Chapter 2: Livestock and Grazed Land Emissions

2.1 Summary of U.S. Greenhouse Gas Emissions from Livestock

A total of 259 Tg CO_2 eq. of greenhouse gases (GHGs) were emitted from livestock, managed livestock waste, and grazed land in 2005 (Table 2-1, Figure 2-1). This represents about 49% of total emissions from the agricultural sector (EPA 2007). Compared to the baseline year (1990), emissions from this source were about 2% lower in 2005. The 95% confidence interval for 2005 was estimated to lie between 239 and 306 Tg CO_2 eq. (Table 2-1).

Enteric fermentation was responsible for almost half (112 Tg CO_2 eq.) of all emissions associated with livestock production, while grazed lands (96 Tg CO_2 eq.) and managed waste (50 Tg CO_2 eq.) accounted for approximately 40% and 20% of the total emissions. All of the emissions from enteric fermentation and about 81% of emissions from managed livestock waste were in the form of methane (CH_4). Of the emissions from grazed lands, 97% were in the form of nitrous oxide (N_2O) (Table 2-2). Grazed lands do not often experience the anaerobic conditions required for CH_4 production to exceed CH_4 uptake. However, a small portion of manure from grazing animals is converted to CH_4. Grazed lands were roughly neutral for CO_2 emissions in 2005 (Table 2-2). The largest total emissions associated with livestock production were from Texas and California (Map 2-1). Emissions were high in Texas primarily because of the large numbers of beef cattle, while dairy cattle emissions are responsible for most emissions in California. Emissions were also high in Iowa, Nebraska, Kansas, Oklahoma, and Missouri.

Table 2-1 Greenhouse Gas Emission Estimates and Uncertainty Intervals in 2005

	Estimate	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Source		*Tg CO_2 eq.*			%
CH_4 enteric fermentation	112	100	132	(11)	18
CH_4 managed waste + grazed land	43	35	52	(18)	20
N_2O managed waste	10	8	12	(16)	24
N_2O grazed land	94	82	136	(13)	44
CO_2 grazed land remaining grazed land	16	13	18	(18)	15
CO_2 land converted to grazed land	(16)	(18)	(14)	(13)	14
Total	**259**	**239**	**306**	**(8)**	**18**

Beef cattle were responsible for the largest fraction (65%) of GHG emissions from livestock in 2005, with the majority of emissions in the form of CH_4 from enteric fermentation and N_2O from grazed land soils (Figure 2-1, Table 2-2). Dairy cattle were the second largest livestock source of GHG emissions (20%), primarily CH_4 from enteric fermentation and managed waste. The third largest GHG source from livestock was swine (8%), nearly all of which was CH_4 from waste. Horses, goats, and sheep caused relatively small GHG emissions when compared to other animal groups, because populations of these types are relatively small.

Table 2-2 Greenhouse Gas Emissions by Livestock Category and Source in 2005

	Enteric Fermentation	Managed Livestock Waste		Grazed Land			
	CH_4	CH_4	N_2O	N_2O[1]	CH_4	CO_2	***Total***
Animal Type			*Tg CO_2 eq.*				
Beef cattle	79.22	0.41	5.78	81.14	1.91	(0.19)	**168.3**
Dairy cattle	27.69	18.75	2.52	2.25	0.00	(0.01)	**51.2**
Swine	1.92	18.65	0.48	0.00	0.00	0.00	**21.0**
Horses	2.00	0.00	0.20	8.30	0.47	(0.02)	**11.0**
Poultry	0.00	2.66	0.44	0.00	0.00	0.00	**3.1**
Sheep	1.03	0.00	0.07	1.73	0.08	(0.00)	**2.9**
Goats	0.30	0.00	0.02	0.78	0.02	(0.00)	**1.1**
Total	**112.2**	**40.5**	**9.5**	**94.2**	**2.5**	**(0.2)**	**258.6**

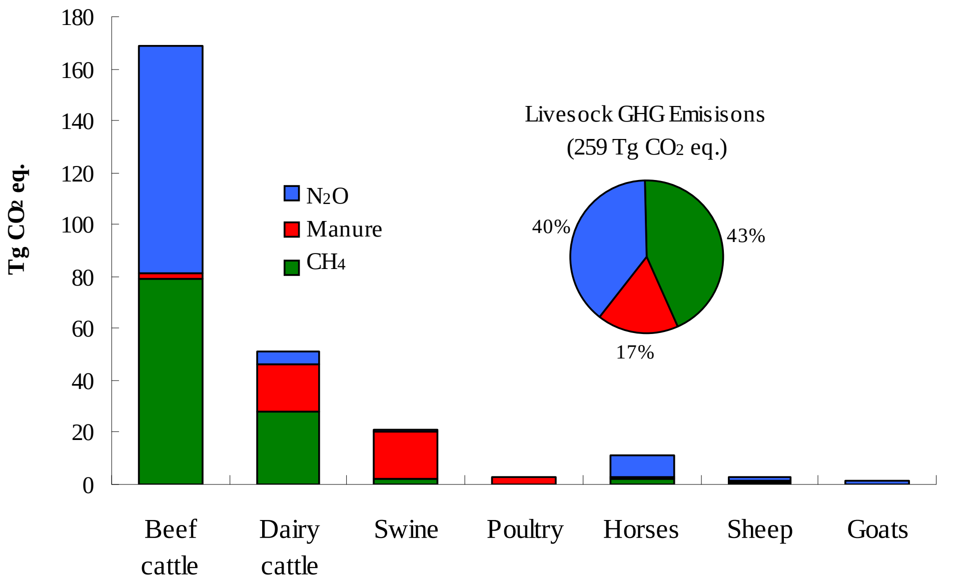
Note: Parenthesis indicate a net sequestration.

[1]Includes direct and indirect emissions.

Livestock contribute GHGs to the atmosphere both directly and indirectly. Livestock emit CH_4 directly as a byproduct of digestion through a process called enteric fermentation. In addition, livestock manure and urine ("waste") cause CH_4 and N_2O emissions to the atmosphere through increased decomposition and nitrification/denitrification. Managed waste that is collected and stored emits CH_4 and N_2O. Grazing animals influence soil processes (nitrification/denitrification) that result in N_2O emissions from the nitrogen (N) in their waste, which increases N_2O emissions. Forage legumes on grazed lands also contribute to N_2O emissions because legumes fix nitrogen from the atmosphere which can become mineralized in the soil and contribute to nitrification and denitrification. Grazed lands can also act as a sink for atmospheric carbon dioxide (CO_2), depending on whether carbon inputs to the soil from plant residues and manure exceed carbon losses from decomposition of soil organic matter. Soils that have been historically cropped using conventional tillage are often depleted of carbon because tillage disturbs soil aggregates and warms soil, both of which increase decomposition rates. Carbon-depleted soils can

Figure 2-1

Greenhouse Gas Emissions from Livestock in 2005



act as CO_2 sinks upon conversion to grazing because grazed soils are typically not plowed. Factors such as grazing intensity and weather patterns also influence net CO_2 fluxes, so grazed soils may be a net source or sink of carbon during any given year.

This chapter provides national and State-level data on CH_4 emissions from enteric fermentation, CH_4 and N_2O emissions from managed livestock waste, and CO_2, N_2O and CH_4 fluxes for grazed lands. Nitrous oxide emissions from managed livestock waste applied to cropped soils are included in the Cropland Agriculture chapter, although emissions associated with waste applied to grazed land are included in this chapter. State-level livestock population data also are presented in this chapter because GHG emissions from livestock are related to livestock population sizes.

In contrast to the first edition of the USDA GHG report (USDA 2004) that relied exclusively on IPCC (1997) methodology, this edition includes estimates for N_2O emissions and CO_2 fluxes from grazed land obtained from the DAYCENT and CENTURY ecosystem models. Another change compared to the first edition is that carbon (C) stock changes in grazed lands that were previously included in the Cropland Agriculture chapter are now included in this chapter.

