6. Agriculture

Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes. This chapter provides an assessment of non-carbon dioxide emissions from the following source categories: enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues (see Figure 6-1). Carbon dioxide (CO_2) emissions and removals from agriculture-related land-use activities, such as conversion of grassland to cultivated land, are discussed in the Land-Use Change and Forestry chapter. Carbon dioxide emissions from on-farm energy use are accounted in the Energy chapter.

Figure 6-1: 2002 Agriculture Chapter Greenhouse Gas Sources

In 2002, agricultural activities were responsible for emissions of 467.1 Tg CO_2 Eq., or 6.7 percent of total U.S. greenhouse gas emissions. Methane (CH_4) and nitrous oxide (N_2O) were the primary greenhouse gases emitted by agricultural activities. Methane emissions from enteric fermentation and manure management represent about 19 percent and 7 percent of total CH_4 emissions from anthropogenic activities, respectively. Of all domestic animal types, beef and dairy cattle were by far the largest emitters of CH_4. Rice cultivation and agricultural crop residue burning were minor sources of CH_4. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of U.S. N_2O emissions, accounting for 69 percent. Manure management and field burning of agricultural residues were also small sources of N_2O emissions.

Table 6-1 and Table 6-2 present emission estimates for the Agriculture chapter. Between 1990 and 2002, CH_4 emissions from agricultural activities increased by 3.0 percent while N_2O emissions increased by 9.4 percent. In addition to CH_4 and N_2O, field burning of agricultural residues was also a minor source of the ambient air pollutants carbon monoxide (CO) and nitrogen oxides (NO_x).

Table 6-1: Emissions from Agriculture (Tg CO_2 Eq.)

Gas/Source	1990	1996	1997	1998	1999	2000	2001	2002
CH_4	**156.7**	**162.8**	**162.9**	**164.1**	**164.3**	**161.9**	**161.5**	**161.4**
Enteric Fermentation	117.9	120.5	118.3	116.7	116.6	115.7	114.3	114.4
Manure Management	31.0	34.6	36.3	38.8	38.6	38.0	38.8	39.5
Rice Cultivation	7.1	7.0	7.5	7.9	8.3	7.5	7.6	6.8
Field Burning of Agricultural Residues	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7
N_2O	**279.3**	**305.5**	**310.9**	**312.0**	**309.9**	**308.0**	**307.0**	**305.6**
Agricultural Soil Management	262.8	288.1	293.2	294.2	292.1	289.7	288.6	287.3
Manure Management	16.2	17.0	17.3	17.3	17.4	17.7	18.0	17.8
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.5	0.4	0.5	0.5	0.4
Total	**436.0**	**468.3**	**473.8**	**476.2**	**474.2**	**469.9**	**468.6**	**467.1**

Note: Totals may not sum due to independent rounding.

Table 6-2: Emissions from Agriculture (Gg)

Gas/Source	1990	1996	1997	1998	1999	2000	2001	2002
CH_4	**7,462**	**7,752**	**7,756**	**7,816**	**7,823**	**7,711**	**7,693**	**7,688**
Enteric Fermentation	5,612	5,737	5,635	5,557	5,551	5,509	5,443	5,450
Manure Management	1,478	1,648	1,728	1,846	1,840	1,807	1,849	1,879
Rice Cultivation	339	332	356	376	395	357	364	325
Field Burning of Agricultural Residues	33	36	37	38	37	38	37	34
N_2O	**901**	**985**	**1,003**	**1,007**	**1,000**	**993**	**990**	**986**
Agricultural Soil Management	848	929	946	949	942	935	931	927

Manure Management	52	55	56	56	56	57	58	58
Field Burning of Agricultural Residues	1	1	1	1	1	1	1	1

Note: Totals may not sum due to independent rounding.

6.1. Enteric Fermentation (IPCC Source Category 4A)

Methane is produced as part of normal digestive processes in animals. During digestion, microbes resident in an animal's digestive system ferment food consumed by the animal. This microbial fermentation process, referred to as enteric fermentation, produces CH_4 as a by-product, which can be exhaled or eructated by the animal. The amount of CH_4 produced and excreted by an individual animal depends primarily upon the animal's digestive system, and the amount and type of feed it consumes.

Among domesticated animal types, ruminant animals (e.g., cattle, buffalo, sheep, goats, and camels) are the major emitters of CH_4 because of their unique digestive system. Ruminants possess a rumen, or large "fore-stomach," in which microbial fermentation breaks down the feed they consume into products that can be metabolized. The microbial fermentation that occurs in the rumen enables them to digest coarse plant material that non-ruminant animals cannot. Ruminant animals, consequently, have the highest CH_4 emissions among all animal types.

Non-ruminant domesticated animals (e.g., swine, horses, and mules) also produce CH_4 emissions through enteric fermentation, although this microbial fermentation occurs in the large intestine. These non-ruminants emit significantly less CH_4 on a per-animal basis than ruminants because the capacity of the large intestine to produce CH_4 is lower.

In addition to the type of digestive system, an animal's feed quality and feed intake also affects CH_4 emissions. In general, a lower feed quality and a higher feed intake leads to higher CH_4 emissions. Feed intake is positively related to animal size, growth rate, and production (e.g., milk production, wool growth, pregnancy, or work). Therefore, feed intake varies among animal types as well as among different management practices for individual animal types.

Methane emission estimates from enteric fermentation are provided in Table 6-3 and Table 6-4. Total livestock CH_4 emissions in 2002 were 114.4 Tg CO_2 Eq. (5,450 Gg), increasing very slightly since 2001 due to minor increases in some animal populations and dairy cow milk production. Beef cattle remain the largest contributor of CH_4 emissions from enteric fermentation, accounting for 72 percent in 2002. Emissions from dairy cattle in 2002 accounted for 24 percent, and the remaining emissions were from horses, sheep, swine, and goats.

From 1990 to 2002, emissions from enteric fermentation have decreased by 3 percent. Generally, emissions have been decreasing since 1995, mainly due to decreasing populations of both beef and dairy cattle and improved feed quality for feedlot cattle. During this timeframe, populations of sheep and goats have also decreased, while horse populations increased and the populations of swine fluctuated.

Table 6-3: CH_4 Emissions from Enteric Fermentation (Tg CO_2 Eq.)

Livestock Type	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Beef Cattle	83.2	88.8	86.6	85.0	84.7	83.5	82.1	82.1
Dairy Cattle	28.9	26.3	26.4	26.3	26.6	27.0	26.9	27.1
Horses	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0
Sheep	1.9	1.4	1.3	1.3	1.2	1.2	1.2	1.1
Swine	1.7	1.8	1.8	2.0	1.9	1.9	1.9	1.9
Goats	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**117.9**	**120.5**	**118.3**	**116.7**	**116.6**	**115.7**	**114.3**	**114.4**

Note: Totals may not sum due to independent rounding.

Table 6-4: CH_4 Emissions from Enteric Fermentation (Gg)

Livestock Type	1990		1996	1997	1998	1999	2000	2001	2002
Beef Cattle	3,961		4,227	4,124	4,046	4,035	3,976	3,911	3,912
Dairy Cattle	1,375		1,254	1,255	1,251	1,266	1,284	1,283	1,289
Horses	91		93	93	94	93	94	95	95
Sheep	91		68	64	63	58	56	56	53
Swine	81		84	88	93	90	88	88	90
Goats	13		10	10	10	10	10	10	10
Total	**5,612**		**5,737**	**5,635**	**5,557**	**5,551**	**5,509**	**5,443**	**5,450**

Note: Totals may not sum due to independent rounding.

Methodology

Livestock emission estimates fall into two categories: cattle and other domesticated animals. Cattle, due to their large population, large size, and particular digestive characteristics, account for the majority of CH_4 emissions from livestock in the United States. Cattle production systems in the United States are better characterized in comparison with other livestock production systems. A more detailed methodology (i.e., IPCC Tier 2) was therefore applied to estimating emissions for cattle. Emission estimates for other domesticated animals were handled using a less detailed approach (i.e., IPCC Tier 1).

While the large diversity of animal management practices cannot be precisely characterized and evaluated, significant scientific literature exists that describes the quantity of CH_4 produced by individual ruminant animals, particularly cattle. A detailed model that incorporates this information and other analyses of livestock population, feeding practices and production characteristics was used to estimate emissions from cattle populations.

National cattle population statistics were disaggregated into the following cattle sub-populations:

Dairy Cattle
- Calves
- Heifer Replacements
- Cows

Beef Cattle
- Calves
- Heifer Replacements
- Heifer and Steer Stockers
- Animals in Feedlots
- Cows
- Bulls

Calf birth estimates, end of year population statistics, detailed feedlot placement information, and slaughter weight data were used in the model to initiate and track cohorts of individual animal types having distinct emissions profiles. The key variables tracked for each of the cattle population categories are described in Annex 3.9. These variables include performance factors such as pregnancy and lactation as well as average weights and weight gain. Annual cattle population data were obtained from the U.S. Department of Agriculture's National Agricultural Statistics Service (1995a,b, 1999a,c,d,f, 2000a,c,d,f, 2001a,c,d,f, 2002a,c,d,f, 2003a,c,d,f).

Diet characteristics were estimated by region for U.S. dairy, beef, and feedlot cattle. These estimates were used to calculate Digestible Energy (DE) values and CH_4 conversion rates (Y_m) for each population category. The IPCC recommends Y_m values of 3.5 to 4.5 percent for feedlot cattle and 5.5 to 6.5 percent for all other cattle. Given the availability of detailed diet information for different regions and animal types in the United States, DE and Y_m values unique to the United States were developed, rather than using the recommended IPCC values. The diet characterizations and estimation of DE and Y_m values were based on contact with state agricultural extension specialists, a review of published forage quality studies, expert opinion, and modeling of animal physiology. The diet characteristics for dairy cattle were from Donovan (1999), while beef cattle were derived from NRC (2000). DE and Y_m for dairy cows were calculated from diet characteristics using a model simulating ruminant digestion in growing and/or lactating cattle (Donovan and Baldwin 1999). For feedlot animals, DE and Y_m values recommended by Johnson (1999) were used. Values from EPA (1993) were used for dairy replacement heifers. For grazing beef cattle, DE values were based on diet information in NRC (2000) and Y_m values were based on Johnson (2002). Weight data were estimated from Feedstuffs (1998), Western Dairyman (1998), and expert opinion. See Annex 3.9 for more details on the method used to characterize cattle diets in the United States.

In order to estimate CH_4 emissions from cattle, the population was divided into region, age, sub-type (e.g., calves, heifer replacements, cows, etc.), and production (i.e., pregnant, lactating, etc.) groupings to more fully capture differences in CH_4 emissions from these animal types. Cattle diet characteristics were used to develop regional emission factors for each sub-category. Tier 2 equations from IPCC (2000) were used to produce CH_4 emission factors for the following cattle types: dairy cows, beef cows, dairy replacements, beef replacements, steer stockers, heifer stockers, steer feedlot animals, and heifer feedlot animals. To estimate emissions from cattle, population data were multiplied by the emission factor for each cattle type. More details are provided in Annex 3.9.

