ANNEX K

Methodology for Estimating CH_4 and N_2O Emissions from Manure Management

This annex presents a discussion of the methodology used to calculate methane and nitrous oxide emissions from manure management systems. More detailed discussions of selected topics may be found in supplemental memoranda in the supporting docket to this inventory.

The following steps were used to estimate methane and nitrous oxide emissions from the management of livestock manure. Nitrous oxide emissions associated with pasture, range, or paddock systems and daily spread systems are included in the emissions estimates for Agricultural Soil Management.

Step 1: Collect Livestock Population Characterization Data

Annual animal population data for 1990 through 1999 for all livestock types, except horses and goats, were obtained from the USDA National Agricultural Statistics Service (USDA 1994a-b, 1995a-b, 1998a, 1999a-c, 2000a-g). The actual population data used in the emissions calculations for cattle and swine were downloaded from the USDA National Agricultural Statistics Service Population Estimates Data Base (<http://www.nass.usda.gov:81/ipedb/>). Horse population data were obtained from the FAOSTAT database (FAO 2000). Goat population data for 1992 and 1997 were obtained from the Census of Agriculture (USDA 1999d). Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000).

A summary of the livestock population characterization data used to calculate methane and nitrous oxide emissions is presented in Table K-1. Information on collection of population data for specific animal types is provided in the following sections.

Dairy Cattle: The total annual dairy cow and heifer state population data for 1990 through 1999 are provided in various USDA National Agricultural Statistics Service reports (USDA 1995a, 1999a, 2000a-b). The actual total annual dairy cow and heifer state population data used in the emissions calculations were downloaded from the U.S. Department of Agriculture National Agricultural Statistics Service Published Estimates Database (<http://www.nass.usda.gov:81/ipedb/>).

Beef Cattle: The total annual beef cattle population data for each state for 1990 through 1999 are provided in various USDA National Agricultural Statistics Service reports (USDA 1995a, 1999a, 2000a-b). The actual data used in the emissions calculations were downloaded from the U.S. Department of Agriculture National Agricultural Statistics Service Published Estimates Database (<http://www.nass.usda.gov:81/ipedb/>). Additional information regarding the percent of beef steer and heifers on feedlots was obtained from contacts with the national USDA office (Milton 2000).

For all beef cattle groups (i.e., cows, heifers, steer, bulls, and calves), the USDA data provide cattle inventories from January and July of each year. Cattle inventory changes over the course of the year, sometimes significantly, as new calves are born and as fattened cattle are slaughtered; therefore, to develop the best estimate for the annual animal population, the average inventory of cattle by state was calculated. The USDA provides January inventory data for each state; however, July inventory data is only presented as a total for the United States. In order to estimate average annual populations by state, a “scaling factor” was developed that adjusts the January state-level data to reflect July inventory changes. This factor equals the average of the U.S. January and July data divided by the January data. The scaling factor is derived for each cattle group and is then applied to the January state-level data to arrive at the state-level annual population estimates.

Swine: The total annual swine population data for each state for 1990 through 1999 are provided in various USDA National Agricultural Statistics Service reports (USDA 1994a, 1998a, 2000c). The USDA data provide quarterly data for each swine subcategory: breeding, market under 60 pounds (<27 kg), market 60 to 119 pounds (27 to 54 kg), market 120 to 179 pounds (54 to 81 kg), and market 180 pounds and over (>82 kg). The average of the quarterly data was used in the emissions calculations. For states where only December inventory is reported, the December data were used directly. The actual data used in the emissions calculations were downloaded from the

U.S. Department of Agriculture National Agricultural Statistics Service Published Estimates Database (<http://www.nass.usda.gov:81/ipedb/>).

Sheep: The total annual sheep population data for each state for 1990 through 1999 were obtained from USDA National Agricultural Statistics Service (USDA 1994b, 1999c, 2000f). Population data for lamb and sheep on feed were not available after 1993. The number of lamb and sheep on feed for 1994 through 1999 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep and lamb "on feed" are not necessarily on "feedlots"; they may be on pasture/crop residue supplemented by feed. Data for those animals on feed that are on feedlots versus pasture/crop residue were provided only for lamb in 1993. To calculate the populations of sheep and lamb on feedlots for all years, it was assumed that the percentage of sheep and lamb on feed that are on feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: Annual goat population data by state were available for only 1992 and 1997 (USDA 1999d). The data for 1992 were used for 1990 through 1992 and the data for 1997 were used for 1997 through 1999. Data for 1993 through 1996 were interpolated using the 1992 and 1997 data.

Poultry: Annual Poultry population data by state for the various animal categories (i.e., hens 1 year and older, pullets of laying age, pullets 3 months old and older not of laying age, pullets under 3 months of age, other chickens, broilers, and turkeys) were obtained from USDA National Agricultural Statistics Service (USDA 1995b, 1998b, 1999b, 2000d,e,g). The annual population data for boilers and turkeys were adjusted for turnover (i.e., slaughter) rate (Lange 2000).

Horses: The Food and Agriculture Organization (FAO) publishes annual horse population data, which were accessed from the FAOSTAT database at <http://apps.fao.org/> (FAO 2000).

