give too much weight to the practices used on smaller farms which have a relatively small contribution to the overall level of ammonia emissions from a particular livestock type or practice. Thus, some uncertainty is expected as a result of the limited quantity of data available regarding manure management practices throughout the country.

As was previously discussed by Pinder et al.[3], one of the factors most limiting to the FEM’s skill is the lack of information about manure managment practices throughout the country. It is unclear whether these uncertainties result in the overprediction or underprediction of total ammonia emissions from livestock in the United States.

**Beef**

As stated previously, information regarding beef manure management practices was provided through the USDA National Animal Health Monitoring Study (NAHMS) with a regional distribution of practices. Beef data was provided for beef housed on feedlots as well as those that are a part of cow-calf systems. Cow-calf systems are those in which cattle are left on pasture or rangeland and the cows are kept with their calves, often until the calves are 1-2 years old and ready for sale. Feedlots are a much denser style of production in which large numbers of cattle are housed on concrete or packed earth lots and fed a mixture of corn and grains. From the information from NAHMS and the animal numbers in the USDA 2012 agriculture census, we were able to discern the fraction of cattle in each state that were housed on feedlots as opposed those raised in a pasture-based farm system; the fraction on feed in 2012 was used to inform the number of cattle on feed for the 2014 population numbers.

The distribution of manure management practices for the states included in the National Animal Health Monitoring System (NAHMS) (as split between feedlots and cow-calf systems) can be seen in Table S1 in the supplemental information [4]–[8]. The regional distribution of cattle on feed can be seen in the Figure 1 below. There have been relatively few studies that have characterized the emissions from cow-calf or pasture-based systems in the United States, especially compared to the emissions characterization that has been done at a variety of Texas and Oklahoma feedlots. The grazing portion of the beef farm emission model is therefore less constrained and may result in the underprediction of emissions of ammonia from beef not housed on feedlots.

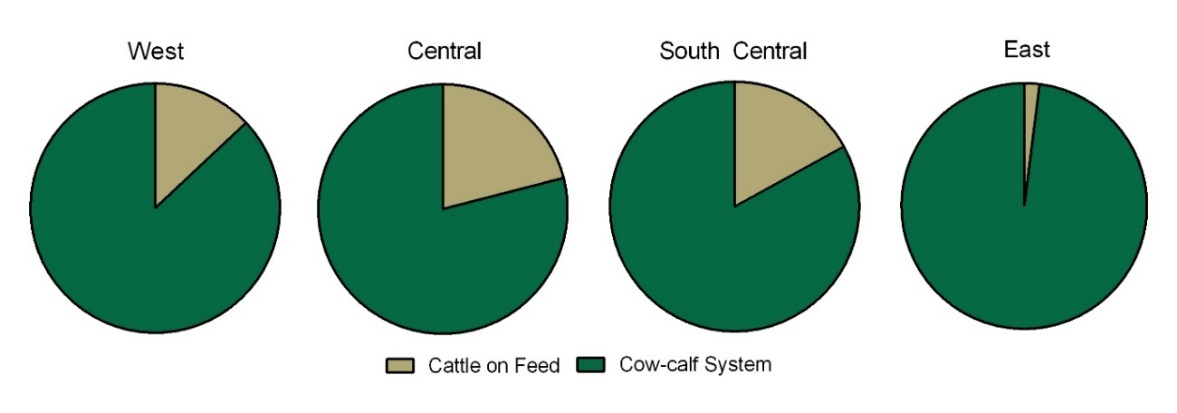


Figure 1. Regional distribution of beef cattle on feed. States in the West include: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. The states in the Central region are: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin. Texas and Oklahoma are in the South Central region. The remaining states are in the East.

Based on the information provided by NAHMS and the USDA Agricultural census, we have considerd two manure managment alternatives, often called manure management trains (MMTs). The first is an all grazing system where emissions are affected by the rate of manure infiltration and directly exposed to the elements (temperature, windspeed, precipitation). The alternative is a feedlot system with solid manure storage and broadcast application. Key parameters for the beef model are discussed in the model parameters portion of the document.

**Dairy**

The distribution of practices used in dairy cattle is unlikely to have changed substantially in the years following the work of Pinder et al.[1], [2], as seen when comparing the two most recent NAHMS results (from 2002 and 2007) to the 1996 NAHMS data used in the cited work. However, the data available for the 2002 and 2007 NAHMS was less regionally specific than was used in the previous work [9]–[13]. The manure management practice information received at that time included state-specific data, something not available for the current study years. Addtionally, storage and application data for 2002 and 2007 was only available by fraction of surveyed operations rather than by population which may give too much weight to practices employed primarily at smaller dairy farms. Manure management practices can be described regionally as either in the West or East; the distribution of practices is shown below in Figure 2a-b.