Emission estimates for other animal types were based on average emission factors representative of entire populations of each animal type. Methane emissions from these animals accounted for a minor portion of total CH_4 emissions from livestock in the United States from 1990 through 2002. Also, the variability in emission factors for each of these other animal types (e.g. variability by age, production system, and feeding practice within each animal type) is less than that for cattle. Annual livestock population data for these other livestock types, except horses, as well as feedlot placement information were obtained from the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA 1994a-b, 1998, 1999b,e, 2000b,e, 2001b,e, 2002b,e, 2003b,e). Horse data were obtained from the Food and Agriculture Organization (FAO) statistical database (FAO 2002), because USDA does not estimate U.S. horse populations. Methane emissions from sheep, goats, swine, and horses were estimated by using emission factors utilized in Crutzen et al. (1986, cited in IPCC/UNEP/OECD/IEA 1997). These emission factors are representative of typical animal sizes, feed intakes, and feed characteristics in developed countries. The methodology is the same as that recommended by IPCC (IPCC/UNEP/OECD/IEA 1997, IPCC 2000).

See Annex 3.9 for more detailed information on the methodology and data used to calculate CH_4 emissions from enteric fermentation.

Uncertainty

Quantitative uncertainty of this source category was performed through the IPCC-recommended Tier 2 uncertainty estimation methodology, Monte Carlo Stochastic Simulation technique. These estimates were developed for the 2001 inventory estimates. No significant changes occurred in the method of data collection, data estimation methodology, or other factors that influence the uncertainty ranges around the 2002 activity data and emission factor input variables. Consequently, these uncertainty estimates were directly applied to the 2002 emission estimates.

A total of 185 primary input variables (178 for cattle and 8 for non-cattle) were identified as key input variables for uncertainty analysis. The normal distribution was assumed for almost all activity- and emission factor-related input variables. The triangular distribution was assigned for three input variables (specifically, for cow-birth ratios for the current and the past two years). For some key input variables, the uncertainty ranges around their estimates (used for inventory estimation) were collected from published documents and other public sources. In addition, both endogenous and exogenous correlations between selected primary input variables were modeled. The exogenous correlation coefficients between the probability distributions of selected activity-related variables were developed as educated estimates.

The uncertainty ranges associated with the activity-related input variables were plus or minus 10 percent or lower. However, for many emission factor-related input variables, the lower- and/or the upper-bound uncertainty estimates were over 20 percent. The preliminary results of the quantitative uncertainty analysis (Table 6-5) indicate that, on average, in 19 out of 20 times (i.e., there is a 95 percent probability), the total greenhouse gas emissions estimate from this source is within the range of approximately 101.9 to 135.0 Tg CO_2 Eq. (or that the actual CH_4 emissions are likely to fall within the range of approximately 11 percent below and 18 percent above the emission estimate of 144.4 Tg CO_2 Eq.). Among the individual sub-source categories, beef cattle accounts for the largest amount of methane emissions as well as the largest degree of uncertainty in the inventory emission estimates. Consequently, the cattle sub-source categories together contribute to the largest degree of uncertainty in the inventory estimates of methane emissions from livestock enteric fermentation. Among non-cattle, horses account for the largest degree of uncertainty in the inventory emission estimates.

Table 6-5: Quantitative Uncertainty Estimates for CH_4 Emissions from Enteric Fermentation (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2002 Emission Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emission Estimate[a]**			
			(Tg CO_2 Eq.)		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Enteric Fermentation	CH_4	114.4	101.9	135.0	-11%	+18%

[a] Range of emissions estimates predicted by Monte Carlo Stochastic Simulation for a 95% confidence interval

QA/QC and Verification

In order to ensure the quality of the emission estimates from enteric fermentation, the IPCC Tier 1 and Tier 2 Quality Assurance/Quality Control (QA/QC) procedures were implemented that were consistent with the U.S. QA/QC plan. Tier 2 QA procedures included independent peer review of the emission estimates and input parameters by national agricultural experts. Particular emphasis was placed this year on review of the feed characteristic inputs and the output of volatile solids excretion from the cattle model. Energy consumption and waste output (as represented by the volatile solids production) were verified against published nutritional balances and the waste excretion rates. During the next inventory cycle, an improvement workshop is planned which will focus on specific aspects of uncertainty in the enteric model and bring together national experts for discussion on ways to improve aspects of the modeling.

Recalculations Discussion

While there were no changes in the methodologies used for estimating CH_4 emissions from enteric fermentation, emissions were revised slightly due to changes in historical data. The USDA has revised population estimates for some cattle statistics, such as population, livestock placements, and slaughter statistics for 2000 and 2001. Emission estimates changed for these years for both beef and dairy cattle because inputs were revised to reflect updated USDA estimates. In 2000, both beef and dairy cattle emissions changed less than one Gg. In 2001, beef cattle CH_4 emissions decreased 25 Gg while dairy cattle emissions increased one Gg. For other livestock types, there was a slight increase in swine population for 2001, which resulted in an increase in CH_4 emissions of less than one Gg in that year.

Planned Improvements

In addition to the peer review workshop planned for the next year's inventory, revisions to the cattle enteric model are currently underway to produce nitrogen excretion rates for the different cattle groups modeled. Similar to the volatile solids excretion rates, this would allow the nitrogen output data to be used directly as input to the manure management inventory, which would improve consistency between the two categories. Additional review and possible updates to the feed characteristics will be considered as more peer review feedback is obtained on these values. The objective of these improvements will be to produce more representative feed regimes for different regions of the country, and for the different sub-groups of cattle.

6.2. Manure Management (IPCC Source Category 4B)

The management of livestock manure can produce anthropogenic CH_4 and N_2O emissions. Methane is produced by the anaerobic decomposition of manure. Nitrous oxide is produced as part of the nitrogen cycle through the nitrification and denitrification of the organic nitrogen in livestock manure and urine.

When livestock or poultry manure are stored or treated in systems that promote anaerobic conditions (e.g., as a liquid/slurry in lagoons, ponds, tanks, or pits), the decomposition of materials in the manure tends to produce CH_4. When manure is handled as a solid (e.g., in stacks or pits) or deposited on pasture, range, or paddock lands, it tends to decompose aerobically and produce little or no CH_4. A number of other factors related to how the manure is handled also affect the amount of CH_4 produced. Ambient temperature, moisture, and manure storage or residency time affect the amount of CH_4 produced because they influence the growth of the bacteria responsible for CH_4 formation. For example, CH_4 production generally increases with rising temperature and residency time. Also, for non-liquid based manure systems, moist conditions (which are a function of rainfall and humidity) favor CH_4 production. Although the majority of manure is handled as a solid, producing little CH_4, the general trend in manure management, particularly for large dairy and swine producers, is one of increasing use of liquid systems. In addition, use of daily spread systems at smaller dairies is decreasing, due to new regulations limiting the application of manure nutrients, which has resulted in an increase of manure managed and stored on site at these smaller dairies.

The composition of the manure also affects the amount of CH_4 produced. Manure composition varies by animal type, including the animal's digestive system and diet. In general, the greater the energy content of the feed, the greater the potential for CH_4 emissions. For example, feedlot cattle fed a high-energy grain diet generate manure with a high CH_4-producing capacity. Range cattle fed a low energy diet of forage material produce manure with about 50 percent of the CH_4-producing potential of feedlot cattle manure. However, some higher energy feeds also are more digestible than lower quality forages, which can result in less overall waste excreted from the animal. Ultimately, a combination of diet types and the growth rate of the animals will affect the quantity and characteristics of the manure produced.

A very small portion of the total nitrogen excreted is expected to convert to N_2O in the waste management system. The production of N_2O from livestock manure depends on the composition of the manure and urine, the type of bacteria involved in the process, and the amount of oxygen and liquid in the manure system. For N_2O emissions to occur, the manure must first be handled aerobically where ammonia or organic nitrogen is converted to nitrates and nitrites (nitrification), and then handled anaerobically where the nitrates and nitrites are reduced to nitrogen gas (N_2), with intermediate production of N_2O and nitric oxide (NO) (denitrification) (Groffman, et al. 2000). These emissions are most likely to occur in dry manure handling systems that have aerobic conditions, but that also contain pockets of anaerobic conditions due to saturation. For example, manure at cattle drylots is deposited on soil, oxidized to nitrite and nitrate, and has the potential to encounter saturated conditions following rain events.

Certain N_2O emissions are accounted for and discussed under Agricultural Soil Management. These are emissions from livestock manure and urine deposited on pasture, range, or paddock lands, as well as emissions from manure and urine that is spread onto fields either directly as "daily spread" or after it is removed from manure management systems (e.g., lagoon, pit, etc.).

Table 6-6 and Table 6-7 provide estimates of CH_4 and N_2O emissions from manure management by animal category. Estimates for CH_4 emissions in 2002 were 39.5 Tg CO_2 Eq. (1,879 Gg), 27 percent higher than in 1990. The majority of this increase was from swine and dairy cow manure, where emissions increased 35 percent, and is attributed to shifts by the swine and dairy industries towards larger facilities. Larger swine and dairy farms tend to use liquid systems to manage (flush or scrape) and store manure. Thus the shift toward larger facilities is translated into an increasing use of liquid manure management systems, which have higher potential methane emissions than dry systems. This shift was accounted for by incorporating state-specific weighted CH_4 conversion factor (MCF) values in combination with the 1992 and 1997 farm-size distribution data reported in the *Census of Agriculture* (USDA 1999e). From 2001 to 2002, there was a 1.6 percent increase in CH_4 emissions, due to minor shifts in the animal populations.

As stated previously, smaller dairies are moving away from daily spread systems. Therefore, more manure is managed and stored on site, contributing to additional CH_4 emissions over the time series. A description of the emission estimation methodology is provided in Annex 3.10.

Total N_2O emissions from manure management systems in 2002 were estimated to be 17.8 Tg CO_2 Eq. (58 Gg). The 10 percent increase in N_2O emissions from 1990 to 2002 can be partially attributed to a shift in the poultry industry away from the use of liquid manure management systems, in favor of litter-based systems and high-rise houses. In addition, there was an overall increase in the population of poultry and swine from 1990 to 2002, although swine populations declined slightly in 1993, 1995, 1996, 1999, and 2000 from previous years. Nitrous oxide emissions showed a 0.7 percent decrease from 2001 to 2002, due to minor shifts in animal population.

The population of beef cattle in feedlots increased over the period of 1990 to 2002, resulting in increased N_2O emissions from this sub-category of cattle. Although dairy cow populations decreased overall for the period 1990 to 2002, the population of dairies managing and storing manure on site—as opposed to using pasture, range, or paddock or daily spread systems—increased. Over the same period, dairies also experienced a shift to more liquid manure management systems at large operations, which result in lower N_2O emissions then dry systems. The net result is a slight decrease in dairy cattle N_2O emissions over the period 1990 to 2002. As stated previously, N_2O emissions from livestock manure deposited on pasture, range, or paddock land and manure immediately applied to land in daily spread systems are accounted for under Agricultural Soil Management.

Table 6-6: CH_4 and N_2O Emissions from Manure Management (Tg CO_2 Eq.)