2.2 Sources of Greenhouse Gas Emissions from Livestock

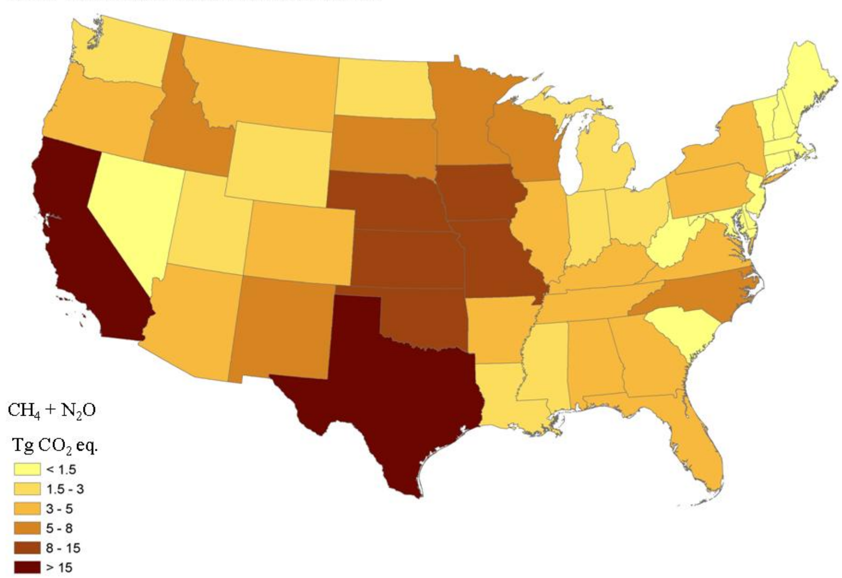
The mechanisms and important factors in generating GHG fluxes from livestock, waste management, and grazed lands are detailed below.

2.2.1 Enteric Fermentation

Enteric fermentation is a normal digestive process where anaerobic microbial populations in the digestive tract ferment food and produce CH_4 gas as a by-product. Methane is then emitted from the animal to the atmosphere through exhaling or eructation. Ruminant livestock, including cattle, sheep, and goats, have greater rates of enteric fermentation because of their unique digestive system, which includes a large rumen or fore-stomach where enteric fermentation takes place. Non-ruminant livestock such as swine, horses, and mules produce less CH_4 from enteric fermentation because it takes place in the large intestine, which has a smaller capacity to produce CH_4 than the

Map 2-1

GHG Emissions from Livestock in 2005



rumen. The energy content and quantity of animal feed also affect the amount of CH_4 produced in enteric fermentation, with lower quality and higher quantities of feed causing greater emissions.

2.2.2 Managed Livestock Waste

Livestock waste is "unmanaged" when it is deposited directly on grazed lands. Alternatively, livestock waste can be "managed" in storage and treatment systems, or spread on fields in lieu of long-term storage. Many livestock producers in the U.S. manage livestock waste in systems such as solid storage,

Table 2-3 Descriptions of Livestock Waste Deposition and Storage Pathways

		Relative Emissions	
Manure Management System	**Description**	CH_4	N_2O
Pasture/Range/Paddock	Manure and urine from pasture and range grazing animals is deposited directly onto the soil.	low	high
Daily Spread	Manure and urine are collected and spread on fields, there is little or no storage of the manure/urine before it is applied to soils.	low	zero[1]
Solid Storage	Manure and urine (with or without litter) are collected by some means and placed under long-term bulk storage.	low	high
Dry Lot	Manure and urine are deposited directly onto unpaved feedlots where the manure is allowed to dry and it is periodically removed (after removal it is sometime spread onto fields).	low	high
Liquid/Slurry	Manure and unine are collected and transported in a liquid state to tanks for storage. The liquid/slurry mixture may be storaed for a long-time and water may be added to facilitate handling.	moderate to high	low
Anaerobic Lagoon	Manure and urine are collected using a flush systems and transported to lagoons for storage. Manure/urine reside in lagoons for 30-200 days.	variable	low
Pit Storage	Combined storage of manure and urine in pits below livestock confinements.	moderate to high	low
Poultry with Litter	Enclosed poultry houses use bedding derived from wood shavings, chopped straw, or other products depending on availability. The bedding absorbs moisture and dilutes manure. Litter is cleaned out once a year. This system is used for breeder flocks and meat	low	high
Poultry without Litter	In high-rise cages or scrape-out/belt systems, manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored. This high rise system is a form of passive windrow composting.	low	low

Adapted from IPCC (2000) Chapter 4.

[1] Nitrous oxide emissions are assumed to be zero during the transport/storage phase but not after the waste has been applied to soils.

dry lots, liquid-slurry storage, deep pit storage, and anaerobic lagoons. Table 2-3 provides descriptions of managed and unmanaged pathways for livestock waste, indicating the relative impacts of different pathways on GHG emissions. Sometimes livestock waste that is stored and treated is subsequently applied as a nutrient amendment to agricultural soils. GHG emissions from the application of treated waste to cropped soils as a nutrient amendment are discussed in the next chapter along with GHG emissions from other nutrient amendments for crop production.

The magnitude of CH_4 and N_2O emissions from managed livestock waste depends in large part on environmental conditions. Methane is emitted under anaerobic conditions, when oxygen is not available to the bacteria which decompose waste. Storage in ponds, tanks, or pits such as those that are coupled with liquid/slurry flushing systems often promote anaerobic conditions (i.e., where oxygen is not available and CH_4 is produced) whereas solid waste stored in stacks or shallow dry pits tends to provide aerobic conditions (i.e., where oxygen is available and CH_4 is not produced). High temperatures generally accelerate the rate of decomposition of organic compounds in waste, increasing CH_4 emissions under anaerobic conditions. In addition, longer residency time in a storage system can increase CH_4 production, while moisture additions, particularly in solid storage systems that normally experience aerobic conditions, can amplify CH_4 emissions.

While environmental conditions are important factors affecting CH_4 emissions from the management of livestock waste, diet, and feed characteristics are also influential. Livestock feed refers to the mixture of grains, hay and byproducts from processed foods that is fed to animals at feedlots and supplemental feed for grazing animals, while diet includes the mixture of plants that animals graze. Livestock feed, diet, and growth rates affect both the amount and quality of manure. Not only do greater amounts of manure lead to higher CH_4 production, but higher energy feed also produces manure with more volatile solids, increasing the substrate from which CH_4 is produced. However, this impact is somewhat offset because some higher energy feeds are more digestible than lower quality forages, and thus less waste is excreted.

The production of N_2O from managed livestock waste depends on the composition of the waste, the type of bacteria involved, and the conditions following excretion. For N_2O emissions to occur, the waste must first be handled aerobically where ammonia or organic nitrogen is converted to nitrates and nitrites (nitrification), and if conditions become sufficiently anaerobic, nitrates and nitrites can be denitrified, i.e., reduced to N oxides and nitrogen gas (N_2) (Groffman et al. 2000). Nitrous oxide is produced as an intermediate product of both nitrification and denitrification and can be directly emitted from soil as a result of both of these processes. These emissions are most likely to occur in dry waste handling systems that have aerobic conditions, but that also contain pockets of anaerobic conditions due to high water contents and high oxygen gas (O_2) demand from decomposition. For example, waste in dry lots is deposited on soil, oxidized to nitrite and nitrate, and encounters anaerobic conditions following precipitation events that increase water content, enhance decomposition, and deplete the supply of O_2.

Managed livestock waste can also contribute to indirect N_2O emissions. Indirect emissions result from nitrogen that was emitted or leached from the manure management system in a form other than N_2O and was then converted to N_2O offsite. These sources of indirect N_2O emission from animal waste are from ammonia (NH_3) volatilization, nitric oxide (NO) emissions from nitrification and denitrification, and nitrate (NO_3) leached or runoff into ground or surface waters. The gaseous losses of NH_3 and NO to the atmosphere can then be deposited to the soil and converted to N_2O by nitrification. The nitrate leached or runoff into waterways can be converted to N_2O by aquatic denitrification.

2.2.3 Grazed Lands

Nitrous oxide from soils is the primary GHG gas associated with grazed lands. Grazed lands contribute to N_2O emissions by adding nitrogen to soils from animal wastes and from forage legumes. Legumes fix atmospheric N_2 into forms that can be used by plants and by soil microbes. Nitrogen from manure and legumes is cycled into the soil and can provide substrates for nitrification and denitrification. Nitrous oxide is a by-product of this cycle; thus more nitrogen added to soils yields more N_2O released to the atmosphere. A portion of the nitrogen cycled within the plant-animal-soil system volatilizes to the atmosphere in various gaseous forms and is eventually re-deposited onto the soils where it can contribute to indirect N_2O emissions. Some nitrogen in the form of nitrate can leach into groundwater and surface runoff, undergo denitrification, and contribute to indirect N_2O emissions. In addition to nitrogen additions, weather, soil type, grazing intensity and other factors influence emissions from grazed lands.