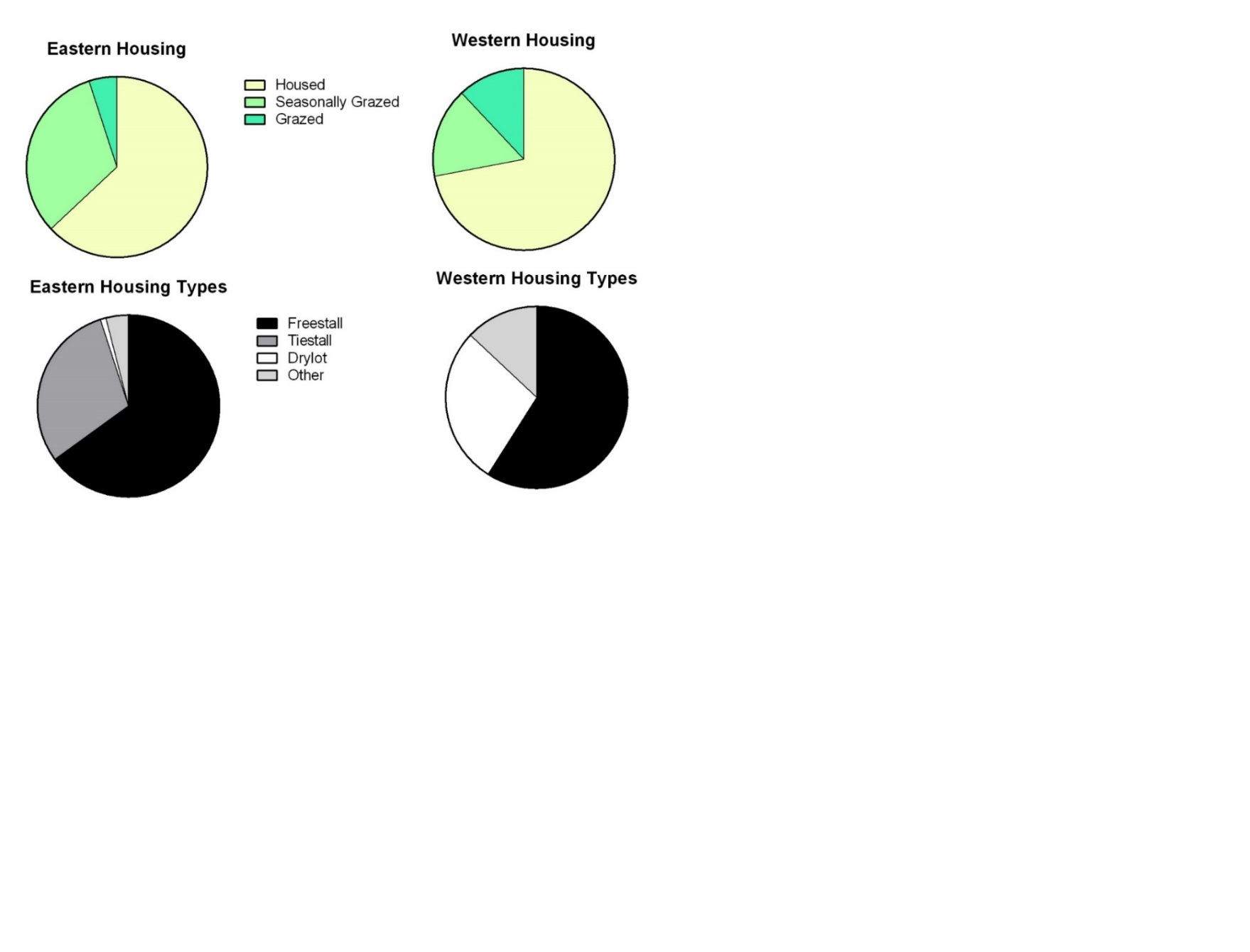


Figure 2a: Regional distribution of dairy housing practices from 2007 NAHMS for Eastern and Western United States. Eastern States include Minnesota, Iowa, Missouri, Arkansas, Louisiana and eastward. Western states are the rest of the continental US.