Gas/Animal Type	1990		1996	1997	1998	1999	2000	2001	2002
CH_4	**31.0**		**34.6**	**36.3**	**38.8**	**38.6**	**38.0**	**38.8**	**39.5**
Dairy Cattle	11.4		12.8	13.4	13.9	14.7	14.6	15.1	15.4
Beef Cattle	3.1		3.2	3.1	3.1	3.1	3.0	3.0	3.0
Swine	13.1		15.3	16.4	18.4	17.6	17.1	17.4	17.7
Sheep	0.1		+	+	+	+	+	+	+
Goats	+		+	+	+	+	+	+	+
Poultry	2.7		2.6	2.7	2.7	2.6	2.6	2.7	2.6
Horses	0.6		0.6	0.6	0.6	0.6	0.6	0.6	0.6
N_2O	**16.2**		**17.0**	**17.3**	**17.3**	**17.4**	**17.7**	**18.0**	**17.8**
Dairy Cattle	4.3		4.0	4.0	3.9	4.0	4.0	3.9	3.9
Beef Cattle	4.9		5.1	5.4	5.5	5.5	5.9	6.1	5.9
Swine	0.4		0.4	0.4	0.4	0.4	0.4	0.4	0.4
Sheep	+		+	+	+	+	+	+	+
Goats	+		+	+	+	+	+	+	+
Poultry	6.3		7.2	7.2	7.2	7.2	7.2	7.3	7.4
Horses	0.2		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**47.2**		**51.6**	**53.6**	**56.1**	**56.0**	**55.7**	**56.8**	**57.3**

+ Does not exceed 0.05 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Table 6-7: CH_4 and N_2O Emissions from Manure Management (Gg)

Gas/Animal Type	1990		1996	1997	1998	1999	2000	2001	2002
CH_4	**1,478**		**1,648**	**1,728**	**1,846**	**1,840**	**1,807**	**1,849**	**1,879**
Dairy Cattle	545		611	639	661	700	694	719	735
Beef Cattle	149		152	149	146	146	145	144	143
Swine	623		729	781	876	839	813	826	844
Sheep	3		2	2	2	2	2	2	2
Goats	1		1	1	1	1	1	1	1
Poultry	128		124	127	130	123	124	127	124
Horses	29		29	29	30	29	30	30	30
N_2O	**52**		**55**	**56**	**56**	**56**	**57**	**58**	**58**
Dairy Cattle	14		13	13	13	13	13	13	13
Beef Cattle	16		16	17	18	18	19	20	19
Swine	1		1	1	1	1	1	1	1
Sheep	+		+	+	+	+	+	+	+
Goats	+		+	+	+	+	+	+	+
Poultry	20		23	23	23	23	23	23	24

Horses	1		1	1	1	1	1	1	1

+ Does not exceed 0.5 Gg
Note: Totals may not sum due to independent rounding.

Methodology

The methodologies presented in *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000) form the basis of the CH_4 and N_2O emissions estimates for each animal type. The calculation of emissions requires the following information:

- Animal population data (by animal type and state)
- Amount of nitrogen produced (amount per 1000 pound animal times average weight times number of head)
- Amount of volatile solids produced (amount per 1000 pound animal times average weight times number of head)
- Methane producing potential of the volatile solids (by animal type)
- Extent to which the CH4 producing potential is realized for each type of manure management system (by state and manure management system)
- Portion of manure managed in each manure management system (by state and animal type)
- Portion of manure deposited on pasture, range, or paddock or used in daily spread systems

Following is a summary of the methodologies used to estimate CH_4 and N_2O emissions from manure management for this inventory. See Annex 3.10 for more detailed information on the methodology and data used to calculate CH_4 and N_2O emissions from manure management.

Both CH_4 and N_2O emissions were estimated by first determining activity data, including animal population, waste characteristics, and manure management system usage. For swine and dairy cattle, manure management system usage was determined for different farm size categories using data from USDA (USDA 1996b, 1998d, 2000h) and EPA (ERG 2000a, EPA 2001a, 2001b). For beef cattle and poultry, manure management system usage data was not tied to farm size (ERG 2000a, USDA 2000i). For other animal types, manure management system usage was based on previous estimates (EPA 1992).

Next, MCFs and N_2O emission factors were determined for all manure management systems. MCFs for dry systems and N_2O emission factors for all systems were set equal to 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 as predicted in the van't Hoff-Arrhenius equation (see Annex 3.10 for detailed information on MCF derivations for liquid systems). The MCF calculations model the average monthly ambient temperature, a minimum system temperature, the carryover of volatile solids in the system from month to month due to long storage times exhibited by anaerobic lagoon systems, and a factor to account for management and design practices that result in the loss of volatile solids from lagoon systems.

For each animal group the base emission factors were then weighted to incorporate the distribution of management systems used within each state and thereby to create an overall state-specific weighted emission factor. To calculate this weighted factor, the percent of manure for each animal group managed in a particular system in a state was multiplied by the emission factor for that system and state, and then summed for all manure management systems in the state.

Methane emissions were estimated using the volatile solids (VS) production for all livestock. For poultry and swine animal groups, for example, VS production was calculated using a national average VS production rate from the *Agricultural Waste Management Field Handbook* (USDA 1996a), which was then multiplied by the average weight of the animal and the state-specific animal population. For most cattle groups, regional animal-specific VS production rates that are related to the diet of the animal for each year of the inventory were used (Peterson et al., 2003). The resulting VS for each animal group was then multiplied by the maximum CH_4 producing capacity of the waste (B_o) and the state-specific CH_4 conversion factors.

Nitrous oxide emissions were estimated by determining total Kjeldahl nitrogen (TKN)[1] production for all livestock wastes using livestock population data and nitrogen excretion rates based on measurements of excreted manure. For each animal group, TKN production was calculated using a national average nitrogen excretion rate from the *Agricultural Waste Management Field Handbook* (USDA 1996a), which was then multiplied by the average weight of the animal and the state-specific animal population. State-specific weighted N_2O emission factors specific to the type of manure management system were then applied to total nitrogen production to estimate N_2O emissions.

The data used to calculate the inventory estimates were based on a variety of sources. Animal population data for all livestock types, except horses and goats, were obtained from the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA 1994a-b, 1995a-b, 1998a-b, 1999a-c, 2000a-g, 2001a-f, 2002a-f, 2003a-f). Horse population data were obtained from the FAOSTAT database (FAO 2003), because USDA does not estimate U.S. horse populations. Goat population data 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 (NRCS) personnel (Lange 2000). Dairy cow and swine population data by farm size for each state, used for the weighted MCF and emission factor calculations, were obtained from the *Census of Agriculture*, which is conducted every five years (USDA 1999e).

Manure management system usage data for dairy and swine operations were obtained from USDA's Centers for Epidemiology and Animal Health (USDA 1996b, 1998d, 2000h) for small operations and from preliminary estimates for EPA's Office of Water regulatory effort for large operations (ERG 2000a; EPA 2001a, 2001b). Data for layers were obtained from a voluntary United Egg Producers' survey (UEP 1999), previous EPA estimates (EPA 1992), and USDA's Animal Plant Health Inspection Service (USDA 2000i). Data for beef feedlots were also obtained from EPA's Office of Water (ERG 2000a; EPA 2001a, 2001b). Manure management system usage data for other livestock were taken from previous estimates (EPA 1992). 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, and data provided by those personnel (Poe et al. 1999). These organizations include state NRCS offices, state extension services, state universities, USDA National Agriculture Statistics Service (NASS), and other experts (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, and Wright 2000). Additional information regarding the percent of beef steer and heifers on feedlots was obtained from contacts with the national USDA office (Milton 2000).

Methane conversion factors for liquid systems were calculated based on average ambient temperatures of the counties in which animal populations were located. The average county and state temperature data were obtained from the National Climate Data Center (NOAA 2001, 2002, 2003), and the county population data were calculated from state-level population data from NASS and county-state distribution data from the 1992 and 1997 Census data (USDA 1999e). County population distribution data for 1990 and 1991 were assumed to be the same as 1992; county population distribution data for 1998 through 2002 were assumed to be the same as 1997; and county population distribution data for 1993 through 1996 were extrapolated based on 1992 and 1997 data.

The maximum CH_4 producing capacity of the volatile solids, or B_o, was determined based on data collected in a literature review (ERG 2000b). B_o data were collected for each animal type for which emissions were estimated.

Nitrogen excretion rate data from the USDA *Agricultural Waste Management Field Handbook* (USDA 1996a) were used for all livestock except sheep, goats, and horses. Data from the American Society of Agricultural Engineers (ASAE 1999) were used for these animal types. Volatile solids excretion rate data from the USDA *Agricultural Waste Management Field Handbook* (USDA 1996a) were used for swine, poultry, bulls, and calves not on feed. In addition, volatile solids production rates from Peterson et al. (2003) were used for dairy and beef cows, heifers, and steer for each year of the inventory. Nitrous oxide emission factors and MCFs for dry systems were taken from *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000).

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[1] Total Kjeldahl nitrogen is a measure of organically bound nitrogen and ammonia nitrogen.

Uncertainty

An analysis was conducted on the 2001 manure management inventory to determine the uncertainty associated with estimating nitrous oxide and methane emissions from livestock manure management. Because no substantial modifications were made to the inventory methodology since the development of these estimates, it is expected that this analysis is applicable to the uncertainty associated with the 2002 manure management inventory. The analysis used the Tier 2 uncertainty methodology as outlined in the IPCC Good Practice Guidance (IPCC, 2000).

Quantitative uncertainty of this source category was performed through the IPCC-recommended Tier 2 uncertainty estimation methodology, Monte Carlo Stochastic Simulation technique. The uncertainty analysis was developed on the methods used to estimate nitrous oxide and methane emissions from manure management systems. The series of equations used in the inventory were condensed into a single equation for each animal type and state. The equations for each animal group contained four to five variables around which the uncertainty analysis was performed for each state.

The preliminary results of the quantitative uncertainty analysis (see Table 6-8) indicate that, on average, in 19 out of 20 times (i.e., there is a 95 percent probability), the CH_4 greenhouse gas emissions estimate from this source is within the range of approximately 32.4 to 47.3 Tg CO_2 Eq. (or that the actual CH_4 emissions are likely to fall within the range of approximately 18 percent below and 20 percent above the emission estimate of 39.5 Tg CO_2 Eq.). For N_2O, the emissions estimate is within the range of approximately 15.0 to 22.1 Tg CO_2 Eq. (or that the actual N_2O emissions are likely to fall within the range of approximately 16 percent below and 24 percent above the emission estimate of 17.8 Tg CO_2 Eq.) (ERG, 2003).

Table 6-8: Quantitative Uncertainty Estimates for CH_4 and N_2O Emissions from Manure Management (Tg CO_2 Eq. and %)

Source	**Gas**	**2002 Emission Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emission Estimate[a] (Tg CO_2 Eq.)**		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Manure Management	CH_4	39.5	32.4	47.3	-18%	+20%
Manure Management	N_2O	17.8	15.0	22.1	-16%	+24%

[a]Range of emissions estimates predicted by Monte Carlo Stochastic Simulation for a 95% confidence interval

The primary factors contributing to the uncertainty in emission estimates are a lack of information on the usage of various manure management systems in each regional location and the exact CH_4 generating characteristics of each type of manure management system. Because of significant shifts in the swine and dairy sectors toward larger farms, it is believed that increasing amounts of manure are being managed in liquid manure management systems. The existing estimates reflect these shifts in the weighted MCFs based on the 1992 and 1997 farm-size data. 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 each manure management system type are based on relatively few laboratory and field measurements, and may not match the diversity of conditions under which manure is managed nationally.