Step 2: Develop Waste Characteristics Data

Methane and nitrous oxide emissions calculations are based on the following animal characteristics for each relevant livestock population:

- Volatile solids excretion rate (VS)
- Maximum methane producing capacity (B_o) for U.S. animal waste;
- Nitrogen excretion rate (N_{ex})
- Typical animal mass (TAM)
- Annual state-specific milk production rate

Published sources were reviewed for U.S.-specific livestock waste characterization data that would be consistent with the animal population data discussed in Step 1. Data from the National Engineering Handbook, Agricultural Waste Management Field Handbook (USDA 1996a) were chosen as the primary source of waste characteristics. In some cases, data from the American Society of Agricultural Engineers, Standard D384.1 (ASAE 1999) were used to supplement the USDA data. The volatile solids and nitrogen excretion data for breeding swine are a combination of the types of animals that make up this animal group, namely gestating and farrowing swine and boars. It is assumed that a group of breeding swine is typically broken out as 80 percent gestating sows, 15 percent farrowing swine, and 5 percent boars (Safley 2000). Table K-2 presents a summary of the waste characteristics used in the emissions estimates.

The method for calculating volatile solids production from dairy cows was revised this year to better address the relationship between milk production and volatile solids production. Cows that produce more milk per year also produce more volatile solids in their manure due to their increased feed. Figure 4-1 in the *Agricultural Waste Management Field Handbook* (USDA 1996a) was used to determine the mathematical relationship between volatile solids production and milk production for a 1,400-pound dairy cow. The resulting best fit equation was a second-order polynomial, defined as follows:

$$y = -7E\text{-}08x^2 + 0.0029x - 16.765$$
$$R^2 = 0.9858$$

where,

y = volatile solids (lbs/day)

x = milk production (lb/yr)
R^2 = probability that a data point will be on the best fit line

Annual milk production data, published by USDA's National Agricultural Statistics Service (USDA 2000j), was accessed for each state and for each year. State-specific volatile solids production rates were then calculated instead of a single national volatile solids excretion rate constant. Table K-3 presents the volatile solids production rates used for 1999.

Step 3: Develop Waste Management System Usage Data

Estimates were made of the distribution of wastes by management system and animal type using the following sources of information:

- State contacts to estimate the breakout of dairy cows on pasture, range, or paddock, and the percent of wastes managed by daily spread systems (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, Wright 2000)
- Data collected for EPA's Office of Water, including site visits, to medium and large beef feedlot, dairy, swine, and poultry operations (ERG 2000)
- Contacts with the national USDA office to estimate the percent of beef steer and heifers on feedlots (Milton 2000)
- Survey data collected by USDA (2000h) and re-aggregated by farm size and geographic location, used for small operations
- Survey data collected by the United Egg Producers (UEP 1999) and USDA (2000i) and previous EPA estimates (EPA 1992) of waste distribution for layers
- Survey data collected by Cornell University on dairy manure management operations in New York (Poe 1999)
- Previous EPA estimates of waste distribution for sheep, goat, and horse operations (EPA 1992)

Beef Feedlots: Based on EPA site visits and state contacts, it was assumed that beef feedlot manure is almost exclusively managed in drylots. Therefore, 100 percent of the manure excreted at beef feedlots is expected to be deposited in drylots and generate emissions. In addition, a portion of the manure that is deposited in the drylot will run off of the drylot during rain events and be captured in a waste storage pond. An estimate of the runoff has been made by EPA's Office of Water for various geographic regions of the United States. These runoff estimates were used to estimate emissions from runoff storage ponds located at beef feedlots. (ERG 2000).

Dairy Cows: Based on EPA site visits and state contacts, it was assumed that manure from dairy cows at medium (200-700 head) and large (>700 head) operations were managed using either flush systems or scrape/slurry systems. In addition, they may have a solids separator in place prior to their storage component. Estimates of the percent of farms that use each type of system, by geographic region, were developed by EPA's Office of Water, and were used to estimate the percent of wastes managed in lagoons (i.e., flush systems), liquid/slurry systems (i.e., scrape systems), and solid storage (i.e., separated solids) (ERG 2000).

Manure management system data for small (<200 head) dairies were obtained from USDA (2000h). These operations are more likely to use liquid/slurry and solid storage management systems than anaerobic lagoon systems. The reported manure management systems were deep pit, liquid/slurry (also includes slurry tank, slurry earth-basin, and aerated lagoon), anaerobic lagoon, and solid storage (also includes manure pack, outside storage, and inside storage). The percent of wastes by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA 1999e) were used to determine the percentage of all dairies using the various manure management systems. Due to lack of additional data for other years, it was assumed that the data provided for 1992 were the same as that for 1990 and 1991, and data provided for 1997 were the same as that for 1998 and 1999. Data for 1993 through 1996 were extrapolated using the 1992 and 1997 data.

Data regarding the use of daily spread and pasture, range, or paddock systems for dairy cattle were obtained from personal communications with personnel from several organizations. These organizations include state NRCS offices, state extension services, state universities, USDA National Agricultural Statistics Service (NASS), and other experts (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, and Wright 2000). Contacts at Cornell

University provided survey data on dairy manure management practices in New York (Poe 1999). Census of Agriculture population data for 1992 and 1997 (USDA 1999e) were used in conjunction with the state data obtained from personal communications to determine regional percentages of total dairy cattle and dairy wastes that are managed using these systems. These percentages were applied to the total annual dairy cow and heifer state population data for 1990 through 1999, which were obtained from the USDA National Agricultural Statistics Service (USDA 1995a, 1999a, 2000a-b).

Of the dairies using systems other than daily spread and pasture, range, or paddock systems, some dairies reported using more than one type of manure management system. Therefore, the total percent of systems reported by USDA for a region and farm size is greater than 100 percent. Typically, this means that some of the manure at a dairy is handled in one system (e.g., liquid system), and some of the manure is handled in another system (e.g., dry system). However, it is unlikely that the same manure is moved from one system to another. Therefore, to avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent, using the same distribution of systems. For example, if USDA reported that 65 percent of dairies use deep pits to manage manure and 55 percent of dairies use anaerobic lagoons to manage manure, it was assumed that 54 percent (i.e., 65 percent divided by 120 percent) of the manure is managed with deep pits and 46 percent (i.e., 55 percent divided by 120percent) of the manure is managed with anaerobic lagoons (ERG 2000).