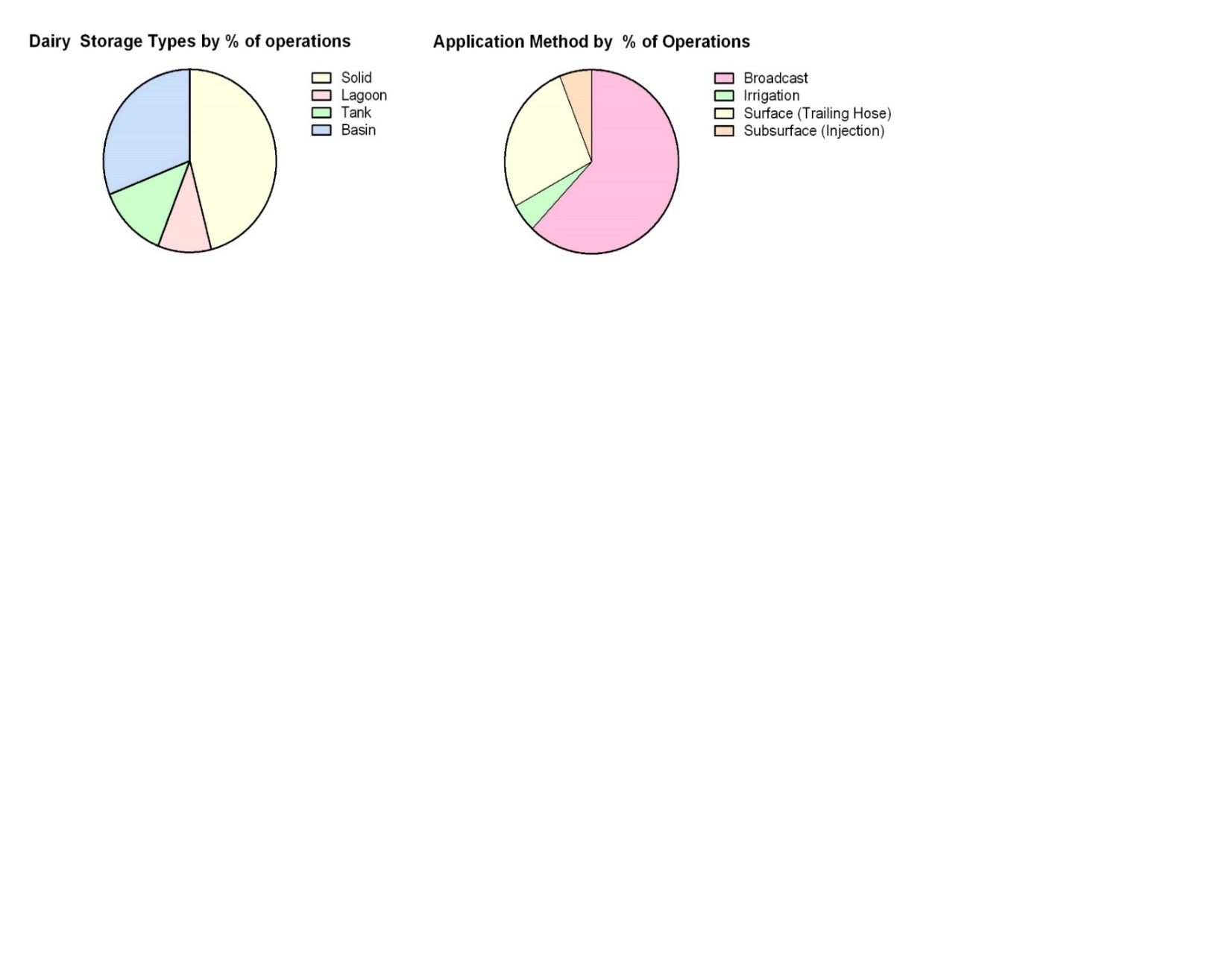


Figure 2b: Distribution of storage and application practices across the US. Regionally separated data was not available from the 2007 NAHMS, and results are presented in terms of percent of farming operations rather than percent of animal population, which may lead to over representation of minor practices.

**Swine**

There is significant regional variability in the housing types and manure management practices (in terms of storage and application) for swine production in the United States. Some of the management choices made are the result of meteorological limitations (i.e. deep-pit versus shallow-pit housing) while others are chosen for economic reasons (less expensive to use irrigation application rather than injection).

Using the information provided by NAHMS, regional distributions of management practices can be described [14]–[17]. The United States can be broken into three regions based on this data: the South, the Midwest, and the East. Each of these groups of states has a unique distribution of housing, storage, and application practices, seen in Figure 3. The re-tuning of manure storage for swine production was the most significant change between the FEM between the literature evaluation [18] and the NAEMS-based evaluation completed later, and this has resulted in a significant increase in the contribution of ammonia emissions from swine lagoon storage.