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 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. In the United States, many livestock waste treatment systems classified as anaerobic lagoons are actually holding ponds that are substantially organically overloaded and therefore not producing CH_4 at the same rate as a properly designed lagoon. In addition, these systems may not be well operated, contributing to higher loading rates when sludge is allowed to enter the treatment portion of the lagoon or the lagoon volume is pumped too low to allow treatment to occur. Rather than setting the MCF for all anaerobic lagoon systems in the United States based on data available from optimized lagoon systems, an MCF methodology was developed that more closely matches observed system performance and accounts for the affect of temperature on system performance.

However, there is uncertainty related to this methodology. 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 is currently estimated based on data from anaerobic lagoons in temperate climates, and from only three systems. However, this methodology is intended to account for systems across a range of management practices. Future work in gathering measurement data from animal waste lagoon systems across the country will contribute to the verification and refinement of this methodology. It will also be evaluated whether lagoon temperatures differ substantially from ambient temperatures and whether the lower bound estimate of temperature established for lagoons and other liquid systems should be revised for use with this methodology.

The IPCC provides a suggested MCF for poultry waste management operations of 1.5 percent. Additional study is needed in this area to determine 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-denitrification occurs in animal waste management systems. Ammonia concentrations 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 on-going research, and warrants further study as more data become available.

Uncertainty also exists with the maximum CH_4 producing potential of volatile solids excreted by different animal groups (i.e., B_o). The B_o 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 B_o values for certain animals, including dairy and swine. The B_o 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, dairy heifer manure will not produce as much CH_4 as manure from a milking cow. However, the data available for B_o values are sparse, and do not necessarily reflect the rapid changes that have occurred in this industry with respect to feed regimens.

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. As part of its Tier 2 level independent peer review, national experts in manure management, excretion, and related issues attended a workshop in July, 2003 for the purpose of discussing and reviewing specific activity data used to develop the manure management estimates. Input was solicited from these experts on the following specific items:

- Volatile Solids Excretion Rates
- Nitrogen Excretion Rates
- Methane Producing Capacity (Bo)
- Temperature Dependence
- Retention Time
- Management and Design Practices
- Methane Conversion Factor
- Methane Production Methodology

Comments were received from the panel on these topics and suggestions for future investigation. These suggestions and comments are being considered for future improvements.

Recalculations Discussion

No changes have been incorporated into the methodology for the manure management emission estimates; however, changes were made to correct errors and updates in the population data from previous inventory submittals. Also, the typical animal mass for two animal groups was adjusted to reflect recent analyses, and the distribution of animals at sheep operations was adjusted to reflect a refined methodology. Each of these changes is described in detail below.

- Population. Two errors in the population data were identified: the value for Hens, Vermont, 1998 was corrected from 12,000 to 30,000; the value for Broilers, Alabama, 1995 was corrected from 16,363,636 to 163,636,363. Additionally, all USDA data from 1998 through the present year underwent review pursuant to USDA NASS annual review procedures. The population data in these years reflects some adjustments due to this review.
- Typical animal mass. The typical animal mass for beef cows and beef calves were reevaluated and adjusted. Typical animal mass of beef cows was adjusted from 590 kilograms to 533 kilograms, and typical animal mass for beef calves was adjusted from 159 kilograms to 118 kilograms (ERG 2003b).
- Sheep distribution. The 1990 through 2001 U.S. Inventory contained estimates of the percentage of sheep on feed based on the 1993 USDA Census of Agriculture estimates of the number of lambs on feed on feedlots. These data only contained data for sixteen states, and the data source indicates this list is not comprehensive. The previous inventory estimates presented data for sheep on feed for those 13 states indicated in the 1993 lambs on feedlots table; however, the data describing the states with sheep on feed contains 28 states. Therefore, the methodology was changed in the current inventory to account for sheep on feedlots from all 28 states using the percent on-feed at feedlots from the average of the 13 states data from lambs on feed at feedlots.
- Implied emission factors. In the previously-submitted Common Reporting Format (CRF) tables, implied emission factors for N2O were above the emission factors that the IPCC recommends. The implied N2O factors from specific waste management systems were incorrectly calculated using the product of the total national nitrous oxide emitted and the percent waste management system distribution, without consideration of the emission factor specific to that system. For the current inventory, this methodology has been changed so that the CRF reports implied nitrous oxide factors from specific waste management systems according to both percent distribution and the emission factor for that specific component.

Planned Improvements

Currently, temperate zone MCFs are used for non-liquid waste management systems, including pasture/range/paddock, daily spread, solid storage, and drylot operations. However, there are some states that have an annual average temperature that would fall below 15°C (i.e., “cool”). Therefore, CH_4 emissions from certain non-liquid waste management systems may be overestimated; however, the difference is expected to be relatively small due to the low MCFs for all “dry” management systems. The use of both cool and temperate MCFs for non-liquid waste management systems will be investigated for future inventories.

Although an effort was made to introduce the variability in volatile solids production due to differences in diet for beef and dairy cows, heifers, and steer, further research is needed to confirm and track diet changes over time. A methodology to assess variability in swine volatile solids production would be useful in future inventory estimates.

The American Society of Agricultural Engineers is publishing new standards for manure production characteristics in 2004. These data will be investigated and evaluated for incorporation into future estimates.

The development of the National Ammonia Emissions Inventory for the United States used similar data sources to the current estimates of emissions from manure management, and through the course of development of the Ammonia Inventory, updated waste management distribution data were identified. Future estimates will attempt to reflect these updated data.

The methodology to calculate MCFs for liquid systems will be examined to determine how to account for a maximum temperature in the liquid systems. Additionally, available research will be investigated to develop a relationship between ambient air temperature and temperature in liquid waste management systems in order to improve that relationship in the MCF methodology.

Research will be initiated into the estimation and validation of the maximum CH_4-producing capacity of animal manure (B_o), for the purpose of obtaining more accurate data to develop emission estimates.

The 2002 Census of Agriculture is expected to be available in mid-2004. These data will be used to update assumptions that previously relied on the 1992 and 1997 Census of Agriculture.

6.3. Rice Cultivation (IPCC Source Category 4C)

Most of the world's rice, and all rice in the United States, is grown on flooded fields. When fields are flooded, aerobic decomposition of organic material gradually depletes the oxygen present in the soil and floodwater, causing anaerobic conditions in the soil to develop. Once the environment becomes anaerobic, CH_4 is produced through anaerobic decomposition of soil organic matter by methanogenic bacteria. As much as 60 to 90 percent of the CH_4 produced is oxidized by aerobic methanotrophic bacteria in the soil (Holzapfel-Pschorn et al. 1985, Sass et al. 1990). Some of the CH_4 is also leached away as dissolved CH_4 in floodwater that percolates from the field. The remaining un-oxidized CH_4 is transported from the submerged soil to the atmosphere primarily by diffusive transport through the rice plants. Minor amounts of CH_4 also escape from the soil via diffusion and bubbling through floodwaters.

The water management system under which rice is grown is one of the most important factors affecting CH_4 emissions. Upland rice fields are not flooded, and therefore are not believed to produce CH_4. In deepwater rice fields (i.e., fields with flooding depths greater than one meter), the lower stems and roots of the rice plants are dead so the primary CH_4 transport pathway to the atmosphere is blocked. The quantities of CH_4 released from deepwater fields, therefore, are believed to be significantly less than the quantities released from areas with more shallow flooding depths. Some flooded fields are drained periodically during the growing season, either intentionally or accidentally. If water is drained and soils are allowed to dry sufficiently, CH_4 emissions decrease or stop entirely. This is due to soil aeration, which not only causes existing soil CH_4 to oxidize but also inhibits further CH_4 production in soils. All rice in the United States is grown under continuously flooded conditions; none is grown under deepwater conditions. Mid-season drainage does not occur except by accident (e.g., due to levee breach).

Other factors that influence CH_4 emissions from flooded rice fields include fertilization practices (especially the use of organic fertilizers), soil temperature, soil type, rice variety, and cultivation practices (e.g., tillage, seeding and weeding practices). The factors that determine the amount of organic material that is available to decompose (i.e., organic fertilizer use, soil type, rice variety,[2] and cultivation practices) are the most important variables influencing the amount of CH_4 emitted over an entire growing season because the total amount of CH_4 released depends primarily on the amount of organic substrate available. Soil temperature is known to be an important factor regulating the activity of methanogenic bacteria, and therefore the rate of CH_4 production. However, although temperature controls the amount of time it takes to convert a given amount of organic material to CH_4, that time is short relative to a growing season, so the dependence of total emissions over an entire growing season on soil temperature is weak. The application of synthetic fertilizers has also been found to influence CH_4 emissions; in particular, both nitrate and sulfate fertilizers (e.g., ammonium nitrate, and ammonium sulfate) appear to inhibit CH_4 formation.

[2] The roots of rice plants shed organic material, which is referred to as "root exudate." The amount of root exudate produced by a rice plant over a growing season varies among rice varieties.

Rice is cultivated in eight states: Arkansas, California, Florida, Louisiana, Mississippi, Missouri, Oklahoma, and Texas. Soil types, rice varieties, and cultivation practices for rice vary from state to state, and even from farm to farm. However, most rice farmers utilize organic fertilizers in the form of rice residue from the previous crop, which is left standing, disked, or rolled into the fields. Most farmers also apply synthetic fertilizer to their fields, usually urea. Nitrate and sulfate fertilizers are not commonly used in rice cultivation in the United States. In addition, the climatic conditions of Arkansas, southwest Louisiana, Texas, and Florida allow for a second, or ratoon, rice crop. Methane emissions from ratoon crops have been found to be considerably higher than those from the primary crop. This second rice crop is produced from regrowth of the stubble after the first crop has been harvested. Because the first crop's stubble is left behind in ratooned fields, and there is no time delay between cropping seasons (which would allow for the stubble to decay aerobically), the amount of organic material that is available for decomposition is considerably higher than with the first (i.e., primary) crop.

Rice cultivation is a small source of CH_4 in the United States (Table 6-9 and Table 6-10). In 2002, CH_4 emissions from rice cultivation were 6.8 Tg CO_2 Eq. (325 Gg). Although annual emissions fluctuated unevenly between the years 1990 and 2002, ranging from an annual decrease of 11 percent to an annual increase of 17 percent, there was an overall decrease of 4 percent over the twelve-year period, due to an overall decrease in ratoon crop area.[3] The factors that affect the rice acreage in any year vary from state to state, although the price of rice relative to competing crops is the primary controlling variable in most states. Price is the primary factor affecting rice area in Arkansas, as farmers will plant more of what is most lucrative amongst soybeans, rice, and cotton. Government support programs have also been influential in so much as they affect the price received for a rice crop (Slaton 2001b, Mayhew 1997). California rice area is primarily influenced by price and government programs, but is also affected by water availability (Mutters 2001). In Florida, rice acreage is largely a function of the price of rice relative to sugarcane and corn. Most rice in Florida is rotated with sugarcane, but sometimes it is more profitable for farmers to follow their sugarcane crop with sweet corn or more sugarcane instead of rice (Schueneman 1997, 2001b). In Louisiana, rice area is influenced by government support programs, the price of rice relative to cotton, soybeans, and corn, and in some years, weather (Saichuk 1997, Linscombe 2001b). For example, a drought in 2000 caused extensive saltwater intrusion along the Gulf Coast, making over 32,000 hectares unplantable. The dramatic decrease in ratooned area in Louisiana in 2002 was the result of hurricane damage to that state's rice-cropped area. In Mississippi, rice is usually rotated with soybeans, but if soybean prices increase relative to rice prices, then some of the acreage that would have been planted in rice, is instead planted in soybeans (Street 1997, 2001). In Missouri, rice acreage is affected by weather (e.g., rain during the planting season may prevent the planting of rice), the price differential between rice and soybeans or cotton, and government support programs (Stevens 1997, Guethle 2001). In Oklahoma, the state having the smallest harvested rice area, rice acreage is limited to the areas in the state with the right type of land for rice cultivation. Acreage is limited to growers who can afford the equipment, labor, and land for this intensive crop (Lee 2003). Texas rice area is affected mainly by the price of rice, government support programs, and water availability (Klosterboer 1997, 2001b).