Manure deposited on grazed lands also produces CH_4 emissions. Methane emissions from this source are relatively small, less than 3% of total grazed land GHG emissions, because of the predominately aerobic conditions that exist on most pastures and ranges.

Grazed lands can be emission sources or net sinks for CO_2. Typically, cropland that has recently been converted to grazed land stores CO_2 from the atmosphere in the form of soil organic carbon. But after sufficient time, soil organic carbon reaches a steady state, given consistent weather patterns. Long-term soil carbon levels are sensitive to climate change, and soils that were previously sinks can revert to being sources of CO_2.

2.3 U.S. Livestock Populations

Greenhouse gas emissions from livestock are related to population size. Livestock population data are collected annually by USDA's National Agricultural Statistics Service (NASS) (USDA NASS). Those data are an input into the GHG estimates from livestock in the U.S. GHG Inventory.

Beef and dairy cattle, swine, sheep, goats, poultry, and horses are raised throughout the United States. Detailed livestock population numbers for each State in 2005 are provided in Appendix Table A-1. Appendix Table A-2 shows total national livestock population sizes from 1990 to 2005 by livestock categories. Trends for beef cattle, dairy cattle, and swine are described in more detail below because of their relatively high population numbers and consequently high contributions to GHG emissions.

Texas raised by far the most beef cattle at just over 14 million head in 2005 (Appendix Table A-1). Kansas, Nebraska, Oklahoma, and Missouri each raised from 6 to 4 million head of beef cattle, while several other States raised ~2 million head. Fewer dairy cattle than beef cattle are raised in the United

States. Dairy cattle populations were highest in California (~2.4 million) and Wisconsin (~1.9 million) (Appendix Table A-1). Minnesota, New York, and Pennsylvania had the next largest populations of dairy cattle, ranging from 730,000 to 940,000 head in each State. Most States had fewer than 500,000 head of dairy cattle.
Iowa was the largest swine producer with 16 million head in 2005 (Appendix Table A-1). North Carolina housed the second largest swine population at 10 million head. Illinois, Indiana, Minnesota, Missouri, Nebraska, and Oklahoma also have sizeable swine populations.

Arkansas and Georgia had the largest poultry populations in 2005, with roughly 260 million head of poultry in each State (Appendix Table A-1). Alabama, North Carolina, Mississippi, and Texas also had large populations of poultry, between 138 and 205 million head each. Indiana, Kentucky, Maryland, Oklahoma, and Virginia had poultry populations between 50 and 60 million head.

2.4 Enteric Fermentation

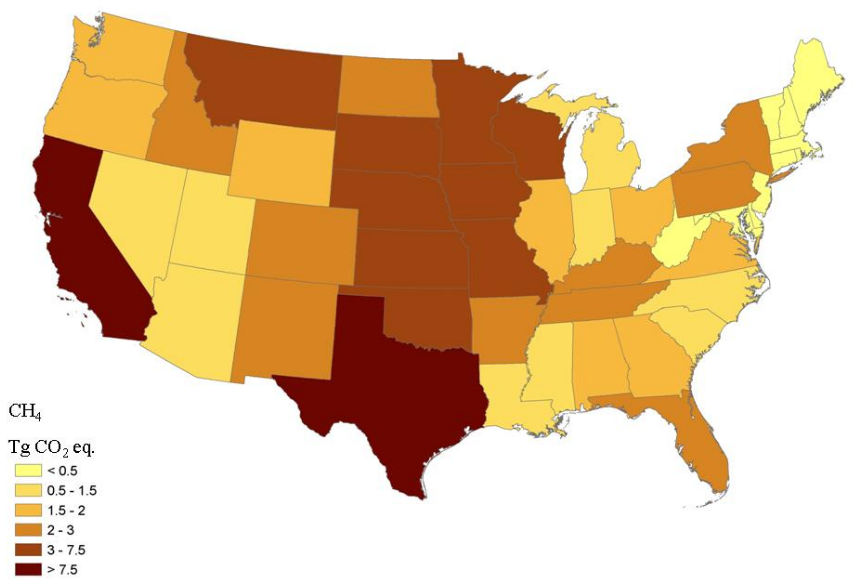
Just about half (43%) of emissions associated with livestock production were from CH_4 produced by enteric fermentation. Cattle were responsible for the vast majority of enteric CH_4 emissions (95%) in 2005 (Table 2-2). Texas (14.4 Tg CO_2 eq.) and California (7.8 Tg CO_2 eq.) had the largest CH_4 emissions from enteric fermentation across all livestock types in 2005 (Map 2-2, Appendix Table A-3, Appendix Table A-4). These emissions were largely tied to the sizable populations of cattle in both States. However, enteric fermentation emissions in Texas were mostly from beef cattle, whereas in California they were mostly from dairy cattle (Appendix Table A-4). Central, Northern Plains, and some Great Lakes States also had relatively high CH_4 emissions from enteric fermentation, ranging between 3 and 7.5 Tg CO_2 eq. per State in 2005. Emissions tended to be lower from some States in the Northeast, Southeast, and the desert Southwest, mainly because cattle populations are low in these States.

Annual emissions of CH_4 from enteric fermentation fluctuated up and down by less than approximately 10 Tg CO_2 eq. between 1990 and 2005 (Table 2-4). Emissions peaked in 1995 and then decreased by about 10 Tg CO_2 eq. by 2005 (~9% of total). Overall, by 2005, CH_4 emissions from enteric fermentation declined by about 4% compared to 1990 levels.

2.4.1 Methods for Estimating Methane Emissions from Enteric Fermentation

Map 2-2

Methane Emissions from Enteric Fermentation in 2005



The official U.S. GHG Inventory estimates for enteric fermentation are calculated according to the methodological framework provided by the Intergovernmental Panel on Climate Change (IPCC) for preparing national GHG inventories. The IPCC guidance is organized into a hierarchical, tiered analytical structure, in which higher tiers correspond to more complex and detailed methodologies. The methods detailed below correspond to both tier 1 and tier 2 approaches. With the permission of EPA, Annex 3.9 from the official U.S. GHG Inventory is summarized below.

Methane emissions from enteric fermentation were estimated for five livestock categories: cattle, horses, sheep, swine, and goats. Emissions from cattle represent the majority of U.S. emissions; consequently, the more detailed IPCC Tier 2 methodology was used to estimate emissions from cattle and the IPCC Tier 1 methodology was used to estimate emissions from the other types of livestock.

2.4.1.1 Estimating Methane Emissions from Cattle

This section describes the process used to estimate enteric fermentation emissions of CH_4 from cattle on a regional basis. A model based on recommendations provided in IPCC (1997) and IPCC (2000) was developed that uses information on population, energy requirements, digestible energy, and the fraction of energy converted to methane to estimate CH_4 emissions. The emission estimation methodology consists of the following three steps: (1) characterize the cattle population to account for cattle

Table 2-4 U.S. Methane Emissions from Enteric Fermentation in 1990, 1995-2005

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Animal Type						*Tg CO_2 eq.*						
Beef cattle	83.2	89.7	88.8	86.6	85.0	84.9	83.4	82.5	82.4	82.6	80.4	79.2
Dairy cattle	28.9	27.7	26.3	26.4	26.3	26.6	27.0	26.9	27.1	27.3	27.0	27.7
Horses	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Sheep	1.9	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0
Swine	1.7	1.9	1.8	1.8	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Goats	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Total	**117.9**	**123.0**	**120.5**	**118.3**	**116.7**	**116.8**	**115.6**	**114.6**	**114.7**	**115.1**	**112.6**	**112.1**

population categories with different emissions profiles; (2) characterize cattle diets to generate information needed to estimate emissions factors; and (3) estimate emissions using these data and the IPCC Tier 2 equations.