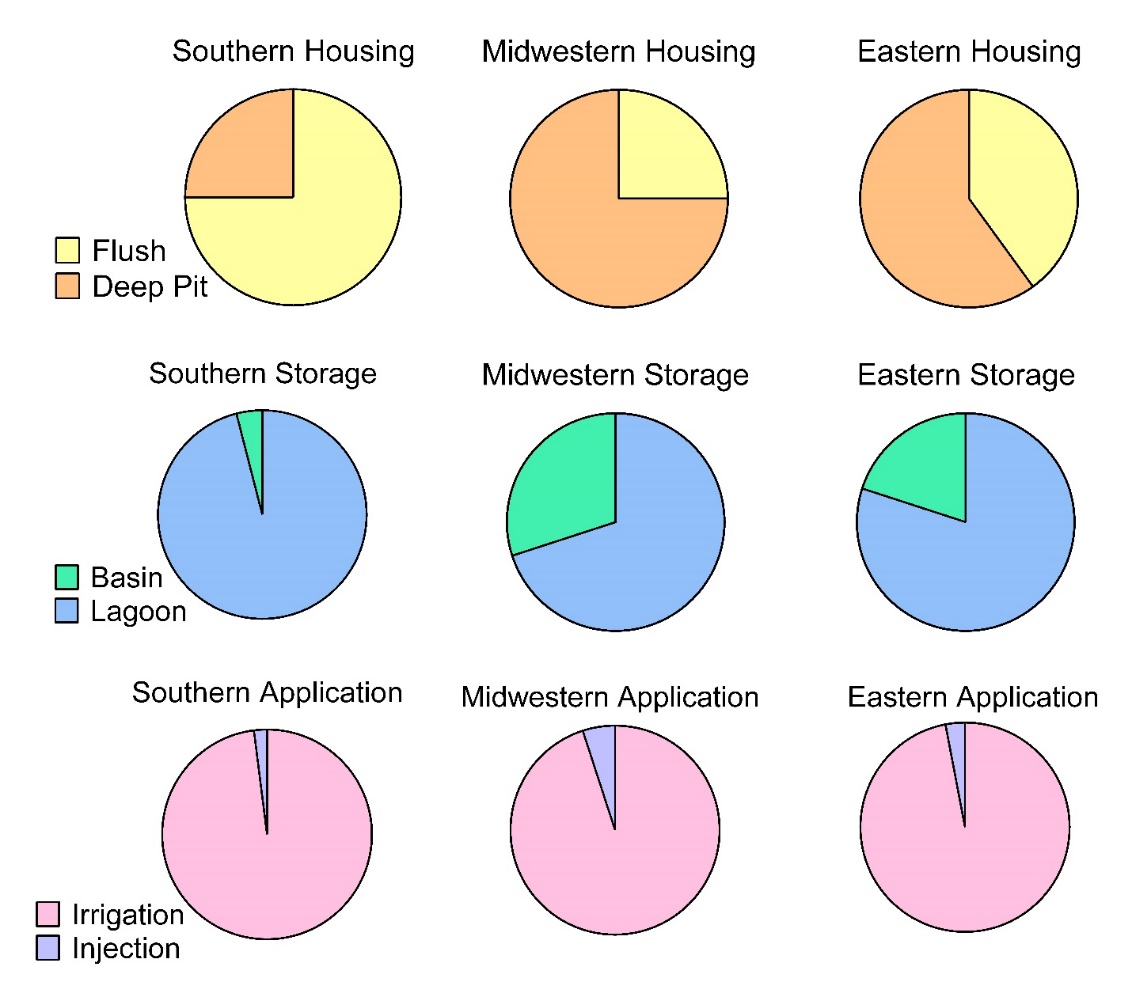


Figure 3: Regional Distribution of swine manure management practices. The Midwest includes: Idaho, Iowa, Minnesota, Montana, North Dakota, Nebraska, South Dakota, Wisconsin and Wyoming. The Eastern states include Connecticut, Delaware, Illinois, Indiana, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, and Vermont. The remainder of the states are included in the Southern region.

**Poultry**

**Broilers**

The major differences in broiler chicken production occur not in terms of farm type, but in the frequency with which barns are entirely cleaned out of their litter material; literature suggests that barns that are cleaned out more frequently have lower emissions than those in which litter material is built up and reused [19]–[22]. Additional factors that may alter the emissions from these facilities include what the bedding or litter material is made up of as well as how long each barn stays empty between flocks. There is not sufficient data to include either bedding material or the time between flocks within the emissions inventory. In fact, much of the variability that might be caused by these factors on a single farm will likely be averaged out as a result of short lifecycle of these birds, which take less than two months to reach market size. Additionally, we have not included pasture-raised or organic practices as they make up a very small fraction of total bird population and the emissions from these farms has not been characterized in the literature. The limited data available regarding manure storage and application from broiler housing may result in the underestimation of ammonia emissions from this animal type.

**Layers**

There are two major housing types used in the production of layer chickens in the United States. These are high-rise layer houses and manure-belt layer houses. The chief difference between these two housing types is the frequency with which manure is removed; in high-rise barns, manure is removed 1-2 times each year, while manure is removed on a daily or weekly basis from manure-belt barns, which results in lower housing emissions and ammonia concentrations but leaves greater quantities in the manure that is headed toward storage and application or processing. High-rise housing operations are more prevalent than manure-belt houses throughout the United States (Figure 5), but manure-belt are somewhat more common in the western and central portions of the United States. There are some limitations on the abiility of the FEM for both the storage and application of poultry manure as there have been few studies to characterize these emissions. The majority of ammonia emissions from poultry are expected to be from housing (particularly for high-rise facilities).

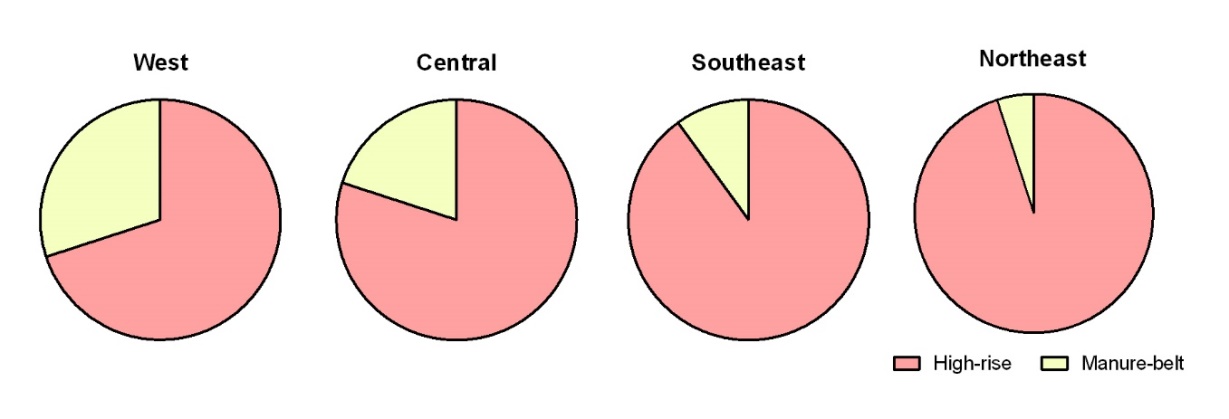


Figure 4. Regional distribution of layer housing types. The West includes: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oklahoma, Oregon, Texas, Utah, Washington, and Wyoming. The Central states are: Arkansas, Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Southeastern states are: Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia. The remaining states are considered to be in the Northeast.