Table 6-9: CH_4 Emissions from Rice Cultivation (Tg CO_2 Eq.)

State	1990		1996	1997	1998	1999	2000	2001	2002
Primary	**5.1**		**5.0**	**5.6**	**5.8**	**6.3**	**5.5**	**5.9**	**5.7**
Arkansas	2.1		2.1	2.5	2.7	2.9	2.5	2.9	2.7
California	0.7		0.9	0.9	0.8	0.9	1.0	0.8	0.9
Florida	+		+	+	+	+	+	+	+
Louisiana	1.0		1.0	1.0	1.1	1.1	0.9	1.0	1.0
Mississippi	0.4		0.4	0.4	0.5	0.6	0.4	0.5	0.5
Missouri	0.1		0.2	0.2	0.3	0.3	0.3	0.4	0.3
Oklahoma	+		+	+	+	+	NA	+	+
Texas	0.6		0.5	0.5	0.5	0.5	0.4	0.4	0.4
Ratoon	**2.1**		**1.9**	**1.9**	**2.1**	**2.0**	**2.0**	**1.7**	**1.1**
Arkansas	0.0		0.0	0.0	+	+	0.0	0.0	0.0

[3] The 11 percent decrease occurred between 1992 and 1993; the 17 percent increase happened between 1993 and 1994.

Florida	+	0.1	0.1	0.1	0.1	0.1	+	+
Louisiana	1.1	1.1	1.2	1.2	1.2	1.3	1.1	0.5
Texas	0.9	0.8	0.7	0.8	0.7	0.7	0.6	0.5
Total	**7.1**	**7.0**	**7.5**	**7.9**	**8.3**	**7.5**	**7.6**	**6.8**

+ Less than 0.05 Tg CO_2 Eq.
NA (Not Available)
Note: Totals may not sum due to independent rounding.

Table 6-10: CH_4 Emissions from Rice Cultivation (Gg CH_4)

State	1990	1996	1997	1998	1999	2000	2001	2002
Primary	**241**	**240**	**265**	**279**	**300**	**260**	**283**	**274**
Arkansas	102	99	118	126	138	120	138	128
California	34	43	44	39	43	47	40	45
Florida	1	2	2	2	2	2	1	1
Louisiana	46	45	50	53	52	41	46	45
Mississippi	21	18	20	23	27	19	22	22
Missouri	7	8	10	12	16	14	18	15
Oklahoma	+	+	+	+	+	NA	+	+
Texas	30	25	22	24	22	18	18	18
Ratoon	**98**	**92**	**91**	**98**	**95**	**97**	**81**	**52**
Arkansas	0	0	0	+	+	0	0	0
Florida	2	3	3	3	4	2	2	2
Louisiana	52	50	55	59	58	61	52	25
Texas	45	38	33	36	33	34	27	24
Total	**339**	**332**	**356**	**376**	**395**	**357**	**364**	**325**

+ Less than 0.5 Gg
NA (Not Available)
Note: Totals may not sum due to independent rounding.

Methodology

The *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997) recommends utilizing harvested rice areas and area-based seasonally integrated emission factors (i.e., amount of CH_4 emitted over a growing season per unit harvested area) to estimate annual CH_4 emissions from rice cultivation. This methodology is followed with the use of U.S.-specific emission factors derived from rice field measurements. Seasonal emissions have been found to be much higher for ratooned crops than for primary crops, so emissions from ratooned and primary areas are estimated separately using emission factors that are representative of the particular growing season. This is consistent with IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000).

The harvested rice areas for the primary and ratoon crops in each state are presented in Table 6-11. Primary crop areas for 1990 through 2002 for all states except Florida and Oklahoma were taken from U.S. Department of Agriculture's *Field Crops Final Estimates 1987-1992* (USDA 1994), *Field Crops Final Estimates 1992-1997* (USDA 1998), *Crop Production 2000 Summary* (USDA 2001), *Crop Production 2001 Summary* (USDA 2002), and *Crop Production 2002 Summary* (USDA 2003). Harvested rice areas in Florida, which are not reported by USDA, were obtained from Tom Schueneman (1999b, 1999c, 2000, 2001a) and Arthur Kirstein (2003), Florida agricultural extension agents, and Dr. Chris Deren (2002) of the Everglades Research and Education Centre at the University of Florida. Harvested rice areas for Oklahoma, which also are not reported by USDA, were obtained from Danny Lee of the Oklahoma Farm Services Agency (Lee 2003). Acreages for the ratoon crops were derived from conversations with the agricultural extension agents in each state. In Arkansas, ratooning occurred only in 1998 and 1999, when the ratooned area was less than 1 percent of the primary area (Slaton 1999, 2000, 2001a). In Florida, the ratooned area was 50 percent of the primary area from 1990 to 1998 (Schueneman 1999a), about 65 percent of the primary area in 1999 (Schueneman 2000), around 41 percent of the primary area in 2000 (Schueneman 2001a), about 60 percent of the primary area in 2001(Deren 2002), and about 54 percent of the primary area in 2002 (Kirstein 2003). In Louisiana, the percentage of the primary area that was ratooned was constant at 30 percent over the 1990 to 1999 period, but increased to approximately 40 percent in 2000, before returning to 30 percent in 2001 and dropping to 15 percent in 2002 (Linscombe 1999a, 2001a, 2002, 2003 and Bollich 2000). In Texas, the percentage of the primary area that was ratooned was constant at 40 percent over the entire 1990 to 1999 period and in 2001, but increased to 50 percent in 2000 due to an early primary crop; it then decreased to 40 percent in 2001 and 37 percent in 2002 (Klosterboer 1999, 2000, 2001a, 2002, 2003).

Table 6-11: Rice Areas Harvested (Hectares)

State/Crop	1990		1996	1997	1998	1999	2000	2001	2002
Arkansas									
Primary	485,633		473,493	562,525	600,971	657,628	570,619	656,010	608,256
Ratoon*	NO		NO	NO	202	202	NO	NO	NO
California	159,854		202,347	208,822	185,350	204,371	221,773	190,611	213,679
Florida									
Primary	4,978		8,903	7,689	8,094	7,229	7,801	4,562	5,077
Ratoon	2,489		4,452	3,845	4,047	4,673	3,193	2,752	2,734
Louisiana									
Primary	220,558		215,702	235,937	250,911	249,292	194,253	220,963	216,512
Ratoon	66,168		64,711	70,781	75,273	74,788	77,701	66,289	32,477
Mississippi	101,174		84,176	96,317	108,458	130,716	88,223	102,388	102,388
Missouri	32,376		38,446	47,349	57,871	74,464	68,393	83,772	73,654
Oklahoma	617		19	12	19	220	NA	265	274
Texas									
Primary	142,857		120,599	104,816	114,529	104,816	86,605	87,414	83,367
Ratoon	57,143		48,240	41,926	45,811	41,926	43,302	34,966	30,846
Total Primary	***1,148,047***		***1,143,685***	***1,263,468***	***1,326,203***	***1,428,736***	***1,237,668***	***1,345,984***	***1,303,206***
Total Ratoon	***125,799***		***117,402***	***116,552***	***125,334***	***121,589***	***124,197***	***104,006***	***66,056***
Total	**1,273,847**		**1,261,087**	**1,380,020**	**1,451,536**	**1,550,325**	**1,361,864**	**1,449,991**	**1,369,262**

* Arkansas ratooning occurred only in 1998 and 1999.
NO (Not Occurring)
NA (Not Available)
Note: Totals may not sum due to independent rounding.

To determine what seasonal CH_4 emission factors should be used for the primary and ratoon crops, CH_4 flux information from rice field measurements in the United States was collected. Experiments which involved atypical or nonrepresenative management practices (e.g., the application of nitrate or sulfate fertilizers, or other substances believed to suppress CH_4 formation), as well as experiments in which measurements were not made over an entire flooding season or floodwaters were drained mid-season, were excluded from the analysis. The remaining experimental results[4] were then sorted by season (i.e., primary and ratoon) and type of fertilizer amendment (i.e., no fertilizer added, organic fertilizer added, and synthetic and organic fertilizer added). The experimental results from primary crops with synthetic and organic fertilizer added (Bossio et al. 1999, Cicerone et al. 1992, Sass et al. 1991a and 1991b) were averaged to derive an emission factor for the primary crop, and the experimental results from ratoon crops with synthetic fertilizer added (Lindau and Bollich 1993, Lindau et al. 1995) were averaged to derive an emission factor for the ratoon crop. The resultant emission factor for the primary crop is 210 kg CH_4/hectare-season, and the resultant emission factor for the ratoon crop is 780 kg CH_4/hectare-season.

[4] In some of these remaining experiments, measurements from individual plots were excluded from the analysis because of the reasons just mentioned. In addition, one measurement from the ratooned fields (i.e., the flux of 2.041 g/m^2/day in Lindau and Bollich 1993) was excluded since this emission rate is unusually high compared to other flux measurements in the United States, as well as in Europe and Asia (IPCC/UNEP/OECD/IEA 1997).

Uncertainty

The largest uncertainty in the calculation of CH_4 emissions from rice cultivation is associated with the emission factors. Seasonal emissions, derived from field measurements in the United States, vary by more than one order of magnitude. This inherent variability is due to differences in cultivation practices, in particular, fertilizer type, amount, and mode of application; differences in cultivar type; and differences in soil and climatic conditions. A portion of this variability is accounted for by separating primary from ratooned areas. However, even within a cropping season or a given management regime, measured emissions may vary significantly. Of the experiments used to derive the emission factors applied here, primary emissions ranged from 22 to 479 kg CH_4/hectare-season and ratoon emissions ranged from 481 to 1,490 kg CH_4/hectare-season. From these ranges, an uncertainty for the emission factors of 109 percent for primary crops and 65 percent for ratoon was calculated. In order to perform a Tier 2-level Monte Carlo type uncertainty analysis, some information regarding the statistical distribution of the uncertainty is required. Variability about the rice emission factor means were not normally distributed for either primary or ratooned crops, but rather skewed, with a tail trailing to the right of the mean, and a lognormal-type statistical distribution was applied. The bounds of the distribution were set at 0 (indicating that CH_4 absorption was unlikely given this management system) and three times the emission factor itself.

Uncertainty regarding primary cropping area is an additional consideration. Uncertainty associated with primary rice-cropped area for each state was obtained from expert judgment, and ranged from 4 percent to 10 percent of the mean area. A triangular distribution of uncertainty was assumed about the mean for areas, which was bounded at half and one and a half times the estimated area.