Dairy Heifers: The percent of dairy heifer operations that are pasture, range, or paddock or that operate as daily spread was estimated using the same approach as dairy cows. Similar to beef cattle, dairy heifers are housed on drylots when not pasture based. Based on data from EPA's Office of Water (ERG 2000), it was assumed that 100 percent of the manure excreted by dairy heifers is deposited in drylots and generates emissions. Estimates of runoff have been made by EPA's Office of Water for various geographic regions of the US (ERG 2000).

Swine: Based on data collected during site visits for EPA's Office of Water (ERG 2000), manure from swine at large (>2000 head) and medium (200 to 2000 head) operations were primarily managed using deep pit systems, liquid/slurry systems, or anaerobic lagoons. Manure management system data were obtained from USDA (1998d). It was assumed those operations with less than 200 head use pasture, range, or paddock systems. The percent of waste by system was estimated using the USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992 and 1997 Census of Agriculture (USDA 1999e) were used to determine the percentage of all swine utilizing the various manure management systems. The reported manure management systems were deep pit, liquid/slurry (also includes above- and below-ground slurry), anaerobic lagoon, and solid storage (also includes solids separated from liquids).

Some swine operations reported using more than one management system; therefore, the total percent of systems reported by USDA for a region and farm size is greater than 100 percent. Typically, this means that some of the manure at a swine operation is handled in one system (e.g., liquid system), and some of the manure is handled in another system (e.g., dry system). However, it is unlikely that the same manure is moved from one system to another. Therefore, to avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent, using the same distribution of systems, as explained under “Dairy Cows.”

Sheep: It was assumed that all sheep wastes not deposited on feedlots were deposited on pasture, range, or paddock lands (Anderson 2000).

Goats/Horses: Estimates of manure management distribution were obtained from EPA (1992).

Poultry – Layers: Waste management system data for layers for 1990 were obtained from Appendix H of *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). The percentage of layer operations using a shallow pit flush house with anaerobic lagoon or high-rise house without bedding was obtained for 1999 from United Egg Producers, voluntary survey (UEP 1999). These data were augmented for key poultry states (i.e., AL, AR, CA, FL, GA, IA, IN, MN, MO, NC, NE, OH, PA, TX, and WA) with USDA data (USDA 2000i). It was assumed that the change in system usage between 1990 and 1999 was proportionally distributed among those years. It was also assumed that one percent of poultry wastes were deposited on pasture, range, or paddock lands (EPA 1992).

Poultry - Broilers/Turkeys: The percentage of turkeys and broilers on pasture or in high-rise houses without bedding was obtained from *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). It was assumed that one percent of poultry wastes were deposited in pastures, range, and paddocks (EPA 1992).

Step 4: Calculate Base Emission Factor Calculations

Base methane conversion factors (MCFs) and nitrous oxide emission factors used in the emission calculations were determined using the methodologies described below:

Methane Conversion Factors (MCFs)

Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) for anaerobic lagoon systems published default methane conversion factors of 0 percent to 100 percent, which reflects the wide range in performance that may be achieved with these systems. There exist relatively few data points on which to determine country-specific MCFs for these systems. Therefore, a climate-based approach was identified to estimate MCFs for anaerobic lagoon and other liquid storage systems.

The following approach was used to develop the base MCFs for liquid/slurry and deep pit systems, and is based on the van't Hoff-Arrhenius equation used to forecast performance of biological reactions. One practical way of estimating MCFs for liquid manure handling systems is based on the mean ambient temperature and the van't Hoff-Arrhenius equation with a base temperature of 30°C, as shown in the following equation (Safley and Westerman 1990):

$$f = \exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

where,

T_1 = 303.16K
T_2 = ambient temperature (K) for climate zone (in this case, a weighted value for each state)
E = activation energy constant (15,175 cal/mol)
R = ideal gas constant (1.987 cal/K mol)

The factor "f" correlates well to the MCF values suggested by IPCC for liquid/slurry and deep pit systems at a given temperature, and represents the proportion of volatile solids that are biologically available for conversion to methane based on the temperature of the system. Therefore, the MCF for liquid/slurry and deep pit systems is set equal to the factor "f" shown above. For those animal populations using liquid systems (i.e., dairy cow, dairy heifer, layers, beef on feedlots, and swine), annual average state temperatures were based on the counties where the specific animal population resides (i.e., the temperatures were weighted based on the percent of animals located in each county). The average county and state temperature data were obtained from the National Climate Data Center (NOAA 2000), and the county population data were based on 1992 and 1997 Census data (USDA 1999e). County population data for 1990 and 1991 were assumed to be the same as 1992, county population data for 1998 and 1999 were assumed to be the same for 1997, and county population data for 1993 through 1996 were extrapolated based on 1992 and 1997 data.

The approach used to calculate the base MCF for anaerobic lagoons is also based on the van't Hoff-Arrhenius equation, but is calculated on a monthly basis to account for the longer retention time and associated build up of volatile solids in these systems. Base annual MCFs for anaerobic lagoons are calculated as follows for each animal type, state, and year of the inventory:

1) Monthly temperatures are calculated by using county-level temperature and population data. The weighted-average temperature for a state is calculated using the population estimates and average monthly temperature in each county.

2) Monthly temperatures are used to calculate a monthly van't Hoff-Arrhenius "f" factor, using the equation presented above.