Step 1: Characterize U.S. Cattle Population

Each stage in the cattle lifecycle was modeled to simulate the cattle population from birth to slaughter. This level of detail accounts for the variability in CH_4 emissions associated with each life stage. Given that the time in which cattle can be in a stage can be less than 1 year (e.g., beef calves are weaned at 7 months), the stages are modeled on a per-month basis. The type of cattle use also impacts CH_4 emissions (e.g., beef versus dairy). Consequently, cattle life stages were modeled for several categories of dairy and beef cattle. These categories are listed in Appendix Table A-5.

The key variables tracked for each of these cattle population categories[1] includes calving rates, pregnancy and lactation (Appendix Table A-6), average weights and weight gains (Appendix Table A-7), feedlot placements (Appendix Table A-8), death rates, number of animals per category each month, and animal characteristics (i.e., age, gender, etc.) data.

Cattle population data were taken from USDA NASS (Appendix Table A-2). The USDA NASS publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Cattle and calf populations, feedlot placement statistics (e.g., number of animals placed in feedlots by weight class), slaughter numbers, and lactation data were obtained from the USDA NASS (Cattle: USDA NASS 2002a, 2001a, 2000a, 1999a, 1995, Livestock slaughter: USDA NASS 2002b, 2001b, 2000b). Beef calf birth percentages were obtained from the USDA APHIS National Animal Health Monitoring System (USDA APHIS NAHMS 1998, 1994, 1993).

Step 2: Characterize U.S. Cattle Diets

To support development of digestible energy (DE), the percent of gross energy intake digestible to the animal and CH_4 conversion rate (Y_m), the fraction of gross energy converted to CH_4 values for each of the cattle population categories, data were collected on diets considered representative of different regions. For both grazing animals and animals being fed mixed rations, representative regional diets were estimated using information collected from State livestock specialists and from USDA APHIS NAHMS (1996). The data for each of the diets (e.g., proportions of different feed constituents, such as hay or grains) were used to determine chemical composition for use in estimating DE and Y_m for each animal type. Region and cattle type specific estimates for DE and Y_m were developed for the U.S. (Appendix Table A-9). Regions are defined in Appendix Table A-10. Additional detail on the regional diet characterization is provided in EPA (2000).

Step 3: Estimate Methane Emissions from Cattle

Emissions were estimated in three steps: a) determine gross energy intake using the IPCC (2000) equations, b) determine an emissions factor using the GE values and other factors, and c) sum the daily emissions for each animal type. The necessary data values include:

[1] Except bulls. Only end-of-year census population statistics and a national emission factor are used to estimate CH_4 emissions from the bull population.

- Body weight (kg)
- Weight gain (kg/day)
- Net energy for activity (Mj/day)
- Standard reference weight (dairy = 1,324 lbs; beef = 1,195 lbs)
- Milk production (kg/day)
- Milk fat (% of fat in milk = 4)
- Pregnancy (% of population that is pregnant)
- DE (% of gross energy intake digestible)
- Y_m (the fraction of gross energy converted to CH_4)

This process was repeated for each month, and the totals for each subcategory were summed to achieve an emissions estimate for the entire year. The estimates for each of the ten subcategories of cattle are listed in Appendix Table A-11. The CH_4 emissions for each subcategory were then summed to estimate total emissions from beef cattle and dairy cattle for the entire year. The cattle emissions calculation model estimates emissions on a regional scale. Individual State-level estimates were developed from these regional estimates using the proportion of each cattle population subcategory in the State relative to the population in the region.

2.4.1.2 Emission Estimates From Other Livestock

All livestock population data, except for horses, were taken from USDA NASS reports (Hogs and pigs: USDA NASS 2002c, 2001c, 2000c, 1999b, 1998, 1994a, Sheep and goats: USDA NASS 2002d, 2001d, 2000d, 1999c, 1994b). Appendix Table A-2 shows the population data for all livestock that were used for estimating all livestock-related emissions. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System, while historical data were downloaded from USDA NASS. The Food and Agriculture Organization (FAO) of the United Nations publishes horse population data. These data were accessed from the FAOSTAT database (FAO 2002). National-level emission calculations for other livestock were developed from national population totals. State-level emissions for each livestock type were developed from these national totals based on the proportion of livestock population in each State relative to the national total population for the particular livestock category and by assuming that emissions are proportional to populations. Appendix Table A-12 shows the emission factors used for these other livestock.

2.4.2 Uncertainty in Estimating Methane Emissions from Enteric Fermentation

The following discussion of uncertainty in the enteric fermentation estimates is from the U.S. GHG Inventory (EPA 2007) and reproduced here with permission from EPA.

Uncertainty is estimated using the Monte Carlo Stochastic Simulation technique. Emission factors and animal population data are the primary sources of uncertainty in estimating CH_4 emissions from enteric fermentation. One hundred eighty-five input variables were identified as key input variables for uncertainty analysis (e.g., estimates of births by month, weight gain of animals by age class, and placement of animals into feedlots based on placement statistics and slaughter weight data). The uncertainty associated with these input variables are ±10% or lower. However, the uncertainty for many of the emission factors are over ±20%. The overall 95% confidence interval around the estimate of 112 Tg CO_2 eq. ranges from 100 to 132 Tg CO_2 eq. (Table 2-1).

2.5 Managed Livestock Waste

Greenhouse gas emissions from managed livestock waste are composed of CH_4 and N_2O from livestock waste storage and treatment and CH_4 emissions from the daily spread of livestock waste. Emissions from these sources are discussed below, with estimates disaggregated spatially and by livestock category where possible.

Methane was the predominant GHG emitted from managed livestock waste in 2005, accounting for 81% of 50 Tg CO_2 eq. total emissions from this source (Table 2-5). The remaining 19% of GHG emissions from managed livestock waste was N_2O. Dairy cattle and swine were each responsible for approximately 40% of total managed waste emissions (Figure 2-2). Poultry (6%) and beef cattle (16%) were also important sources in 2005. For beef cattle, N_2O was the predominate form (71%) of waste emissions. Over time, emissions from managed waste increased by ~28% from 1990 to 2005 (Figure 2-3). Most of the increase was from higher CH_4 emissions due to the trend of storing more waste in liquid systems and anaerobic lagoons which facilitate CH_4 production.

While beef cattle are responsible for the largest overall emissions from all livestock, (Table 2-2, Figure 2-1), emissions from beef cattle managed waste are relatively small (Figure 2-2) because most waste generated by beef cattle is unmanaged. Emissions from beef cattle managed manure changed little between 1990 and 2005.

Managed manure emissions from horses, sheep, and goats are small due to the relatively small population of these animals (Appendix Table A-2), as for beef cattle, most of the manure is unmanaged or managed in dry systems (EPA 2007).

Table 2-5 Greenhouse Gas Emissions from Managed Livestock Waste in 1990, 1995-2005

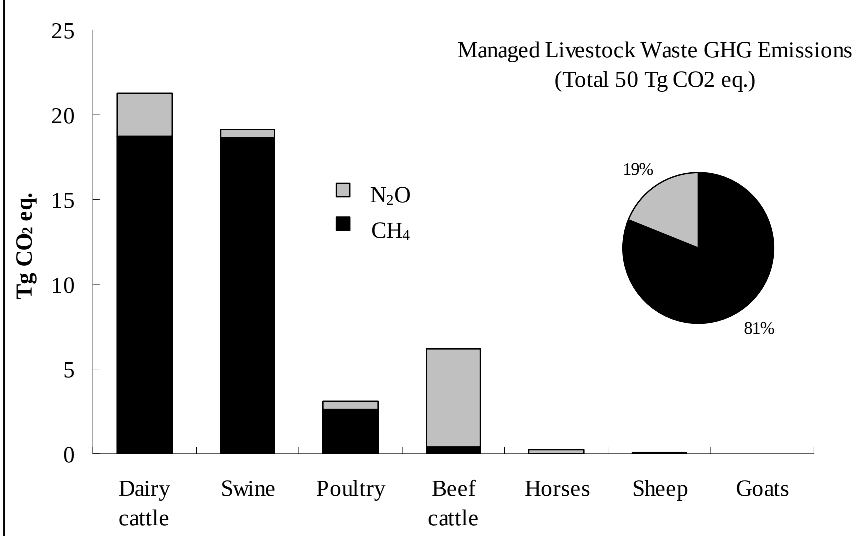
	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
GHG Type						*Tg CO_2 eq.*						
Nitrous Oxide[1]	8.6	9.0	8.7	9.0	9.2	9.2	9.6	9.8	9.7	9.3	9.4	9.5
Methane[2]	30.9	35.1	33.7	35.4	38.7	38.3	38.7	40.1	41.1	40.5	39.7	41.3
Total	**39.5**	**44.1**	**42.4**	**44.4**	**47.9**	**47.5**	**48.3**	**50.0**	**50.8**	**49.8**	**49.2**	**50.8**

[1] Does not include emissions from managed manure applied to cropped soils.