Additionally, the most recent NAHMS information does not capture the more recent trend towards cage-free housing or pasture-raised layer chickens [23]–[25]. Cage-free housing is a relatively minor housing practice currently (<10% of all layer chickens are raised on cage free farms, but state-specific data is unavailable so this may vary significantly by state, and this may not represent a similar fraction of total eggs produced), but is poised to grow as a result of concerns about animal health and welfare and the demand for cage-free eggs increases. According to the most recently completed NAHMS, cage-free production occurs at approximately 3% of large layer operations (more than 100,000 layers), and approximately one-quarter of smaller farms. The data provided by NAHMS does not specify the fractions of total layer populations raised at particular farm sizes, but large farms have become increasingly common and it is expected that most eggs are produced from larger farms [25]. Cage-free and organic products are more likely to come from smaller farms whose emissions have not been well-characterized in the literature. Cage-free production is more common in Europe than the United States, so emissions studies from Europe could be used to better characterize cage-free housing emissions [26]–[28].

**Model Parameters**

The farm emissions model was originally tuned solely to data gathered from literature predating the National Air Emissions Monitoring study (NAEMS) [29] and designed to produce monthly emission factors for a particular farm type. With the advent of the NAEMS data, one approach would be to test the previously tuned model against the novel and wholly independent NAEMS data. However, the NAEMS data goes substantially above and beyond what was previously available for model tuning, exploring emissions under conditions that were not sampled previously, and in some cases, looking qualitatively different. It was apparent that predicting NAEMS measurements under conditions that were not sampled previously is essentially an extrapolation of the model and unlikely to be informative or successful. Therefore, it was decided to re-tune the FEMs to the full suite of available data, including both NAEMS and the earlier literature measurements. The model evaluation that follows, therefore, does not reflect the ability of the FEMs to predict completely independent measurements but the ability of a relatively simple process-based model, with a single set of mass transfer parameters for each manure management practice, to describe the full range of observed variability.

The NAEMS data and literature data are displayed in Figure 6 below. The range of temperatures studied is most extended for layer hens. With the additional NAEMS data, an apparent inverse relationship between temperature and ammonia emissions is observed, something that was not clear in the prior literature. It has been suggested that this inverse relationship (higher emissions factors for lower temperatures) is related to the drying out of manure in hot barns with high ventilation rates [30]. At lower temperatures, barn ventilation is reduced (to conserve heat) and manure dries slowly, and, therefore more manure urea can be broken down into ammonia, which is then available for volatilization. Additionally, we saw that for some practices, particularly for swine storage, emissions factors from NAEMS were uniformly higher than those previously reported in the literature, for both high and low temperatures. As a result of these differences, the FEM’s tuned parameters were adjusted so that model emission factors fell between NAEMS and literature data, weighting the literature studies equally with the NAEMS observations so as not to over-tune to only the literature or NAEMS data. There is significant value in both previously published studies as well as in the values reported by NAEMS, so the re-tuning done is to ensure that this work takes advantage of all available data.

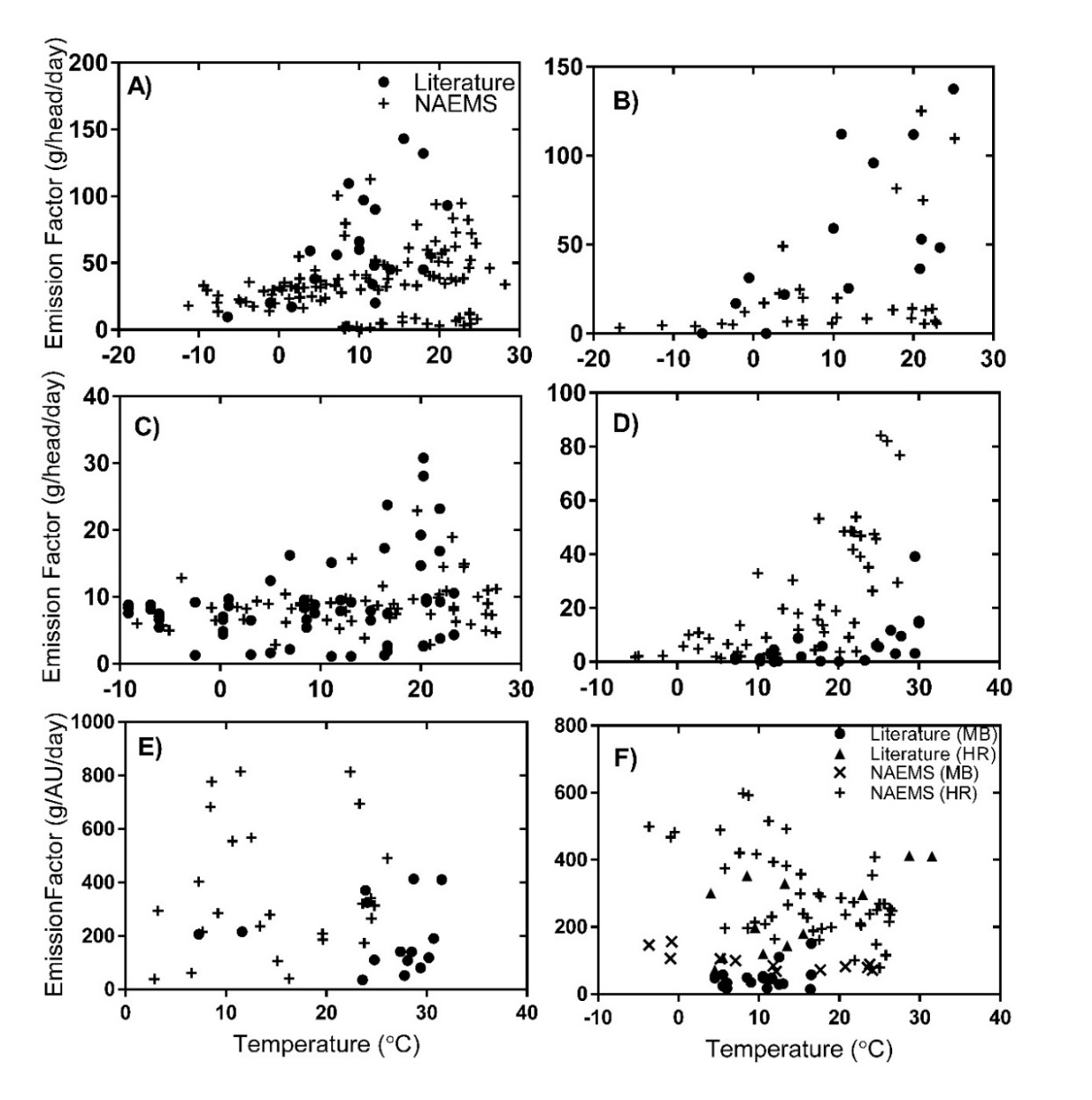
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Figure 6: Emission factors as a function of temperature reported in the prior literature and from the National Air Emissions Monitoring Study (NAEMS). Results are displayed by animal type and management stage as follows: a) free-stall dairy housing emissions, b) dairy lagoon storage emissions, c) deep-pit and flush-type swine housing emissions, d) swine lagoon and basin storage emissions, e) litter-based broiler housing emissions, and f) manure-belt (MB) and high-rise (HR) layer housing emissions. (1 AU = animal unit = 500 kg live animal weight)