Another source of uncertainty lies in the ratooned areas, which are not compiled regularly. Ratooning accounts for less than 5 percent of the total rice-cropped area, though it is responsible for a proportionately larger portion of emissions. Expert judgment estimated the uncertainty associated with ratooned areas at between 0 percent and 7.5 percent. A triangular distribution of uncertainty was assumed, and bound at half and one and a half times the estimated proportion of ratooned area.

To account for each of these uncertainties, a Tier 2-level uncertainty analysis was performed using the information provided above. The preliminary results of the quantitative uncertainty analysis (see Table 6-12) indicate that, on average, in 19 out of 20 times (i.e., there is a 95 percent probability), the total greenhouse gas emissions estimate from this source is within the range of approximately 2.8 to 14.7 Tg CO_2 Eq. (or that the actual CH_4 emissions are likely to fall within the range of approximately 58 percent below and 116 percent above the emission estimate of 6.8 Tg CO_2 Eq.).

A final source of uncertainty is in the practice of flooding outside of the normal rice season. According to agricultural extension agents, all of the rice-growing states practice this on some part of their rice acreage. Estimates of these areas range from 5 to 68 percent of the rice acreage. Fields are flooded for a variety of reasons: to provide habitat for waterfowl, to provide ponds for crawfish production, and to aid in rice straw decomposition. To date, however, CH_4 flux measurements have not been undertaken over a sufficient geographic range or under representative conditions to account for this source or its associated uncertainty adequate for inclusion in the emission estimates or uncertainty evaluations presented here.

Table 6-12: Quantitative Uncertainty Estimates for CH_4 Emissions from Rice Cultivation (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2002 Emission Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emission Estimate[a]**			
			(Tg CO_2 Eq.)		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Rice Cultivation	CH_4	6.8	2.8	14.7	-58%	+116%

[a]Range of emissions estimates predicted by Monte Carlo Stochastic Simulation for a 95% confidence interval

Recalculations Discussion

In researching another component of this Inventory, it was determined that a previously unaccounted for state (Oklahoma) produces rice on relatively small areas. Methane emissions from rice cultivation have therefore been revised to include harvested rice areas in the state of Oklahoma. This addition caused an average annual increase of 0.01 percent in emissions from 1990 through 2002.

6.4. Agricultural Soil Management (IPCC Source Category 4D)

Nitrous oxide is produced naturally in soils through the microbial processes of nitrification and denitrification.[5] A number of agricultural activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These activities may add nitrogen to soils either directly or indirectly (see Figure 6-2). Direct additions occur through various soil management practices and from the deposition of manure on soils by animals on pasture, range, and paddock (i.e., by animals whose manure is not managed). Soil management practices that add nitrogen to soils include fertilizer use, application of managed livestock manure and sewage sludge, production of nitrogen-fixing crops and forages, retention of crop residues, and cultivation of histosols (i.e., soils with a high organic matter content, otherwise known as organic soils).[6] Indirect additions of nitrogen to soils occur through two mechanisms: 1) volatilization and subsequent atmospheric deposition of applied nitrogen;[7] and 2) surface runoff and leaching of applied nitrogen into groundwater and surface water. Other agricultural soil management activities, such as irrigation, drainage, tillage practices, and fallowing of land, can affect fluxes of N_2O, as well as other greenhouse gases, to and from soils. However, because there are significant uncertainties associated with these other fluxes, their contributions have not been estimated.

Figure 6-2: Direct and Indirect N_2O Emissions from Agricultural Soils

Agricultural soil management is the largest source of N_2O in the United States.[8] Estimated emissions from this source in 2002 were 287.3 Tg CO_2 Eq. (927 Gg N_2O) (see Table 6-13 and Table 6-14). Although annual agricultural soil management emissions fluctuated between 1990 and 2002, there was a general increase in emissions over the thirteen-year period of approximately 9 percent (see Annex 3.11 for a complete time series of emission estimates). This general increase was due primarily to an increase in synthetic fertilizer use, manure production, and crop and forage production over the period. Year-to-year fluctuations are largely a reflection of annual variations in synthetic fertilizer consumption and crop production.

Table 6-13: N_2O Emissions from Agricultural Soil Management (Tg CO_2 Eq.)

Activity	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**

[5] Nitrification and denitrification are two processes within the nitrogen cycle that are brought about by certain microorganisms in soils. Nitrification is the aerobic microbial oxidation of ammonium (NH_4) to nitrate (NO_3), and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N_2). Nitrous oxide is a gaseous intermediate product in the reaction sequence of denitrification, which leaks from microbial cells into the soil and then into the atmosphere. Nitrous oxide is also produced during nitrification, although by a less well understood mechanism (Nevison 2000).

[6] Cultivation of histosols does not, *per se*, “add” nitrogen to soils. Instead, the process of cultivation enhances mineralization of nitrogen-rich organic matter that is present in histosols, thereby enhancing N_2O emissions from histosols.

[7] These processes entail volatilization of applied nitrogen as ammonia (NH_3) and oxides of nitrogen (NO_x), transformations of these gases within the atmosphere (or upon deposition), and deposition of the nitrogen primarily in the form of particulate ammonium (NH_4), nitric acid (HNO_3), and oxides of nitrogen.

[8] Note that the emission estimates for this source category include applications of nitrogen to *all* soils (e.g., forest soils, urban areas, golf courses, etc.), but the term “Agricultural Soil Management” is kept for consistency with the reporting structure of the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

Direct	**190.5**		**209.1**	**214.5**	**215.6**	**213.5**	**212.6**	**212.8**	**209.9**
Managed Soils	153.3		169.1	175.6	177.6	175.9	175.6	176.1	173.3
Pasture, Range, & Paddock Livestock	37.2		40.0	38.8	38.0	37.6	37.0	36.7	36.6
Indirect	**72.3**		**79.0**	**78.7**	**78.6**	**78.6**	**77.2**	**75.8**	**77.4**
Total	**262.8**		**288.1**	**293.2**	**294.2**	**292.1**	**289.7**	**288.6**	**287.3**

Note: Totals may not sum due to independent rounding.

Table 6-14: N_2O Emissions from Agricultural Soil Management (Gg N_2O)

Activity	1990		1996	1997	1998	1999	2000	2001	2002
Direct	**614**		**675**	**692**	**696**	**689**	**686**	**686**	**677**
Managed Soils	495		545	567	573	568	566	568	559
Pasture, Range, & Paddock Livestock	120		129	125	123	121	119	118	118
Indirect	**233**		**255**	**254**	**254**	**254**	**249**	**245**	**250**
Total	**848**		**929**	**946**	**949**	**942**	**935**	**931**	**927**

Note: Totals may not sum due to independent rounding.

Estimated direct and indirect N_2O emissions, by subsource, are provided in Table 6-15, Table 6-17, and Table 6-19.

Table 6-15: Direct N_2O Emissions from Managed Soils (Tg CO_2 Eq.)

Activity	1990		1996	1997	1998	1999	2000	2001	2002
Commercial Fertilizers*	55.4		61.2	61.3	61.4	61.7	59.9	58.1	60.3
Applied Livestock Manure	13.0		13.7	14.0	14.2	14.2	14.3	14.4	14.4
Sewage Sludge	0.4		0.6	0.7	0.7	0.7	0.7	0.7	0.8
N Fixation	58.5		63.9	68.2	69.2	68.2	68.8	70.6	67.7
Crop Residue	23.2		26.8	28.7	29.3	28.3	29.0	29.3	27.2
Histosol Cultivation	2.8		2.8	2.9	2.9	2.9	2.9	2.9	2.9
Total	**153.3**		**169.1**	**175.6**	**177.6**	**175.9**	**175.6**	**176.1**	**173.3**

Note: Totals may not sum due to independent rounding.
* Excludes sewage sludge and livestock manure used as commercial fertilizers.

Table 6-16: Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure (Tg CO_2 Eq.)

Animal Type	1990		1996	1997	1998	1999	2000	2001	2002
Beef Cattle	32.0		35.6	34.5	33.7	33.4	32.8	32.5	32.4
Dairy Cows	1.7		1.4	1.3	1.3	1.2	1.2	1.2	1.1
Swine	0.5		0.3	0.2	0.2	0.2	0.2	0.2	0.2
Sheep	0.4		0.3	0.3	0.3	0.3	0.3	0.3	0.2
Goats	0.2		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Poultry	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1
Horses	2.2		2.3	2.3	2.3	2.3	2.3	2.3	2.3
Total	**37.2**		**40.0**	**38.8**	**38.0**	**37.6**	**37.0**	**36.7**	**36.6**

Note: Totals may not sum due to independent rounding.

Table 6-17: Indirect N_2O Emissions (Tg CO_2 Eq.)

Activity	1990		1996	1997	1998	1999	2000	2001	2002
Volatilization & Atm. Deposition	**11.4**		**12.4**	**12.3**	**12.3**	**12.3**	**12.1**	**11.9**	**12.1**
Commercial Fertilizers*	4.9		5.4	5.5	5.5	5.5	5.3	5.2	5.4
Total Livestock Manure	6.4		6.8	6.7	6.7	6.6	6.6	6.6	6.6
Sewage Sludge	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.2
Surface Leaching & Runoff	**60.9**		**66.6**	**66.4**	**66.3**	**66.3**	**65.1**	**63.9**	**65.3**
Commercial Fertilizers*	36.9		40.8	40.9	41.0	41.1	39.9	38.7	40.2
Applied and PRP Livestock Manure	23.7		25.3	25.1	24.9	24.7	24.6	24.6	24.6
Sewage Sludge	0.3		0.5	0.5	0.5	0.5	0.5	0.6	0.6
Total	**72.3**		**79.0**	**78.7**	**78.6**	**78.6**	**77.2**	**75.8**	**77.4**

Note: Totals may not sum due to independent rounding.
* Excludes sewage sludge and livestock manure used as commercial fertilizers.

Methodology

The methodology used to estimate emissions from agricultural soil management is consistent with the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997), as amended by the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). The *Revised 1996 IPCC Guidelines* divide this N_2O source category into three components: (1) direct emissions from managed soils due to applied nitrogen and cultivation of histosols; (2) direct emissions from soils due to the deposition of manure by livestock on pasture, range, and paddock; and (3) indirect emissions from soils induced by applied fertilizers, sewage sludge and total livestock manure nitrogen.

Annex 3.11 provides more detailed information on the methodologies and data used to calculate N_2O emissions from each of these three components.

Direct N_2O Emissions from Managed Soils

Direct N_2O emissions from managed soils are composed of two parts, which are estimated separately and then summed. These parts are 1) emissions due to nitrogen applications, and 2) emissions from histosol cultivation.