[2] Includes CH_4 from managed sources and from grazed grasslands. Manure deposited on grasslands produces little CH_4 due to predominantly aerobic conditions.

Figure 2-2

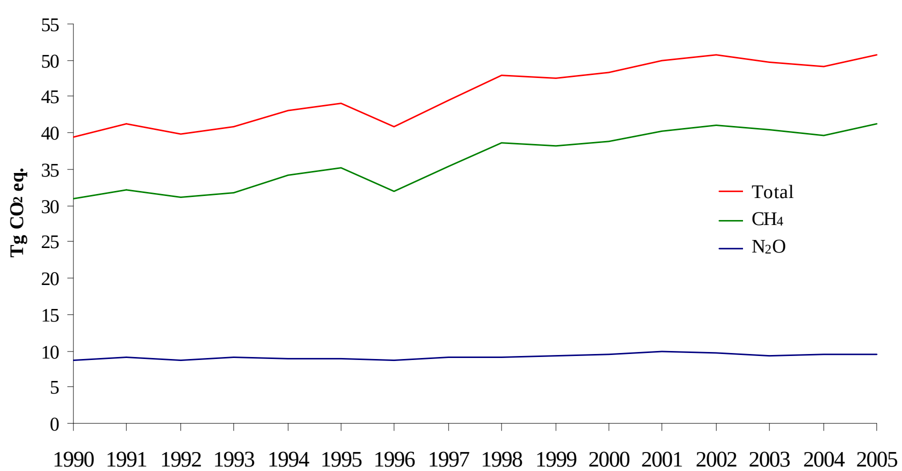
Greenhouse Gas Emissions from Managed Livestock Waste by Livestock Type in 2005



State-level GHG emissions from managed livestock waste varied across States in 2005, with a small number of States responsible for the larger contributions to national GHG emissions. California and Iowa had the largest GHG emissions from managed livestock waste (7 and 6 Tg CO_2 eq., respectively) (Appendix Table A-13, Map 2-3). In California, GHG emissions from managed livestock waste were largely from dairy cattle, while in Iowa, they were largely from swine (Appendix Table A-14, A-15). North Carolina and Texas also had large GHG emissions from managed livestock waste (4 and 3 Tg CO_2 eq., respectively). In North Carolina, this was primarily from swine. In Texas, however, most emissions were from both beef and dairy cattle waste, with a smaller portion from swine (Appendix Table A-14, A-15).

Figure 2-3

Greenhouse Gas Emissions from Managed Livestock Waste, 1990-2005



2.5.1 Methods for Estimating Methane and Nitrous Oxide Emissions from Managed Livestock Waste

This section summarizes how CH_4 and N_2O emissions from livestock waste were calculated in the U.S. GHG Inventory (EPA 2007) as well as for this inventory report. Animal population data is used to estimate CH_4 production potential and nitrogen in waste, and these are multiplied by a methane conversion factor (MCF) and an N_2O emission factor. MCFs are used to determine the amount of CH_4 emissions that are potentially produced by each unit of livestock waste. MCFs vary by livestock type, manure storage system, and the waste storage temperature. Nitrous oxide emission factors are determined by State and livestock type. The EPA provides the USDA with State and national estimates of GHG emissions from managed livestock waste. The estimates of GHG emissions from managed livestock waste were prepared following a methodology developed by EPA and consistent with international guidance, and are described in detail in Annex 3.10 of the U.S. GHG Inventory (EPA 2007).

Data required to calculate emissions from livestock waste:

- State-level animal population data by animal type
- Animal type specific nitrogen excretion rate
- Animal type specific volatile solid production
- Animal type specific CH_4 production potential
- Extent CH_4 production potential is realized (including biogas collection efforts)
- State-level portion of manure in each management system by animal type
- Portion of manure deposited on grasslands and used in spread operations

Seven animal types are considered: dairy cattle, beef cattle, swine, sheep, goats, poultry, and horses. For swine and dairy cattle, manure management system usage is determined for different farm size categories using data from the USDA (USDA 1996a, 1998a, 2000a, 2000b, 2000c) and EPA (ERG 2000, EPA 2002a, 2002b). For beef cattle and poultry, manure management system usage is not tied to farm size and is based on other sources (ERG 2000, USDA 2000d, UEP 1999). For other animal types, manure management system usage is based on previous estimates (EPA 1992a).

Methane and N_2O emissions calculations are based on the following animal characteristics for each relevant livestock population:

- Volatile solids excretion rate (VS)
- Maximum CH_4 producing capacity (B_o) for U.S. animal waste
- Nitrogen excretion rate (N_{ex})
- Typical animal mass (TAM)

Appendix Table A-16 presents a summary of the waste characteristics used in the emissions estimates. The method for calculating volatile solids production from beef and dairy cows, heifers, and steers is based on the relationship between animal diet and energy utilization, which is modeled in the enteric fermentation portion of the inventory. Volatile solids content of manure equals the fraction of the diet consumed by cattle that is not digested and thus excreted as fecal material which, when combined with urinary excretions, constitutes manure. Estimations of gross energy intake and digestible energy were used to calculate the indigestible energy per animal unit as gross energy minus digestible energy plus an additional 2% of gross energy for urinary energy excretion per animal unit. This was then converted to volatile solids production per animal unit using the typical conversion of dietary gross energy to dry organic matter of 20.1 MJ/kg (Garrett & Johnson 1983). Appendix Table A-17 shows volatile solid production rates by State.

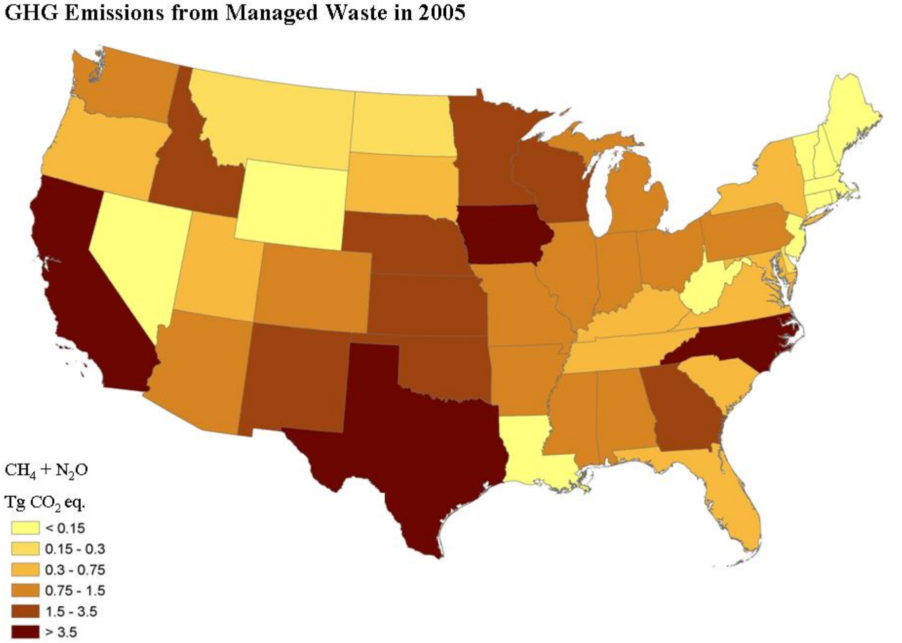
Methane conversion factors for dry manure management systems and N_2O emissions factors for all management systems were set equal to the default IPCC factors for temperate climates (IPCC 2000). MCFs for liquid slurry, anaerobic lagoon, and deep pit systems were calculated based on the forecast performance of biological systems relative to temperature changes. These calculations account for the following: average monthly ambient temperature, minimum system temperature, the carryover of volatile solids from month to month, and a factor to account for management and design practices that result in loss of volatile solids form lagoon systems. State-level emissions factors for liquid slurry, deep pit, and anaerobic lagoon are shown in Appendix Table A-18. Appendix Table A-19 has national scale emission factors for other waste management systems. For each animal type, the base emission factors were weighted to incorporate the distribution of waste management systems within each State to get a State-level weighted emission factor (Appendix Table A-20).