**Manure characteristics**

**Manure characteristics are important input parameters to the model because they govern the amount of nitrogen available for emission, whether or not the nitrogen present is likely to be volatilized, and how well the waste can infiltrate into the soil during manure application. These parameters have been selected based on information extracted from published literature as well as reports from the National Air Emissions Monitoring study. More details about key factors and their values are detailed in the following sections of this report. Table 1 describes the types of parameters and inputs critical to the model and Table 2 presents information about manure volume, nitrogen concentration and pH levels in the waste from each type of animal included in the model.**

**Table 1.** Table 3.1: Description and sources of model inputs and parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Data Type** | **Description** | **Source of input or parameter** | **Input or Tuned Parameter?** |
| Meteorology | Temperature (°C)  Wind speed (m/s)  Precipitation | From National Climate Data Center, based on farm location | Input value (monthly average for seasonal emissions, daily values for daily model run) |
| Manure Management Practice | Type of housing, storage, or application | Unique to each farm type; farm types have a unique set of inputs | Input value |
| Resistance Parameters | Surface mass transfer resistance from manure to atmosphere | Tuned based on literature and NAEMS observations to agree with previous work; constant for a particular management practice (for a particular animal type) | Tuned Parameters |

**Table 2. Model Input parameters related to manure characteristics**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameter Name** | **Animal Type** | **Range of Values** | **Value Used in Model** | **Units** | **Source** |
| Manure Volume | Beef | 12-17 | 15 | l animal-1 day-1 | [2], [31] |
| Dairy |  |  | l animal-1 day-1 | [2] |
| Swine | 4-10 | 6 | l animal-1 day-1 | [32] |
| Poultry-Layer | 0.088 | 0.088 | l animal-1 day-1 | [33], [34] |
| Poultry-Broiler | 4.9 | 4.9 | l finished animal-1 | [33] |
| Manure Urea Concentration | Beef | 47-70 |  | kg N animal-1 year-1 | [33] |
| Dairy |  |  | kg N animal-1 year-1 | [2] |
| Swine | 11-35 |  | kg N animal-1 year-1 | [34], [35] |
| Poultry-Layer | 0.5-0.6 | 0.55 | kg N animal-1 year-1 | [33] |
| Poultry-Broiler | 0.05-0.06 | 0.055 | kg N finished animal-1 | [33] |
| Housing pH | Beef | 7.7 | 7.7 |  | [36] |
| Dairy | 7.5-8.3 | 7.7 |  | [2] |
| Swine | 6.5-7.5 | 7 |  | [37] |
| Poultry-Layer | 7.1-7.6 (MB); 8.4-8.7 | 7.3 |  | [38],[39] |
| Poultry-Broiler | 8 | 8 |  | [40] |
| Storage pH | Dairy | 7.0-8.0 | 7.5 |  | [1] |
| Swine | 7.5-8 | 7.7 |  | [35] |
| Application pH | Beef | 7.5 | 7.5 |  | [41] |
| Dairy | 7.0-7.7 | 7.3 |  | [2] |
| Swine | 7.8-8.2 | 8 |  | [42] |
| Poultry-Layer | 7.2 | 7.2 |  | [43] |
| Poultry-Broiler | 8.8 | 8.8 |  | [44] |
| Storage pH | Beef | 7.7 | 7.7 |  | [2] |
| Dairy | 7.5-8.3 | 7.7 |  | [2] |