3) Monthly production of volatile solids that are added to the system is estimated based on the number of animals present, adjusted for a management and design practices factor. This factor accounts for other mechanisms by which volatile solids are removed from the management system prior to conversion to methane, such as solids being removed from the lagoon for application to cropland. This factor, equal to 0.8, has been estimated using currently available methane measurement data from anaerobic lagoon systems in the United States.

4) The amount of volatile solids available for conversion to methane is assumed to be equal to the amount of volatile solids produced during the month (from Step 3) plus volatile solids that may remain in the system from previous months.

5) The amount of volatile solids consumed during the month is equal to the amount available for conversion multiplied by the "f" factor.

6) The amount of volatile solids carried over from one month to the next is equal to the amount available for conversion minus the amount consumed.

7) The estimated amount of methane generated during the month is equal to the monthly volatile solids consumed multiplied by the maximum methane potential of the waste (B_o).

8) The annual anaerobic lagoon MCF is then calculated as:

   MCF (annual) = CH_4 generated (annual) / (VS generated (annual) $\times$ B_o)

In order to account for the carry over of volatile solids from the year prior to the inventory year for which estimates are calculated, it is assumed in the MCF calculation for lagoons that a portion of the volatile solids from October, November, and December of the year prior to the inventory year are available in the lagoon system starting January of the inventory year.

Following this procedure, the resulting MCF accounts for temperature variation throughout the year, residual volatile solids in a system (carryover), and management and design practices that may reduce the volatile solids available for conversion to methane. The base methane conversion factors presented in Table III by state and waste management system represent the average MCF by state for all animal groups located in that state. However, in the calculation of methane emissions, specific MCFs for each animal type in the state are used.

Nitrous Oxide Emission Factors

Base N_2O emission factors for all manure management systems were set equal to the default IPCC factors (IPCC 2000).

Step 5: Develop Weighted Emission Factors

For beef cattle, dairy cattle, swine, and poultry, the base emission factors for both CH_4 and N_2O were then weighted to incorporate the distribution of wastes by management system for each state. The following equation was used to determine the weighted MCF for a particular animal type in a particular state:

$$MCF_{animal,\ state} = \sum_{system} (MCF_{system,\ state} \times Manure_{animal,\ system,\ state})$$

where,

$MCF_{animal,\ state}$ =	Weighted MCF for that animal group and state
$MCF_{system,\ state}$ =	Base MCF for that system and state (see Step 4)
$Manure_{animal,\ system,\ state}$ =	Percent of manure managed in the system for that animal group in that state (expressed as a decimal)

The weighted N_2O emission factor for a particular animal type in a particular state was determined as follows:

$$EF_{animal,\ state} = \sum_{system} (EF_{system} \times Manure_{animal,\ system,\ state})$$

where,

$EF_{animal,\ state}$ =	Weighted EF for that animal group and state
EF_{system} =	Base EF for that system (see Step 4)
$Manure_{animal,\ system,\ state}$ =	Percent of manure managed in the system for that animal group in that state (expressed as a decimal)

Data for the calculated weighted factors for 1992 were taken from the 1992 Census of Agriculture, combined with assumptions on manure management system usage based on farm size. These values were also used for 1990 and 1991. Data for the calculated weighted factors for 1997 came from the 1997 Census of Agriculture, combined with assumptions on manure management system usage based on farm size, and were also used for 1998 and 1999. Factors for 1993 through 1996 were calculated by interpolating between the two sets of factors. A summary of the weighted MCFs used to calculate beef feedlot, dairy cow and heifer, swine, and poultry emissions for 1999 are presented in Table K-5.

Step 6: Calculate Methane and Nitrous Oxide Emission Calculations

For beef feedlot cattle, dairy cows, dairy heifers, swine, and poultry, methane emissions were calculated for each animal group as follows:

$$Methane_{animal\ group} = \sum_{state}(Population \times VS \times B_o \times MCF_{animal,\ state} \times 0.662)$$

where,

$Methane_{animal\ group}$ =	methane emissions for that animal group (kg CH_4/yr)
Population =	annual average state animal population for that animal group (head)
VS =	total volatile solids produced annually per animal (kg/yr/head)
B_o =	maximum methane producing capacity per kilogram of VS (m^3 CH_4/kg VS)
$MCF_{animal,\ state}$ =	weighted MCF for the animal group and state (see Step 5)
0.662 =	conversion factor of m^3 CH_4 to kilograms CH_4 (kg CH_4 / m^3 CH_4)

Methane emissions from other animals (i.e., sheep, goats, and horses) were based on the 1990 methane emissions estimated using the detailed method described in *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress* (EPA 1993). This approach is based on animal-specific manure characteristics and management system data. This process was not repeated for subsequent years for these other animal types. Instead, national populations of each of the animal types were used to scale the 1990 emissions estimates to the period 1991 through 1999.

Nitrous oxide emissions were calculated for each animal group as follows:

$$\text{Nitrous Oxide}_{\text{animal group}} = \sum_{state}(Population \times N_{ex} \times EF_{animal,\ state} \times 44/28)$$

where,

$\text{Nitrous Oxide}_{\text{animal group}}$ =	nitrous oxide emissions for that animal group (kg/yr)
Population =	annual average state animal population for that animal group (head)
N_{ex} =	total Kjeldahl nitrogen excreted annually per animal (kg/yr/head)
$EF_{animal,\ state}$ =	weighted nitrous oxide EF for the animal group and state (see Step 5)
44/28 =	conversion factor for N_2O-N to N_2O

Emission estimates are summarized in Table K-6 and Table K- 7.