Methane emissions were estimated by multiplying regional or national animal type specific volatile solid production by the animal type specific maximum CH_4 production capacity of the waste and the State specific MCF.

Nitrous oxide emissions were estimated by multiplying total Kjeldahl nitrogen (TKN) production for livestock waste by State-specific emission factors. TKN was calculated for each animal type using national average nitrogen excretion rate (USDA 1996a). N_2O emission factors were weighted by State-level types of manure management.

Map 2-3

GHG Emissions from Managed Waste in 2005



2.5.2 Uncertainty in Estimating Methane and Nitrous Oxide Emissions from Managed Livestock Waste

The following discussion of uncertainty in estimating GHG emissions from livestock waste is modified from information provided in the U.S. GHG Inventory (EPA 2007; 2003). The information is reproduced here with permission from EPA.

An uncertainty analysis based on the Monte Carlo

Stochastic Simulation technique was conducted on the manure management inventory considering the issues described below and based on published data from scientific and statistical literature, the IPCC, and experts in the industry. The results of the uncertainty analysis showed that the manure management CH_4 inventory has a 95% confidence interval from 35 to 52 Tg CO_2 eq. around the inventory value of 43 Tg CO_2 eq., and the manure management N_2O inventory has a 95% confidence interval from 8 to 12 Tg CO_2 eq. around the inventory value of 10 Tg CO_2 eq (Table 2-1).

Uncertainties derive from limited information on regional patterns in the use of manure management systems and CH_4 generating characteristics of each system. It is assumed that shifts in the swine and dairy sectors toward larger farms causes more manure to be managed in liquid manure management systems. Farm-size data from 1992, 1997 and 2002 are used to modify MCFs based on this assumption. However, the assumption of a direct relationship between farm size and liquid system usage may not apply in all cases and may vary based on geographic location. In addition, the CH_4 generating characteristics of manure management systems are based on relatively few laboratory and field measurements. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) published a default range of MCFs for anaerobic lagoon systems of 0% to 100%, reflecting the wide range in performance of these systems globally.

There are potential classification errors when naming manure management systems. For example, many livestock waste treatment systems classified as anaerobic lagoons are actually holding ponds, which may be organically overloaded, thus producing CH_4 at a different rate than estimated. In addition, the performance of manure management systems depends on how they are operated, which undoubtedly varies across facilities. An MCF based on optimized lagoon systems does not take into consideration the actual variation in performance across operational systems. Therefore, an MCF methodology was developed to better match observed system performance and account for the impact of temperature on system performance. The MCF methodology used in the inventory includes a factor to account for management and design practices that result in the loss of volatile solids from the management system. This factor, estimated with data from three systems, all in anaerobic lagoons in temperate climates, was applied broadly to systems across a range of management practices. Additional data are needed on animal waste lagoon systems across the country to verify and refine this methodology. Data are also needed on how lagoon temperatures relate to ambient air temperatures and whether the lower bound estimate of temperature used for lagoons and other liquid systems should be revised. The inventory relies on the IPCC MCF for poultry waste management operations of 1.5%. This factor needs further evaluation to assess if poultry high-rise houses promote sufficient aerobic conditions to warrant a lower MCF.

The default N_2O emission factors published in Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000) were derived using limited information. The IPCC factors are global averages; U.S.-specific emission factors may be significantly different. Manure and urine in anaerobic lagoons and liquid/slurry management systems produce CH_4 at different rates, and would in all likelihood produce N_2O at different rates, although a single N_2O emission factor was used for both system types. In addition, there are little data available to determine the extent to which nitrification and denitrification occur in animal waste management systems. Ammonia concentrations

Table 2-6 Greenhouse Gas Emissions from Grazed Lands in 1990, 1995-2005

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
GHG Type						*$TgCO_2$ eq.*						
Nitrous Oxide[1]	**108.4**	**102.1**	**120.9**	**98.3**	**101.3**	**85.9**	**91.0**	**99.8**	**99.0**	**87.5**	**87.3**	**94.2**
Direct	88.0	77.8	96.5	76.3	79.9	68.9	73.9	74.8	80.1	71.0	71.3	76.4
Indirect Volatilization	10.7	10.3	10.2	10.1	10.1	9.6	9.3	9.4	9.3	9.4	9.1	9.9
Indirect Leaching & Run-Off	9.6	14.0	14.3	11.9	11.2	7.4	7.8	15.7	9.5	7.1	6.9	7.9
Methane[2]	**2.6**	**2.7**	**2.7**	**2.6**	**2.7**	**2.6**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**
Carbon Dioxide	**(14.4)**	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**	**(0.0)**	**(0.1)**	**(0.1)**	**(0.1)**	**(0.2)**	**(0.2)**
Grazed Lands Remaining Grazed	0.1	16.4	16.4	16.4	16.4	16.3	16.3	16.2	16.2	16.2	16.1	16.1
Land Convertd to Grazed Land	(14.6)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)
Total	**96.5**	**104.9**	**123.6**	**101.0**	**104.0**	**88.5**	**93.5**	**102.3**	**101.4**	**89.8**	**89.6**	**96.5**

[1] Does not include emissions from managed manure applied to cropped soils.

[2] Includes CH_4 from managed sources and from grazed grasslands. Manure deposited on grasslands produces little CH_4 due to predominantly aerobic conditions.

that are present in poultry and swine systems suggest that N_2O emissions from these systems may be lower than predicted by the IPCC default factors. At this time, there are insufficient data available to develop U.S.-specific N_2O emission factors; however, this is an area of ongoing research, and warrants further study as more data become available. Similar approaches will be studied for other animal sub-groups.

Additional data would help confirm and track diet changes over time, which are used to introduce variability in volatile solids for beef and dairy cows, heifers, and steers. A similar approach for swine volatile solids production may improve the accuracy of future inventory estimates. Uncertainty also exists with the maximum CH_4 producing potential of volatile solids excreted by different animal groups. The maximum CH_4 producing values used in the CH_4 calculations are published values for U.S. animal waste. However, there are several studies that provide a range of maximum CH_4 producing values for certain animals, including dairy and swine. The maximum CH_4 producing values chosen for dairy assign separate values for dairy cows and dairy heifers to better represent the feeding regimens of these animal groups. For example, dairy heifers do not receive an abundance of high-energy feed and, consequently, their waste will not produce as much CH_4 as would that from milking cows.

2.6 Grazed Lands

Grazed lands emit N_2O due to enhanced nitrogen cycling as well as a relatively small amount of CH_4 emissions from manure deposits. Manure deposited on grazed land (i.e., unmanaged manure) produces little CH_4 due to predominant aerobic conditions. Nitrous oxide sources include direct and indirect emissions of N_2O associated with increased nitrogen from forage legumes and waste from grazing animals. Grazed lands can be a source or a sink of CO_2.

Nitrous oxide was the predominant GHG emitted from grazed lands in 2005, accounting for 98% of all emissions from this source (Table 2-6). The remaining 2% of GHG emissions from grazed lands was CH_4. Grazed lands were roughly CO_2 neutral in 2005, with a small uptake of 0.2 Tg CO_2 eq. through sequestration of CO_2 in soil organic carbon. Nitrous oxide emissions from grazed land totaled 94 Tg CO_2 eq. in 2005 (Table 2-6), including direct and indirect sources. Beef cattle are responsible for the highest proportion of direct N_2O emissions from grazed lands because the vast majority of grazed lands in the U.S. are used for beef production. Texas and Oklahoma had the largest emissions from grazed lands due to the large amounts of rangeland in these States. In aggregate, emissions from managed grazed land were about twice those of managed manure in 2005 and have been since 1990, when national emissions from this source were first estimated (Tables 2-5, 2-6). This is due to large numbers of beef cattle on grazing land (more than 80% of all cattle) compared to feedlots, which are a source of managed waste (Map 2-4).