**There are a limited number of studies which describe the manure nitrogen and manure pH for each animal type. As a result there is considerable uncertainty in these input values which can result in significant uncertainty in predicted emissions from the model.**

**Tunable parameters**

Our model is a balance between an empirical approach and first-principles process-based model. We use a nitrogen mass balance and a process description of ammonia losses, but tune model parameters to reproduce measured emissions factors. We limit model complexity to the most important emissions processes and to inputs that are typically available. The strategy pursued here for developing process-based models is guided by the need to build emissions inventories, and the requirements and data limitations associated with this application. Previous measurement campaigns also often sampled emissions from a single part of the production process. This means that we may not have information about the emissions process from the start to end of production, making nitrogen mass balance in the system difficult. The lack of whole-farm measurements is one gap in much of the literature available and a benefit of the estimates of ammonia emissions produced by the FEM.

**There are 2-3 tunable parameters associated with each submodel in the farm emissions model. These tunable parameters allow us to adjust model-predicted emissions and to correct for the unknowns and uncertainties of the input parameters and to ensure that the model-predicted values are consistent with those that have been reported in the literature and in the National Air Emissions monitoring study; they are constant for a particular farm type—tuning is not done for a particular farm—and as a result, there can be significant disagreement between model predictions and the measured emissions for a single farm. As stated previously, the goal of this work is not necessarily to capture the emissions of single farms perfectly, but rather to capture the effects of various parameters on emissions on a farm typical of a certain set of practices.**

In the FEM, as previously described [29], [45], [46], ammonia emissions are estimated as a function of the nitrogen present in the waste and the mass transfer resistance. This resistance is made up of the following three parts: the aerodynamic (*ra*), quasi-laminar (*rb*), and surface resistances (*rs*) [47]. Aerodynamic and quasi-laminar resistances are used to describe the resistance to transport in the gaseous layer above the animal wastes [45], [48], [49]. These parameters are based on widely used theoretical formulas and are not tuned. The third part of the resistance is the surface resistance from diffusion closest to the gas-liquid (manure) interface. Here, the surface resistance is a function of tuned parameters as well as temperature which ensures the modeled ammonia emission factors are consistent with observations; T**able 3 lists which tunable parameters are used for each animal and each submodel.**

**These values are specific to a particular practice for a particular animal type. This means that a free stall dairy with lagoon storage and injection application would employ the same tuned parameters whether it was located in New York or California. Conversely, two farms in the same location but utilizing different manure management practices would have different tuned parameters in their submodels. The values that have been used for each of these parameters can be found in Table 4 on the following page.**

Table 3. Tuned model parameters for beef, swine, and poultry

|  |  |  |  |
| --- | --- | --- | --- |
| **Submodel** | **Animal Type** | **Description** | **Tuning/Evaluation Sources** |
| Housing | Cattle: Beef & Dairy  Swine  Poultry: Broiler & Layer | Resistance parameters *H1, H2* | [50]–[67], [68]–[72], [73]–[78], [79]–[84] |
| Storage | Dairy Cattle  Swine | Resistance parameters *S1, S2* | [85]–[90] |
| Application | Cattle: Beef & Dairy  Swine  Poultry: Broiler & Layer | Resistance parameters *A1,A2, A3* | [91], [92], [93]–[95], [96], [97] |
| Grazing | Cattle: Dairy & Beef | Resistance parameters *G1, G2* | [98] |

Table 4. Tuned Parameter Values by practice and animal type

|  |  |  |  |
| --- | --- | --- | --- |
| **Submodel** | **Animal Type** | **Description** | **Parameter Values** |
| Housing | Beef cattle | Beef Feedlot | H,=0.1 (s•m-1•°C-1), H2=-0.01 (s2m-2) |
| Swine | Swine—shallow pit | H,=0.08(s•m-1), H2=-0.004(s•m-1•°C-1) |
|  | Swine—deep pit | H,=0.1(s•m-1), H2=-0.008(s•m-1•°C-1) |
| Poultry-Layer | Layer—Manure belt | H,=0.3(s•m-1), H2=-0.015(s•m-1•°C-1) |
|  | Layer—High Rise | H,=0.22(s•m-1), H2=-0.02(s•m-1•°C-1) |
| Poultry-Broiler | Broiler | H,=0.15(s•m-1), H2=-0.035(s•m-1•°C-1) |
| Storage | Swine | Swine lagoon | S1=0.20(s•m-1), S2=4.00(s•m-1•°C-1) |
| Swine basin | S1=0.11(s•m-1), S2=2.24(s•m-1•°C-1) |
| Application | Beef cattle | Beef—broadcast | A,=0.0004, (s•m-1)A2 =0.88, A3=-1.4 |
| Swine | Swine—irrigation | A,=0.001(s•m-1), A2 =-10, A3=20 |
|  | Swine—injection | A,=0.01(s•m-1), A2 =-15, A3=40 |
| Grazing | Beef Cattle | Beef Pasture | G,= 0.12(s•m-1),  G2=5.4 |

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**Supplemental Information**