Table K-1: Livestock Population (Thousand Head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	**14,143**	**13,980**	**13,830**	**13,767**	**13,566**	**13,502**	**13,305**	**13,138**	**12,992**	**13,026**
Dairy Cows	10,007	9,883	9,714	9,679	9,504	9,491	9,410	9,309	9,200	9,142
Dairy Heifer	4,135	4,097	4,116	4,088	4,062	4,011	3,895	3,829	3,793	3,884
Swine	**53,599**	**56,476**	**62,107**	**58,016**	**59,951**	**58,899**	**56,220**	**58,728**	**62,008**	**60,310**
Market Swine	46,747	49,246	54,327	50,859	52,669	51,973	49,581	51,888	55,167	53,920
Market <60 lb.	18,240	19,212	21,043	19,434	20,157	19,656	18,851	19,886	20,700	19,965
Market 60-119 lb.	11,661	12,374	13,611	12,656	13,017	12,836	12,157	12,754	13,561	13,266
Market 120-179 lb.	9,383	9,840	10,838	10,334	10,671	10,545	10,110	10,480	11,242	11,053
Market >180 lb.	7,463	7,821	8,834	8,435	8,824	8,937	8,463	8,768	9,664	9,636
Breeding Swine	6,852	7,231	7,780	7,157	7,282	6,926	6,639	6,840	6,841	6,390
Beef Cattle	**86,065**	**87,267**	**88,548**	**90,321**	**92,571**	**94,391**	**94,269**	**92,290**	**90,730**	**90,032**
Feedlot Steers	7,338	7,920	7,581	7,984	7,797	7,763	7,380	7,644	7,845	7,782
Feedlot Heifers	3,621	4,035	3,626	3,971	3,965	4,047	3,999	4,396	4,459	4,578
NOF Bulls	2,180	2,198	2,220	2,239	2,306	2,392	2,392	2,325	2,235	2,241
NOF Calves	23,909	23,854	24,118	24,209	24,586	25,170	25,042	24,363	24,001	23,895
NOF Heifers	8,857	8,984	9,501	9,848	10,440	10,658	10,839	10,496	9,985	9,747
NOF Steers	7,483	7,317	8,050	7,938	8,376	8,716	9,108	8,436	8,062	7,842
NOF Cows	32,677	32,960	33,453	34,132	35,101	35,645	35,509	34,629	34,143	33,948
Sheep	**11,358**	**11,174**	**10,797**	**10,201**	**9,836**	**8,989**	**8,465**	**8,024**	**7,825**	**7,215**
Sheep not on Feed	10,301	10,211	9,777	9,178	8,965	8,214	7,719	7,293	7,110	6,586
Sheep on Feed	1,058	963	1,020	1,023	871	775	745	731	715	629
Goats	**2,516**	**2,516**	**2,516**	**2,410**	**2,305**	**2,200**	**2,095**	**1,990**	**1,990**	**1,990**
Poultry	**1,537,074**	**1,594,944**	**1,649,998**	**1,707,422**	**1,769,135**	**1,679,704**	**1,882,078**	**1,926,790**	**1,963,919**	**2,007,517**
Hens >1 yr.	119,551	117,178	121,103	131,688	135,094	133,841	138,048	140,966	150,778	151,914
Pullets laying	153,916	162,943	163,397	158,938	163,433	165,230	165,874	171,171	169,916	177,391
Pullets >3 mo	34,222	34,272	34,710	33,833	33,159	34,004	33,518	35,578	39,664	38,587
Pullets <3 mo	38,945	42,344	45,160	47,941	46,694	47,365	48,054	54,766	56,054	58,775
Chickens	6,545	6,857	7,113	7,240	7,369	7,637	7,243	7,549	7,682	9,659
Broilers	1,066,209	1,115,845	1,164,089	1,217,147	1,275,916	1,184,667	1,381,229	1,411,673	1,442,596	1,481,093
Turkeys	117,685	115,504	114,426	110,635	107,469	106,960	108,112	105,088	97,229	90,098
Horses	**5,650**	**5,650**	**5,850**	**5,900**	**6,000**	**6,000**	**6,050**	**6,150**	**6,150**	**6,180**

Note: Totals may not sum due to independent rounding.