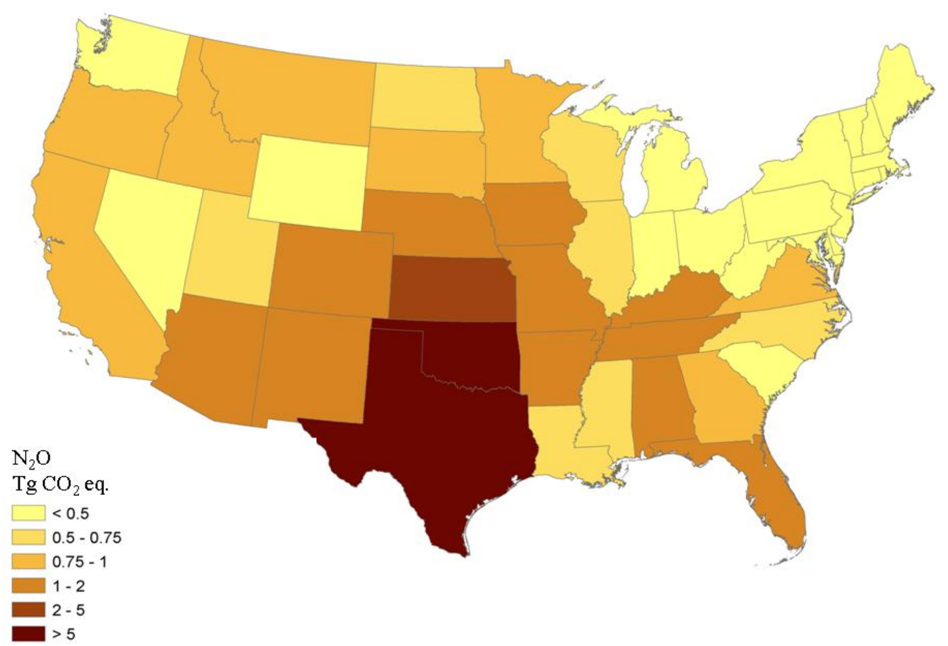
2.6.1 Methodology To Estimate Nitrous Oxide Emissions from Grazed Lands

Estimates of N_2O emissions from this component were based on DAYCENT model simulations of grazed lands, estimates of animal waste production (Appendix Table A-21), and IPCC (2006) methodology for emissions associated with nitrogen from unmanaged manure not accounted for by the DAYCENT simulations (Del Grosso et al. 2006). Unmanaged manure is not managed in manure management systems, but instead is deposited directly on soils by grazing animals in pastures, rangelands, and paddocks. The livestock included in this component were dairy cattle, beef cattle, swine, sheep, goats, poultry, and horses.

The DAYCENT ecosystem model simulated improved pastures and rangelands at county-level resolution for the U.S. Improved pastures are defined as grazing lands that were seeded with legumes and/or were amended with organic nitrogen (e.g., managed manure) or synthetic fertilizer nitrogen. Grazing intensity on improved pastures was assumed to be moderate to heavy while intensity on rangelands was assumed to be light to moderate.

Map 2-4

Nitrous Oxide Emissions from Grazed Land in 2005



Key model inputs are daily weather, soil texture class, vegetation mix, and grazing intensity. The model simulates soil water and temperature flows, plant growth and senescence, decomposition of dead plant material and soil organic matter, mineralization of nutrients, and trace gas fluxes. Nitrous oxide emissions, nitrate (NO_3) leaching, nitrogen volatilization, animal waste deposition, and nitrogen fixation by legumes were simulated on a per unit area basis, and multiplied by the estimated grazed area (NRI, USDA 2000b) in each county to obtain total county level nitrogen losses, animal waste nitrogen production, and legume fixation. The DAYCENT simulations are described in more detail in Chapter 3 of this report and in EPA (2007) and Del Grosso et al. (2006).

Comparisons of animal waste nitrogen production with estimates based on animal numbers show that DAYCENT did not account for 100% of animal waste nitrogen. IPCC (2006) methodology was applied to estimate emissions for the nitrogen inputs from this source not accounted for by the DAYCENT simulations. IPCC methodology was also used to estimate indirect emissions from DAYCENT simulated nitrogen volatilization and NO_3 leaching. IPCC (2006) methodology and details on how animal populations, manure, and nitrogen in waste production data were acquired are described in detail in Appendix 3.11 of the U.S. GHG Inventory (EPA 2007). Waste nitrogen deposited on grazed lands not accounted for by the DAYCENT simulations were multiplied by the default IPCC (2006) emission factor of 0.02 kg N_20-N/kg N to estimate direct N_2O-nitrogen emissions.

Indirect N_2O emissions due to volatilization of applied nitrogen and indirect N_2O emissions due to leaching were calculated using DAYCENT and IPCC (2006) estimates of volatilization and NO_3 leaching and IPCC estimates of the portion of volatilized or leached/runoff nitrogen that is converted to N_2O. Nitrogen volatilized, leached, or runoff are all outputs for the grazed lands simulated by DAYCENT. For animal waste not accounted for by the DAYCENT simulations, 20% of animal waste nitrogen was assumed to volatilize and 30% of animal waste nitrogen was assumed to be leached or runoff. The total volatilized nitrogen was multiplied by the IPCC default emission factor of 0.01 kg N_20- N/kg N (IPCC 2006). The total nitrogen leached or runoff was multiplied by the IPCC (2006) default emission factor of 0.0075 kg N_20-N/kg N.

Total grazed land N_2O emissions were partitioned among different animal types by assuming that emissions are linearly proportional to waste nitrogen production.

2.6.2 Uncertainty in Nitrous Oxide Emissions for Grazed Lands

Uncertainty due to model inputs and model structure were quantified. Model inputs used to represent weather, N inputs, and soil texture are not known precisely and each of these has an associated range of uncertainty represented by a probability density function. Model structural uncertainty refers to the errors inherent in the model. That is, the model is not expected to yield perfect results even if model inputs were precisely known. To address uncertainty in model inputs, a series of Monte Carlo simulations were performed. To address model structural uncertainty, DAYCENT simulated N_2O emissions were compared with measured emissions from eight cropping experiments in North America. IPCC (2006) methodology was used to estimate uncertainties for the grazed land not accounted for by the DAYCENT simulations. Uncertainty from the DAYCENT simulated grazed land was combined with uncertainty for remaining grazed lands calculated using IPCC (2006) methodology by using simple error propagation. The calculated 95% confidence interval around the estimate of 94 Tg CO_2 eq. for grazed soil N_2O emissions was 82 to 136 TgCO_2 eq (Table 2-1). Uncertainty calculations are described in detail in Chapter 3 of this report.

2.6.3 Methodology To Estimate Methane Emissions from Grazed Lands

Methane emissions were estimated by multiplying regional or national animal type specific volatile solid production by the animal type specific maximum CH_4 production capacity of the waste and the national MCF for manure deposited on grazed lands.

2.6.4 Methodology To Estimate Carbon Dioxide Fluxes for Grazed Lands

As with N_2O emissions, carbon dioxide (CO_2) fluxes for grasslands were estimated using results from an ecosystem model (CENTURY) and IPCC (2006) methodology. CENTURY (Parton et al. 1994) uses monthly weather data, surface soil texture class, and current and historical vegetation type and land management information to simulate plant growth and senescence, decomposition of dead plant material and soil organic matter, soil water content and temperature, and other ecosystem variables. CENTURY has been parameterized to simulate continuous grasslands and croplands converted to grasslands but not other land uses converted to grasslands. Consequently, IPCC (2006) methodology was used to estimate CO_2 fluxes for land converted from non-agricultural uses to grazed land. Also, CENTURY has not been well tested with organic soils, so IPCC (2006) methodology was also used for grazed organic soils.

Both CENTURY and IPCC (2006) methodologies rely on land use classifications and land use histories. The National Resources Inventory (NRI, USDA 2000b) was used to identify grassland remaining grassland and land converted to grassland. Grassland includes pasture and rangeland where the primary land use is livestock grazing. The NRI is a statistically based sample of all non-Federal land and includes ~400,000 points in agricultural land. Data has been reported every 5 years starting in 1982 and 1997 is the most recent year that has been reported. According to NRI data, ~32 million ha of grassland (out of a total ~228 million ha reported in 1997) were converted to grassland between 1993 and 1997. An example of land converted to grassland is land that was cropped historically but then placed in the Conservation Reserve Program. Carbon dioxide fluxes for grazed lands were calculated using estimates of changes in soil organic carbon stocks and molecular stoichiometry.