**Table S1. State Beef Cattle Populations (including calves, cattle on feed)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **2012 Pop: Beef** | **2012 Pop: Beef on Feed** | **2012 Fraction on Feed** | **2014 Pop: Beef** | **2014 Pop: Beef on feed** | **Calculated Pop on feed** |
| Alabama | 1236467 | 0 | 0.0% | 1270000 | 0 | 0 |
| Alaska | 10667 | 1922 | 18.0% | 10000 | 1763 | 1802 |
| Arizona | 911334 | 272175 | 29.9% | 920000 | 274000 | 274763 |
| Arkansas | 1615774 | 235 | 0.0% | 1650000 | 235 | 240 |
| California | 5370531 | 488131 | 9.1% | 5250000 | 510000 | 477176 |
| Colorado | 2630082 | 1009873 | 38.4% | 2550000 | 960000 | 979124 |
| Connecticut | 48278 | 104 | 0.2% | 47000 | 99 | 101 |
| Delaware | 18225 | 2545 | 14.0% | 16000 | 2187 | 2234 |
| Florida | 1675323 | 1922 | 0.1% | 1670000 | 1875 | 1916 |
| Georgia | 1033717 | 0 | 0.0% | 1040000 | 0 | 0 |
| Hawaii | 133957 | 0 | 0.0% | 133000 | 0 | 0 |
| Idaho | 2397541 | 263466 | 11.0% | 2240000 | 235000 | 246154 |
| Illinois | 1127630 | 276130 | 24.5% | 1130000 | 260000 | 276710 |
| Indiana | 821265 | 76134 | 9.3% | 860000 | 110000 | 79725 |
| Iowa | 3893683 | 1550523 | 39.8% | 3800000 | 1230000 | 1513217 |
| Kansas | 5922187 | 2255701 | 38.1% | 5800000 | 2130000 | 2209161 |
| Kentucky | 2270871 | 21346 | 0.9% | 2110000 | 18000 | 19834 |
| Louisiana | 788967 | 0 | 0.0% | 790000 | 0 | 0 |
| Maine | 86256 | 2631 | 3.1% | 85000 | 2537.408283 | 2593 |
| Maryland | 194524 | 7851 | 4.0% | 182000 | 10000 | 7346 |
| Massachusetts | 35703 | 442 | 1.2% | 39000 | 472.5220293 | 483 |
| Michigan | 1130477 | 148608 | 13.1% | 1130000 | 150000 | 148545 |
| Minnesota | 2412684 | 536971 | 22.3% | 2300000 | 375000 | 511892 |
| Mississippi | 921508 | 0 | 0.0% | 930000 | 0 | 0 |
| Missouri | 3703120 | 85060 | 2.3% | 3850000 | 75000 | 88434 |
| Montana | 2633740 | 52345 | 2.0% | 2550000 | 54000 | 50681 |
| Nebraska | 6385675 | 2647855 | 41.5% | 6250000 | 2420000 | 2591597 |
| Nevada | 420322 | 1922 | 0.5% | 460000 | 4000 | 2103 |
| New Hampshire | 33392 | 1922 | 5.8% | 32000 | 1802.606048 | 1842 |
| New Jersey | 31449 | 362 | 1.2% | 27000 | 304.1623032 | 311 |
| New Mexico | 1354240 | 44936 | 3.3% | 1310000 | 42541.22222 | 43468 |
| New York | 1419365 | 26976 | 1.9% | 1450000 | 23000 | 27558 |
| North Carolina | 829717 | 2137 | 0.3% | 810000 | 2041.735343 | 2086 |
| North Dakota | 1809613 | 58408 | 3.2% | 1750000 | 38000 | 56484 |
| Ohio | 1242293 | 164487 | 13.2% | 1250000 | 160000 | 165507 |
| Oklahoma | 4245970 | 353923 | 8.3% | 4300000 | 265000 | 358427 |
| Oregon | 1297945 | 84657 | 6.5% | 1280000 | 75000 | 83487 |
| Pennsylvania | 1626374 | 128732 | 7.9% | 1610000 | 110000 | 127436 |
| Rhode Island | 4667 | 1922 | 41.2% | 5000 | 2015.233995 | 2059 |
| South Carolina | 297286 | 0 | 0.0% | 335000 | 0 | 0 |
| South Dakota | 3893251 | 418374 | 10.7% | 3700000 | 375000 | 397607 |
| Tennessee | 1856316 | 3042 | 0.2% | 1760000 | 3000 | 2884 |
| Texas | 11159747 | 2750818 | 24.6% | 11100000 | 2450000 | 2736091 |
| Utah | 776833 | 23857 | 3.1% | 810000 | 26000 | 24876 |
| Vermont | 274251 | 1593 | 0.6% | 260000 | 1478.021658 | 1510 |
| Virginia | 1631882 | 20010 | 1.2% | 1510000 | 20000 | 18515 |
| Washington | 1162792 | 246170 | 21.2% | 1110000 | 195000 | 234994 |
| West Virginia | 414908 | 2794 | 0.7% | 385000 | 5000 | 2593 |
| Wisconsin | 3494084 | 270342 | 7.7% | 3400000 | 260000 | 263063 |
| Wyoming | 1307731 | 76833 | 5.9% | 1270000 | 75000 | 74616 |
| Total | 89994614 | 14386187 | 16.0% | 88526000 | 13008651.96 | 14.7% |