Table K-2: Waste Characteristics Data

Animal Group	Average TAM (kg)	Source	Total Kjeldahl Nitrogen (kg/day) per 1000 kg mass (N_{ex})	Source	Maximum Methane Generation Potential, B_o (m^3 CH_4/kg VS)	Source	Volatile Solids (VS)	Source
Dairy Cow	604	Safley 2000	0.44	USDA 1996a	0.24	Morris 1976	8.45	See Table IIb
Dairy Heifer	476	Safley 2000	0.31	USDA 1996a	0.17	Bryant et. al. 1976	7.77	USDA 1996a
Feedlot Steers	420	USDA 1996a	0.30	USDA 1996a	0.33	Hashimoto 1981	5.44	USDA 1996a
Feedlot Heifers	420	USDA 1996a	0.30	USDA 1996a	0.33	Hashimoto 1981	5.44	USDA 1996a
NOF Bulls	750	Safley 2000	0.31	USDA 1996a	0.17	Hashimoto 1981	6.04	USDA 1996a
NOF Calves	159	USDA 1998c	0.30	USDA 1996a	0.17	Hashimoto 1981	6.41	USDA 1996a
NOF Heifers	420	USDA 1996a	0.31	USDA 1996a	0.17	Hashimoto 1981	6.04	USDA 1996a
NOF Steers	318	Safley 2000	0.31	USDA 1996a	0.17	Hashimoto 1981	6.04	USDA 1996a
NOF Cows	590	Safley 2000	0.33	USDA 1996a	0.17	Hashimoto 1981	6.20	USDA 1996a
Market Swine <60 lb.	15.88	Safley 2000	0.60	USDA 1996a	0.48	Hashimoto 1984	8.80	USDA 1996a
Market Swine 60-119 lb.	40.60	Safley 2000	0.42	USDA 1996a	0.48	Hashimoto 1984	5.40	USDA 1996a
Market Swine 120-179 lb.	67.82	Safley 2000	0.42	USDA 1996a	0.48	Hashimoto 1984	5.40	USDA 1996a
Market Swine >180 lb.	90.75	Safley 2000	0.42	USDA 1996a	0.48	Hashimoto 1984	5.40	USDA 1996a
Breeding Swine	198	Safley 2000	0.24	USDA 1996a	0.48	Hashimoto 1984	2.60	USDA 1996a
Sheep	27	ASAE 1999	0.42	ASAE 1999	NA	NA	NA	NA
Goats	64	ASAE 1999	0.45	ASAE 1999	NA	NA	NA	NA
Horses	450	ASAE 1999	0.30	ASAE 1999	NA	NA	NA	NA
Hens ≥ 1 yr	1.8	ASAE 1999	0.83	USDA 1996a	0.39	Hill 1982a	10.8	USDA 1996a
Pullets laying age	1.8	ASAE 1999	0.62	USDA 1996a	0.39	Hill 1982a	9.7	USDA 1996a
Pullets ≥ 3mo	1.8	ASAE 1999	0.62	USDA 1996a	0.39	Hill 1982a	9.7	USDA 1996a
Pullets ≤ 3mo	1.8	ASAE 1999	0.62	USDA 1996a	0.39	Hill 1982a	9.7	USDA 1996a
Other Chickens	1.8	ASAE 1999	0.83	USDA 1996a	0.39	Hill 1982a	10.8	USDA 1996a
Broilers	0.9	ASAE 1999	1.10	USDA 1996a	0.36	Hill 1984	15.0	USDA 1996a
Turkeys	6.8	ASAE 1999	0.74	USDA 1996a	0.36	Hill 1984	9.7	USDA 1996a

TAM = Typical Animal Mass

Table K-3: Estimated Dairy Cow Volatile Solids Production Rate By State for 1999

State	Volatile Solids[1] (kg/day/1000 kg)
Alabama	7.05
Alaska	6.95
Arizona	9.36
Arkansas	6.48
California	9.11
Colorado	9.11
Connecticut	8.36
Delaware	7.63
Florida	7.51
Georgia	7.87
Hawaii	7.07
Idaho	8.98
Illinois	7.93
Indiana	7.80
Iowa	8.24
Kansas	7.85
Kentucky	6.47
Louisiana	6.17
Maine	7.93
Maryland	7.80
Massachusetts	8.03
Michigan	8.44
Minnesota	8.20
Mississippi	7.29
Missouri	7.09
Montana	8.04
Nebraska	7.58
Nevada	8.88
New Hampshire	8.05
New Jersey	7.93
New Mexico	9.00
New York	8.14
North Carolina	7.98
North Dakota	7.12
Ohio	8.11
Oklahoma	6.94
Oregon	8.57
Pennsylvania	8.30
Rhode Island	7.62
South Carolina	7.58
South Dakota	7.37
Tennessee	7.32
Texas	7.87
Utah	8.24
Vermont	8.07
Virginia	7.63
Washington	9.49
West Virginia	7.54
Wisconsin	8.06
Wyoming	6.84

[1] Volatile solids production estimates based on state average annual milk production rates, combined with a mathematical relationship of volatile solids to milk production (USDA 1996a).

Table K-4: Base Methane Conversion Factors by State for Liquid/Slurry Systems for 1999

State	Liquid/Slurry	Anaerobic Lagoon	Deep Pit
Alabama	0.3439	0.7524	0.3439
Alaska	0.0564	0.4589	0.0564
Arizona	0.3507	0.7863	0.3507
Arkansas	0.3173	0.7595	0.3173
California	0.2398	0.7529	0.2398
Colorado	0.1447	0.6344	0.1447
Connecticut	0.1762	0.6997	0.1762
Delaware	0.2346	0.7364	0.2346
Florida	0.5333	0.7597	0.5333
Georgia	0.3449	0.7492	0.3449
Hawaii	0.5103	0.7422	0.5103
Idaho	0.1401	0.6400	0.1401
Illinois	0.2033	0.7157	0.2033
Indiana	0.1986	0.7114	0.1986
Iowa	0.1665	0.6918	0.1665
Kansas	0.2277	0.7371	0.2277
Kentucky	0.2480	0.7389	0.2480
Louisiana	0.4201	0.7642	0.4201
Maine	0.1281	0.6488	0.1281
Maryland	0.2230	0.7234	0.2230
Massachusetts	0.1659	0.6895	0.1659
Michigan	0.1437	0.6756	0.1437
Minnesota	0.1264	0.6711	0.1264
Mississippi	0.3628	0.7570	0.3628
Missouri	0.2404	0.7358	0.2404
Montana	0.1292	0.6059	0.1292
Nebraska	0.1806	0.7050	0.1806
Nevada	0.2022	0.6761	0.2022
New Hampshire	0.1289	0.6544	0.1289
New Jersey	0.2148	0.7220	0.2148
New Mexico	0.2094	0.7228	0.2094
New York	0.1500	0.6704	0.1500
North Carolina	0.2766	0.7387	0.2766
North Dakota	0.1152	0.6343	0.1152
Ohio	0.1899	0.7027	0.1899
Oklahoma	0.3033	0.7627	0.3033
Oregon	0.1588	0.6279	0.1588
Pennsylvania	0.1727	0.7036	0.1727
Rhode Island	0.1929	0.7027	0.1929
South Carolina	0.3134	0.7498	0.3134
South Dakota	0.1481	0.6802	0.1481
Tennessee	0.2728	0.7426	0.2728
Texas	0.4284	0.7726	0.4284
Utah	0.1760	0.6842	0.1760
Vermont	0.1299	0.6493	0.1299
Virginia	0.2309	0.7179	0.2309
Washington	0.1590	0.6353	0.1590
West Virginia	0.2003	0.7029	0.2003
Wisconsin	0.1376	0.6650	0.1376
Wyoming	0.1224	0.6213	0.1224