Estimates of direct N_2O emissions from nitrogen applications were based on the total amount of nitrogen applied to soils annually through the following practices: (a) the application of synthetic and organic commercial fertilizers, (b) the application of livestock manure through both daily spread operations and through the eventual application of manure that had been stored in manure management systems, (c) the application of sewage sludge, (d) the production of nitrogen-fixing crops and forages, and (e) the retention of crop residues (i.e., leaving residues in the field after harvest). For each of these practices, the annual amounts of nitrogen applied were estimated as follows:

a) Synthetic and organic commercial fertilizer nitrogen applications were derived from annual fertilizer consumption data and the nitrogen content of the fertilizers.

b) Livestock manure nitrogen applications were based on the assumption that all livestock manure is applied to soils except for two components: 1) a small portion of poultry manure that is used as a livestock feed supplement, and 2) the manure from pasture, range, and paddock livestock. The manure nitrogen data were derived from animal population and weight statistics, information on manure management system usage, annual nitrogen excretion rates for each animal type, and information on the fraction of poultry litter that is used as a livestock feed supplement.

c) Sewage sludge nitrogen applications were derived from estimates of annual U.S. sludge production, the nitrogen content of the sludge, and periodic surveys of sludge disposal methods.

d) The amounts of nitrogen made available to soils through the cultivation of nitrogen-fixing crops and forages were based on estimates of the amount of nitrogen in aboveground plant biomass, which were derived from annual crop production statistics, mass ratios of aboveground residue to crop product, dry matter fractions, and nitrogen contents of the plant biomass.

e) Crop residue nitrogen retention data were derived from information about which residues are typically left on the field, the fractions of residues left on the field, annual crop production statistics, mass ratios of aboveground residue to crop product, and dry matter fractions and nitrogen contents of the residues.

After the annual amounts of nitrogen applied were estimated for each practice, the amounts of nitrogen for commercial fertilizers, sewage sludge, and livestock manure were reduced by the fraction that is assumed to volatilize according to the *Revised 1996 IPCC Guidelines* and the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. The net amounts left on the soil from each practice were then summed and added to the applied nitrogen from N-fixing crops and crop residues to yield total unvolatilized applied nitrogen, which was multiplied by the IPCC default emission factor for nitrogen applications.

Estimates of annual N_2O emissions from histosol cultivation were based on estimates of the total U.S. acreage of histosols cultivated annually for each of two climatic zones: 1) temperate, and 2) sub-tropical. To estimate annual emissions, the total temperate area was multiplied by the IPCC default emission factor for temperate regions, and the total sub-tropical area was multiplied by the average of the IPCC default emission factors for temperate and tropical regions.[9]

Total annual emissions from nitrogen applications, and annual emissions from histosol cultivation, were then summed to estimate total direct emissions from managed soils.

Direct N_2O Emissions from Pasture, Range, and Paddock Livestock Manure

Estimates of N_2O emissions from this component are based on the amount of nitrogen in the manure that is deposited annually on soils by livestock on pasture, range, and paddock (PRP). Estimates of annual manure nitrogen from these livestock were derived from animal population and weight statistics; information on the fraction of the total population of each animal type that is on pasture, range, or paddock; and annual nitrogen excretion rates for each animal type. The annual amount of manure nitrogen from each animal type were summed over all animal types to yield total pasture, range, and paddock manure nitrogen, which was then multiplied by the IPCC default emission factor for pasture, range, and paddock nitrogen to estimate N_2O emissions.

Indirect N_2O Emissions from Soils

Indirect emissions of N_2O are composed of two parts, which are estimated separately and then summed. These parts are 1) emissions resulting from volatilization and subsequent deposition of the nitrogen in applied fertilizers, applied sewage sludge, and all livestock manure,[10] and 2) leaching and runoff of nitrogen in applied fertilizers, applied sewage sludge, and applied plus deposited livestock manure. The activity data (i.e., nitrogen in applied fertilizers, applied sewage sludge, all livestock manure, and applied plus deposited livestock manure) were estimated in the same way as for the direct emission estimates.

To estimate the annual amount of applied nitrogen that volatilizes, the annual amounts of applied synthetic fertilizer nitrogen, applied sewage sludge nitrogen, and all livestock manure nitrogen were each multiplied by the appropriate IPCC default volatilization fraction. The three amounts of volatilized nitrogen were then summed, and the sum was multiplied by the IPCC default emission factor for volatilized/deposited nitrogen.

To estimate the annual amount of nitrogen that leaches or runs off, the annual amounts of applied synthetic fertilizer nitrogen, applied sewage sludge nitrogen, and applied plus deposited livestock manure nitrogen were each multiplied by the IPCC default leached/runoff fraction. The three amounts of leached/runoff nitrogen were then summed, and the sum was multiplied by the IPCC default emission factor for leached/runoff nitrogen.

Total annual indirect emissions from volatilization, and annual indirect emissions from leaching and runoff, were then summed to estimate total indirect emissions of N_2O from managed soils.

The activity data used in these calculations were obtained from numerous sources. Annual synthetic and organic fertilizer consumption data for the United States were obtained from annual publications on commercial fertilizer

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[9] Note that the IPCC default emission factors for histosols have been revised in the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). These revised default emission factors (IPCC 2000) were used in these calculations.

[10] Total livestock manure nitrogen is used in the calculation of indirect N_2O emissions from volatilization because all manure nitrogen, regardless of how the manure is managed or used, is assumed to be subject to volatilization.

statistics (TVA 1991, 1992a, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999, 2000b, 2002, 2003). Fertilizer nitrogen contents were taken from these same publications and AAPFCO (2000a). Livestock population data were obtained from USDA publications (USDA 1994b,c; 1995a,b; 1998a,c; 1999a-e; 2000a-g; 2001b-g; 2002b-g; 2003b-g), the FAOSTAT database (FAO 2003), and Lange (2000). Manure management information was obtained from Poe et al. (1999), Safley et al. (1992), and personal communications with agricultural experts (Anderson 2000, Deal 2000, Johnson 2000, Miller 2000, Milton 2000, Stettler 2000, Sweeten 2000, Wright 2000). Livestock weight data were obtained from Safley (2000), USDA (1996, 1998d), and ASAE (1999); daily rates of nitrogen excretion from ASAE (1999) and USDA (1996); and information about the fraction of poultry litter used as a feed supplement from Carpenter (1992). Data collected by the EPA were used to derive annual estimates of land application of sewage sludge (EPA 1993, 1999). The nitrogen content of sewage sludge was taken from Metcalf and Eddy, Inc. (1991). Annual production statistics for nitrogen-fixing crops were obtained from USDA reports (USDA 1994a, 1998b, 2000i, 2001a, 2002a, 2003a), a book on forage crops (Taylor and Smith 1995, Pederson 1995, Beuselinck and Grant 1995, Hoveland and Evers 1995), and personal communications with forage experts (Cropper 2000, Gerrish 2000, Hoveland 2000, Evers 2000, and Pederson 2000). Mass ratios of aboveground residue to crop product, dry matter fractions, and nitrogen contents for nitrogen-fixing crops were obtained from Strehler and Stützle (1987), Barnard and Kristoferson (1985), Karkosh (2000), Ketzis (1999), and IPCC/UNEP/OECD/IEA (1997). Annual production statistics for crops whose residues are left on the field, except for rice in Florida and Oklahoma, were obtained from USDA reports (USDA 1994a, 1998b, 2000i, 2001a, 2002a, 2003a). Production statistics for rice in Florida and Oklahoma are not recorded by USDA, so these were derived from Schueneman (1999, 2001), Deren (2002), and Schueneman and Deren (2002) for Florida and from Lee (2003) and Schueneman and Deren (2002) for Oklahoma. Aboveground residue to crop mass ratios, residue dry matter fractions, and residue nitrogen contents were obtained from Strehler and Stützle (1987), Turn et al. (1997), Ketzis (1999), and Barnard and Kristoferson (1985). Estimates of the fractions of residues left on the field were based on information provided by Karkosh (2000), and on information about rice residue burning (see the Agricultural Residue Burning section). The annual areas of cultivated histosols were estimated from 1982, 1992, and 1997 statistics in USDA's *1997 National Resources Inventory* (USDA 2000h, as extracted by Eve 2001, and revised by Ogle 2002).

All emission factors,[11] volatilization fractions, and the leaching/runoff fraction were taken from the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997), as amended by the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000).

Uncertainty

The amount of N_2O emitted from managed soils depends not only on N inputs, but also on a large number of variables, including organic carbon availability, O_2 partial pressure, soil moisture content, pH, soil temperature, and soil amendment management practices. However, the effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology, which is used here, is based only on N inputs and does not incorporate other variables. As noted in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997), this is a generalized approach that treats all soils equivalently, with the exception of cultivated histosols. IPCC default emission factors do not have associated uncertainties in either the Guidelines or Good Practice Guidance documents (IPCC/UNEP/OECD/IEA 1997, IPCC 2000). In quantifying the uncertainty in N_2O emissions from agricultural soils, we have assumed an uncertainty for these factors as follows.

Uncertainties exist in both the activity data and emission factors used to derive emission estimates. Even when data were derived from published reports, few uncertainty estimates are provided or made available upon request. Where such information is lacking, it was necessary to apply expert judgment in surmising the uncertainty associated with each factor in developing these emission estimates.

[11] Note that the emission factor used for cultivated histosols in the sub-tropics is the average of the tropical and temperate default IPCC emission factors.

Fertilizer statistics include only those fertilizers that enter the commercial market, so non-commercial fertilizers (organics, in particular, excluding manure and crop residues) have not been captured. For the purposes of quantitative uncertainty analysis, the uncertainty in synthetic fertilizer applications was assumed to range from half to one and a half times the estimated value, and uncertainty in organic fertilizers (including manure) was assumed to range from zero to twice the estimated application rate, with a triangular statistical distribution. Managed and daily spread manure N varied from half to one and a half times their estimated values.

The N content of applied fertilizers varied from half to one and a half times the estimated value in a triangular distribution.

Statistics on sewage sludge applied to soils were not available on an annual basis; annual production and application estimates were based on figures and projections that were calculated from surveys that yielded uncertainty levels as high as 14 percent (Bastian 1999). Annual data were obtained by interpolating and extrapolating at constant rates from these uncertain figures, though change between the years was unlikely to be constant (Bastian 2001). Uncertainty in the land application of sewage sludge for the quantitative analysis was assumed to range from half to one and a half times the estimated value for both sludge production and land applications, in a triangular distribution.

Production statistics for nitrogen-fixing crops that are forage legumes are uncertain because statistics are not compiled for any of these crops except alfalfa, and the alfalfa statistics include alfalfa mixtures with other types of forage (e.g., clover). Conversion factors for the nitrogen-fixing crops were based on a limited number of studies, and may not be representative of all conditions in the United States. Uncertainty with this input was assumed to range from half to one and a half times the estimated value in a triangular distribution.

Data on crop residues left on the field are not available, so expert judgment was used to estimate the amount of residues left on soils, with an associated uncertainty ranging from half to one and a half times the estimated value, in a triangular distribution.

Finally, estimates of cultivated histosol areas are uncertain because they are from a natural resource inventory that was not explicitly designed as a soil survey, and contains data for only three years (1982, 1992, and 1997). Annual histosol areas were estimated by linear interpolation and extrapolation, and uncertainty was assumed to range from half to one and a half times the estimated values for both temperate and subtropical histosols, in a triangular distribution.

Livestock excretion values, while based on detailed population and weight statistics, were derived using simplifying assumptions concerning the types of management systems employed. Uncertainties in PRP N, which are derivative activity data, were assumed to range from one half to one and a half times the estimated value, in a triangular distribution.

Uncertainty in the volatilization rates for synthetic and organic fertilizers, manure, and sludge, were triangularly distributed and ranged from half to one and a half times their estimated values. The proportion of N leached or runoff varied from zero to twice the estimated value, distributed in a triangular statistical distribution.