Mineral soil carbon stocks and stock changes for NRI points classified as grasslands remaining grasslands and cropland converted to grassland were estimated using the CENTURY model. In addition to accounting for weather and soil texture, these simulations also included estimates of managed manure additions to grasslands. Waste from grazing animals deposited directly onto grasslands is calculated by the model based on grazing intensity and forage availability. CENTURY estimates carbon stock changes by accounting for carbon inputs from plant material and manure and carbon outputs from grazing and decomposition. For details on sources of the input data required to run CENTURY and how the simulations were conducted see Chapter 3 of this report and Chapter 7 and Annex 3.13 of the U.S. GHG Inventory (EPA 2007).

Mineral soil carbon stocks and stock changes for NRI points classified as land other than cropland converted to grassland and all grasslands growing on organic soils were estimated using IPCC (1997) methodology. U.S.-specific stock change factors based on field data were developed for land converted to grassland and for drained histosols used for grazing. As with grazed land N_2O emissions, CO_2 fluxes were partitioned among different animal types by assuming that fluxes are linearly proportional to waste nitrogen production.

2.6.5 Uncertainty in Carbon Dioxide Fluxes for Grazed Lands

Uncertainty for the estimates of CO_2 fluxes from mineral soil grassland remaining grassland and cropland converted to grassland provided by CENTURY model simulations used a Monte Carlo approach, which addresses uncertainties in model inputs and uncertainties from scaling NRI points to cover all grasslands remaining grassland in the U.S. Uncertainty for estimates from other land uses converted to grassland and all organic soil grasslands provided by IPCC (1997) methodology used a Monte Carlo approach that addressed uncertainties in carbon stock change factors and in land use data. Uncertainties were combined using simple error propagation, the results yielded an uncertainty of 13 to 18 around the estimate of 16 Tg CO_2 eq. in 2005 for land remaining grazed land and (18) to (14) around the estimate of (16) Tg CO_2 eq. for land converted to grazed land in 2005 (Table 2-1).

2.7 Mitigating Greenhouse Gas Emissions from Livestock

2.7.1 Enteric Fermentation

Emissions of CH_4 from enteric fermentation in ruminant and non-ruminant animals are dependent on the animal's digestive system and the amount and type of feed consumed. On average, beef and dairy cattle convert 6% of gross energy intake from feed into CH_4 through enteric fermentation, constituting a loss of energy from the perspective of the animal (Johnson & Johnson 1995). Research on animal nutrition has focused on reducing this energy loss, which consequently reduces CH_4 emissions and increases nutritional efficiency. Through such research, a number of potential strategies have been identified to reduce CH_4 emissions from enteric fermentation, including (Mosier et al. 1998b):

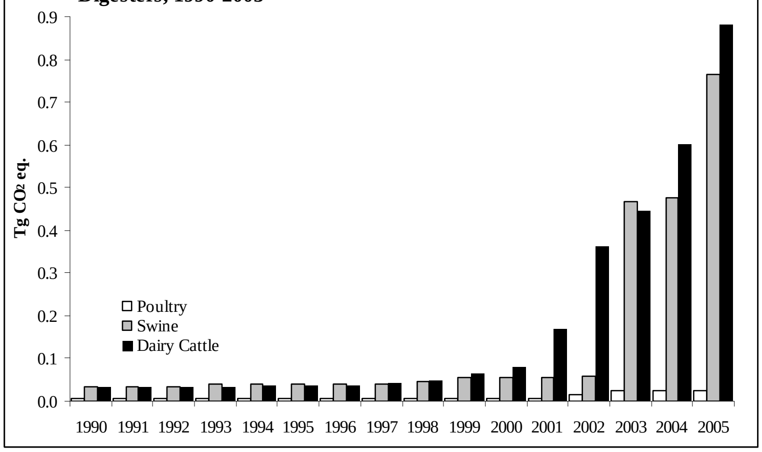
- Increasing the digestibility of forages and feeds;
- Providing feed additives which may tie up hydrogen in the rumen;
- Inhibiting the formation of CH_4 by rumen bacteria;
- Increasing acetic acid in the rumen;
- Improving production efficiency; and
- Modifying bacteria in the rumen.

Currently, government research programs indirectly address mitigation of CH_4 emissions through improved livestock production. Ongoing research development and deployment efforts related to mitigating CH_4 emissions include:

- Decreasing feed digestion time by improving grazing management to increase the digestibility of forages, increasing the digestibility of feed grains, and increasing the feeding of concentrated supplements;
- Adding edible oils in feed to sequester hydrogen making it unavailable for methanogens;
- Using feed additives, ionophores, which inhibit the formation of CH_4 by rumen bacteria;
- Improving livestock production efficiency by feed additives such as hormones to increase milk production and growth regulators for beef production or by improved diet or genetics;
- Enhancing rumen microbes to produce usable products rather than CH_4.

Figure 2-4

Estimated Reductions in Methane Emissions from Anaerobic Digesters, 1990-2005



2.7.2 Livestock Waste

Livestock and poultry waste from production facilities has the potential to produce significant quantities of CH_4 and N_2O, depending on the waste management practices used. In the United States, livestock and poultry manure is managed in myriad ways, suggesting there are multiple options for reducing CH_4 and N_2O emissions. When manure is stored or treated in systems that promote anaerobic conditions, such as lagoons and tanks, the decomposition of the biodegradable fraction of the waste tends to produce CH_4. When manure is handled as a solid, such as in stacks or deposits on pastures, the biodegradable fraction tends to decompose aerobically and produce little or no CH_4, although it does produce N_2O.

A relatively large portion of CH_4 is emitted from livestock and poultry waste in anaerobic lagoons. Current, commercially available technologies that have been the most successful in reducing CH_4 emissions from manure management are anaerobic digestion systems. Unlike conventional lagoons, digestion technologies keep waste treatment and storage functions separate and allow for gas recovery and combustion, pathogen and organic stabilization, odor and other air quality pollution control, and flexible approaches to nutrient management.

The EPA tracks installation and usage of anaerobic digesters under voluntary programs such as AgStar (http://www.epa.gov/agstar/), and uses this data to estimate how much anaerobic digesters have reduced overall CH_4 emissions from livestock waste over the last 11 years.
Figure 2-4 shows an increasing trend in emissions reductions annually from the use of anaerobic digesters, reflecting increasing numbers of digester systems being installed each year.

Other emission reduction processes can include separation, aeration, or shifts to solid handling or storage management systems. These strategies, however, could be limited by other farm or environmental constraints and costs.

2.7.3 Grazed Lands

Nitrous oxide is by far the largest source of emissions from grazed lands so it also provides the largest mitigation potential (Table 2-6). However, because grazed lands are not highly managed, particularly the large expanses of rangeland in the western U.S., mitigation options are limited. One strategy that may be feasible for more intensely managed pastures in the eastern U.S. is nitrification inhibitors. Although synthetic nitrogen fertilizer inputs are low, grazing lands usually have large nitrogen inputs form biological nitrogen fixation because they are seeded with legumes. This mitigation potential has not been quantified but it will be in future DAYCENT model simulations. Although grazed mineral soils are a net sink of $CO_{2,}$ grazed organic soils are a net source. If half of the grazed organic soils were converted back to wetlands, CO_2 emissions from this source could be reduced from approximately 4.6 to 2.3 Tg CO_2 eq. per year. However, the saturated soil conditions characteristic of wetlands would cause an increase in soil CH_4 emissions and it is unclear to what extent this would nullify reduced CO_2 emissions.

Grazed lands are currently roughly GHG neutral for CO_2 emissions (Table 2-6). However, grazed lands in the U.S. have the potential to store over 100 Tg CO_2 per year (Follett et al. 2001). The largest potential is decreasing soil erosion and restoring eroded and degraded soils so that they become net carbon sinks. Other management practices which enhance carbon storage include nutrient/manure additions, legume seeding, and improved grazing management. However, the benefits of increased carbon storage must be compared with the costs of increased N_2O emissions associated with nutrient/manure additions and legume seeding.