Table K-5: Weighted Methane Conversion Factors for 1999

State	Beef Feedlot-Heifer	Beef Feedlot-Steer	Dairy Cow	Dairy Heifer	Swine - Market	Swine - Breeding	Layer	Broiler	Turkey
Alabama	0.0195	0.0195	0.0979	0.0184	0.4619	0.4631	0.3237	0.0150	0.0150
Alaska	0.0157	0.0157	0.1346	0.0156	0.0150	0.0150	0.1260	0.0150	0.0150
Arizona	0.0165	0.0167	0.5879	0.0161	0.4822	0.4822	0.4798	0.0150	0.0150
Arkansas	0.0190	0.0189	0.0716	0.0181	0.5179	0.5215	0.0150	0.0150	0.0150
California	0.0185	0.0187	0.4967	0.0177	0.4741	0.4717	0.1058	0.0150	0.0150
Colorado	0.0156	0.0156	0.3957	0.0155	0.2174	0.2172	0.3832	0.0150	0.0150
Connecticut	0.0168	0.0168	0.0933	0.0164	0.1219	0.1207	0.0494	0.0150	0.0150
Delaware	0.0174	0.0174	0.0854	0.0169	0.2884	0.2884	0.0498	0.0150	0.0150
Florida	0.0216	0.0216	0.4080	0.0201	0.2035	0.2044	0.3265	0.0150	0.0150
Georgia	0.0194	0.0194	0.1399	0.0184	0.4704	0.4677	0.3203	0.0150	0.0150
Hawaii	0.0216	0.0216	0.5116	0.0201	0.3508	0.3508	0.1968	0.0150	0.0150
Idaho	0.0156	0.0155	0.4089	0.0154	0.1615	0.1605	0.3804	0.0150	0.0150
Illinois	0.0162	0.0162	0.0995	0.0160	0.2643	0.2642	0.0293	0.0150	0.0150
Indiana	0.0162	0.0162	0.0834	0.0160	0.2598	0.2600	0.0150	0.0150	0.0150
Iowa	0.0160	0.0160	0.0802	0.0158	0.3619	0.3633	0.0150	0.0150	0.0150
Kansas	0.0164	0.0164	0.0985	0.0161	0.2786	0.2786	0.0295	0.0150	0.0150
Kentucky	0.0175	0.0175	0.0378	0.0170	0.4202	0.4189	0.0511	0.0150	0.0150
Louisiana	0.0205	0.0205	0.1076	0.0192	0.1919	0.1912	0.4653	0.0150	0.0150
Maine	0.0163	0.0163	0.0526	0.0160	0.0150	0.0150	0.0469	0.0150	0.0150
Maryland	0.0171	0.0171	0.0804	0.0167	0.2571	0.2568	0.0511	0.0150	0.0150
Massachusetts	0.0167	0.0167	0.0655	0.0163	0.1660	0.1655	0.0487	0.0150	0.0150
Michigan	0.0159	0.0159	0.1333	0.0158	0.2354	0.2343	0.0284	0.0150	0.0150
Minnesota	0.0158	0.0158	0.0708	0.0157	0.2287	0.2284	0.0150	0.0150	0.0150
Mississippi	0.0197	0.0197	0.0904	0.0186	0.5373	0.5383	0.4596	0.0150	0.0150
Missouri	0.0164	0.0164	0.0925	0.0162	0.2843	0.2839	0.0150	0.0150	0.0150
Montana	0.0155	0.0155	0.2221	0.0154	0.1942	0.1941	0.3721	0.0150	0.0150
Nebraska	0.0161	0.0161	0.0837	0.0159	0.2506	0.2502	0.0289	0.0150	0.0150
Nevada	0.0156	0.0156	0.4796	0.0155	0.0150	0.0150	0.0150	0.0150	0.0150
New Hampshire	0.0163	0.0164	0.0597	0.0161	0.1008	0.1000	0.0472	0.0150	0.0150
New Jersey	0.0170	0.0170	0.0717	0.0166	0.1631	0.1653	0.0503	0.0150	0.0150
New Mexico	0.0159	0.0159	0.5027	0.0157	0.0150	0.0150	0.4503	0.0150	0.0150
New York	0.0165	0.0165	0.0785	0.0162	0.1704	0.1701	0.0478	0.0150	0.0150
North Carolina	0.0177	0.0177	0.0606	0.0171	0.5556	0.5543	0.3181	0.0150	0.0150
North Dakota	0.0157	0.0157	0.0491	0.0156	0.1858	0.1864	0.0270	0.0150	0.0150
Ohio	0.0161	0.0161	0.0858	0.0159	0.2477	0.2481	0.0150	0.0150	0.0150
Oklahoma	0.0162	0.0162	0.3285	0.0159	0.5299	0.5391	0.4658	0.0150	0.0150
Oregon	0.0171	0.0170	0.2527	0.0166	0.0999	0.0993	0.1656	0.0150	0.0150
Pennsylvania	0.0168	0.0168	0.0515	0.0164	0.2657	0.2648	0.0150	0.0150	0.0150
Rhode Island	0.0169	0.0169	0.0341	0.0165	0.1677	0.1677	0.0480	0.0150	0.0150
South Carolina	0.0191	0.0191	0.0996	0.0182	0.4825	0.4805	0.4564	0.0150	0.0150
South Dakota	0.0159	0.0159	0.0721	0.0157	0.2279	0.2282	0.0282	0.0150	0.0150
Tennessee	0.0177	0.0177	0.0511	0.0172	0.3951	0.3942	0.0514	0.0150	0.0150
Texas	0.0165	0.0164	0.4963	0.0161	0.5055	0.5055	0.1063	0.0150	0.0150
Utah	0.0157	0.0157	0.3368	0.0155	0.2491	0.2477	0.4217	0.0150	0.0150
Vermont	0.0163	0.0163	0.0701	0.0160	0.0150	0.0150	0.0463	0.0150	0.0150
Virginia	0.0172	0.0172	0.0478	0.0168	0.4669	0.4674	0.0500	0.0150	0.0150
Washington	0.0171	0.0172	0.3067	0.0167	0.1824	0.1803	0.0879	0.0150	0.0150
West Virginia	0.0170	0.0170	0.0605	0.0166	0.1806	0.1799	0.0497	0.0150	0.0150
Wisconsin	0.0158	0.0159	0.0798	0.0157	0.2139	0.2136	0.0280	0.0150	0.0150
Wyoming	0.0155	0.0155	0.2020	0.0154	0.2166	0.2143	0.3763	0.0150	0.0150

Table K-6: CH_4 Emissions from Livestock Manure Management (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	**422**	**451**	**448**	**464**	**503**	**527**	**532**	**561**	**583**	**593**
Dairy Cows	412	441	438	454	493	517	523	552	573	583
Dairy Heifer	10	10	10	10	10	10	10	10	9	10
Swine	**527**	**549**	**568**	**555**	**620**	**630**	**610**	**670**	**770**	**728**
Market Swine	409	425	444	436	489	502	487	537	624	595
Market <60 lb.	86	89	92	89	99	100	97	107	122	114
Market 60-119 lb.	86	90	93	90	100	102	98	109	125	118
Market 120-179 lb.	115	119	124	124	138	141	137	151	174	166
Market >180 lb.	122	127	135	134	152	160	155	171	203	197
Breeding Swine	118	123	124	119	131	128	123	133	146	133
Beef Cattle	**150**	**154**	**154**	**158**	**162**	**165**	**164**	**162**	**160**	**159**
Feedlot Steers	22	23	22	23	23	23	22	23	23	23
Feedlot Heifers	11	12	11	12	12	12	12	13	13	14
NOF Bulls	6	6	6	6	6	7	7	6	6	6
NOF Calves	15	15	15	15	15	16	16	15	15	15
NOF Heifers	14	14	15	15	16	17	17	16	16	15
NOF Steers	9	9	10	9	10	10	11	10	10	9
NOF Cows	74	74	75	77	79	80	80	78	77	77
Sheep	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**2**
Goats	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Poultry	**125**	**125**	**122**	**126**	**127**	**122**	**123**	**126**	**130**	**124**
Hens >1 yr.	31	29	32	33	33	32	31	31	33	30
Total Pullets	61	62	57	58	58	56	55	58	59	56
Chickens	4	4	4	4	4	4	3	3	4	3
Broilers	19	20	21	21	22	21	24	25	25	26
Turkeys	10	10	10	10	9	9	9	9	8	8
Horses	**29**	**29**	**30**	**30**	**31**	**31**	**31**	**31**	**31**	**31**

Note: Totals may not sum due to independent rounding.

Table K- 7: N_2O Emissions from Livestock Manure Management (Gg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Dairy Cattle	**13.6**	**13.3**	**13.2**	**13.1**	**12.9**	**12.9**	**12.6**	**12.4**	**12.3**	**12.3**
Dairy Cows	9.2	9.0	8.7	8.6	8.4	8.3	8.2	8.0	7.8	7.7
Dairy Heifer	4.4	4.4	4.4	4.5	4.6	4.6	4.5	4.5	4.5	4.6
Swine	**1.0**	**1.0**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.1**	**1.2**	**1.2**
Market Swine	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9
Market <60 lb.	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Market 60-119 lb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market 120-179 lb.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Market >180 lb.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Breeding Swine	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Beef Cattle	**15.8**	**17.3**	**16.2**	**17.3**	**17.0**	**17.1**	**16.5**	**17.4**	**17.8**	**17.9**
Feedlot Steers	10.6	11.5	11.0	11.5	11.3	11.2	10.7	11.1	11.3	11.3
Feedlot Heifers	5.2	5.8	5.2	5.7	5.7	5.9	5.8	6.4	6.4	6.6
Sheep	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Goats	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Poultry	**20.5**	**20.9**	**21.3**	**21.6**	**22.1**	**20.9**	**23.2**	**23.3**	**23.2**	**23.2**
Hens >1 yr.	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
Pullets	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.8	0.8
Chickens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Broilers	12.0	12.5	13.1	13.7	14.3	13.3	15.5	15.9	16.2	16.7
Turkeys	6.7	6.6	6.5	6.3	6.1	6.1	6.2	6.0	5.6	5.1
Horses	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**	**0.8**	**0.8**

+ Less than 0.5 Gg

Note: Totals may not sum due to independent rounding.