All emission factors (e.g., emission factors for applied N, temperate and subtropical histosols, PRP manure, volatilization, and leaching and runoff) were assumed to have a lognormal statistical distribution ranging from zero to three times their estimated value.

The preliminary results of the quantitative uncertainty analysis Table 6-18 indicate that, on average, in 19 out of 20 times (i.e., there is a 95 percent probability), the total greenhouse gas emissions estimate from this source is within the range of approximately 100.3 to 736.5 Tg CO_2 Eq. (or that the actual emissions are likely to fall within the range of approximately 65 percent below and 156 percent above the emission estimate of 287.3 Tg CO_2 Eq.).

Table 6-18: Quantitative Uncertainty Estimates of N_2O Emissions from Agricultural Soil Management (Tg CO_2 Eq. and Percent)

Source	Gas	2002 Emission Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Agricultural Soil Management	Direct N_2O	209.9	63.2	596.5	-70%	+184%
Agricultural Soil Management	Indirect N_2O	77.4	12.7	298.8	-84%	+286%
Agricultural Soil Management	**Total N_2O**	**287.3**	**100.3**	**736.5**	**-65%**	**+156%**

[a]Range of emissions estimates predicted by Monte Carlo Stochastic Simulation for a 95% confidence interval.

Recalculations Discussion

Estimates of N_2O emissions from agricultural soil management have been revised due to methodological and historical data changes in the calculations of nitrogen from livestock that is applied to soils. These changes include corrections to: the typical animal mass value for beef cows and calves; the accounting of sheep in New England states; state broiler populations; and updated NASS animal population estimates for the years 1998 through 2001. Additionally, the factor for converting short tons to metric tons was revised to include another significant digit, and the percent residue applied for rice in the year 2001 was corrected. In combination, these changes resulted in an average annual decrease of 4.9 Tg CO_2 Eq. (2 percent) in N_2O emissions over the 1990 through 2001 period.

Planned Improvements

EPA is currently working in collaboration with the Agricultural Research Service and the Natural Resource Ecology Lab at Colorado State University to use the DAYCENT ecosystem process model (Del Grosso et al. 2001, Parton et al. 1998) to estimate N_2O emissions from agricultural soil management in next year's Inventory. In countries like the United States, which cover large land areas and have a diversity of climate, soils, land use and management systems, the use of an ecosystem process model such as DAYCENT can have great advantages over the single emission factor approach as specified in the IPCC Guidelines for estimating N_2O emissions. Potential advantages of a dynamic simulation-based approach include the use of actual observed weather, observed annual crop yields, and detailed soil and management information for estimating N_2O emissions. One of the greatest challenges involved in this effort will be obtaining the activity data (e.g., synthetic fertilizer and manure nitrogen inputs) at the appropriate spatial scale for use in the DAYCENT model. This effort will develop county-level estimates of N_2O emissions from agricultural soils that can be summed to produce a national-level estimate.

6.5. Field Burning of Agricultural Residues (IPCC Source Category 4F)

Large quantities of agricultural crop residues are produced by farming activities. There are a variety of ways to dispose of these residues. For example, agricultural residues can be left on or plowed back into the field, composted and then applied to soils, landfilled, or burned in the field. Alternatively, they can be collected and used as fuel, animal bedding material, or supplemental animal feed. Field burning of crop residues is not considered a net source of CO_2, because the carbon released to the atmosphere as CO_2 during burning is assumed to be reabsorbed during the next growing season. Crop residue burning is, however, a net source of CH_4, N_2O, CO, and NO_x, which are released during combustion.

Field burning is not a common method of agricultural residue disposal in the United States; therefore, emissions from this source are minor. The primary crop types whose residues are typically burned in the United States are wheat, rice, sugarcane, corn, barley, soybeans, and peanuts. Of these residues, less than 5 percent is burned each year, except for rice.[12] Annual emissions from this source over the period 1990 through 2002 have remained

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[12] The fraction of rice straw burned each year is significantly higher than that for other crops (see "Methodology" discussion below).

relatively constant, averaging approximately 0.7 Tg CO_2 Eq. (35 Gg) of CH_4, 0.4 Tg CO_2 Eq. (1 Gg) of N_2O, 706 Gg of CO, and 33 Gg of NO_x (see Table 6-19 and Table 6-20).

Table 6-19: Emissions from Field Burning of Agricultural Residues (Tg CO_2 Eq.)

Gas/Crop Type	1990		1996	1997	1998	1999	2000	2001	2002
CH_4	**0.7**		**0.8**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**	**0.7**
Wheat	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rice	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sugarcane	+		+	+	+	+	+	+	+
Corn	0.3		0.3	0.3	0.3	0.3	0.4	0.3	0.3
Barley	+		+	+	+	+	+	+	+
Soybeans	0.1		0.2	0.2	0.2	0.2	0.2	0.2	0.2
Peanuts	+		+	+	+	+	+	+	+
N_2O	**0.4**		**0.4**	**0.4**	**0.5**	**0.4**	**0.5**	**0.5**	**0.4**
Wheat	+		+	+	+	+	+	+	+
Rice	+		+	+	+	+	+	+	+
Sugarcane	+		+	+	+	+	+	+	+
Corn	0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1
Barley	+		+	+	+	+	+	+	+
Soybeans	0.2		0.2	0.3	0.3	0.3	0.3	0.3	0.3
Peanuts	+		+	+	+	+	+	+	+
Total	**1.1**		**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.1**

+ Does not exceed 0.05 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Table 6-20: Emissions from Field Burning of Agricultural Residues (Gg)*

Gas/Crop Type	1990		1996	1997	1998	1999	2000	2001	2002
CH_4	**33**		**36**	**37**	**38**	**37**	**38**	**37**	**34**
Wheat	7		5	6	6	5	5	5	4
Rice	4		4	3	3	4	4	4	3
Sugarcane	1		1	1	1	1	1	1	1
Corn	13		16	16	17	16	17	16	15
Barley	1		1	1	1	+	1	+	+
Soybeans	7		9	10	10	10	10	11	10
Peanuts	+		+	+	+	+	+	+	+
N_2O	**1**		**1**	**1**	**1**	**1**	**1**	**1**	**1**
Wheat	+		+	+	+	+	+	+	+
Rice	+		+	+	+	+	+	+	+
Sugarcane	+		+	+	+	+	+	+	+
Corn	+		+	+	+	+	+	+	+
Barley	+		+	+	+	+	+	+	+
Soybeans	1		1	1	1	1	1	1	1
Peanuts	+		+	+	+	+	+	+	+
CO	**689**		**753**	**767**	**788**	**767**	**790**	**770**	**706**
Wheat	137		114	124	128	115	112	98	81
Rice	86		91	72	64	76	76	77	60
Sugarcane	18		19	21	22	23	24	23	24
Corn	282		328	328	347	336	353	338	320
Barley	16		15	13	13	10	12	9	8
Soybeans	148		183	207	211	204	212	222	210
Peanuts	2		2	2	2	2	2	3	2
NO_x	**28**		**32**	**34**	**35**	**34**	**35**	**35**	**33**
Wheat	4		3	3	3	3	3	3	2
Rice	3		3	3	2	3	3	3	2

Sugarcane	+		+	+	+	+	+	+	+
Corn	7		8	8	8	8	8	8	8
Barley	1		+	+	+	+	+	+	+
Soybeans	14		17	20	20	19	20	21	20
Peanuts	+		+	+	+	+	+	+	+

* Full molecular weight basis.
+ Does not exceed 0.5 Gg
Note: Totals may not sum due to independent rounding.

Methodology

The methodology for estimating greenhouse gas emissions from field burning of agricultural residues is consistent with the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). In order to estimate the amounts of carbon and nitrogen released during burning, the following equations were used:[13]

Carbon Released = (Annual Crop Production) × (Residue/Crop Product Ratio)
× (Fraction of Residues Burned *in situ*) × (Dry Matter Content of the Residue)
× (Burning Efficiency) × (Carbon Content of the Residue) × (Combustion Efficiency)[14]

Nitrogen Released = (Annual Crop Production) × (Residue/Crop Product Ratio)
× (Fraction of Residues Burned *in situ*) × (Dry Matter Content of the Residue)
× (Burning Efficiency) × (Nitrogen Content of the Residue) × (Combustion Efficiency)

Emissions of CH_4 and CO were calculated by multiplying the amount of carbon released by the appropriate IPCC default emission ratio (i.e., CH_4-C/C or CO-C/C). Similarly, N_2O and NO_x emissions were calculated by multiplying the amount of nitrogen released by the appropriate IPCC default emission ratio (i.e., N_2O-N/N or NO_x-N/N).

The crop residues that are burned in the United States were determined from various state-level greenhouse gas emission inventories (ILENR 1993, Oregon Department of Energy 1995, Wisconsin Department of Natural Resources 1993) and publications on agricultural burning in the United States (Jenkins et al. 1992, Turn et al. 1997, EPA 1992).

Crop production data for all crops except rice in Florida and Oklahoma were taken from the USDA's *Field Crops, Final Estimates 1987-1992, 1992-1997* (USDA 1994, 1998), *Crop Production 1999 Summary* (USDA 2000), *Crop Production 2000 Summary* (USDA 2001), *Crop Production 2001 Summary* (USDA 2002), and *Crop Production 2002 Summary* (USDA 2003). Rice production data for Florida and Oklahoma, which are not collected by USDA, were estimated by applying average primary and ratoon crop yields for Florida (Schueneman and Deren 2002) to Florida acreages (Schueneman 1999b, 2001; Deren 2002; Kirstein 2003) and Oklahoma acreages[15] (Lee 2003). The production data for the crop types whose residues are burned are presented in Table 6-21.

[13] Note: As is explained later in this section, the fraction of rice residues burned varies among states, so these equations were applied at the state level for rice. These equations were applied at the national level for all other crop types.

[14] Burning Efficiency is defined as the fraction of dry biomass exposed to burning that actually burns. Combustion Efficiency is defined as the fraction of carbon in the fire that is oxidized completely to CO_2. In the methodology recommended by the IPCC, the "burning efficiency" is assumed to be contained in the "fraction of residues burned" factor. However, the number used here to estimate the "fraction of residues burned" does not account for the fraction of exposed residue that does not burn. Therefore, a "burning efficiency factor" was added to the calculations.

[15] Rice production yield data are not available for Oklahoma so the Florida values are used as a proxy.

The percentage of crop residue burned was assumed to be 3 percent for all crops in all years, except rice, based on state inventory data (ILENR 1993, Oregon Department of Energy 1995, Noller 1996, Wisconsin Department of Natural Resources 1993, and Cibrowski 1996).[16] Estimates of the percentage of rice residue burned were derived from state-level estimates of the percentage of rice area burned each year, which were multiplied by state-level, annual rice production statistics. The annual percentages of rice area burned in each state were obtained from the agricultural extension agents in each state and reports of the California Air Resources Board (CARB) (Bollich 2000; Deren 2002; Guethle 1999, 2000, 2001, 2002, 2003; Fife 1999; California Air Resources Board 1999, 2001; Klosterboer 1999a, 1999b, 2000, 2001, 2002, 2003; Lindberg 2002, 2003; Linscombe 1999a, 1999b, 2001, 2002, 2003; Mutters 2002, 2003; Najita 2000, 2001; Schueneman 1999a, 1999b, 2001; Slaton 1999a, 1999b, 2000; Street 1999a, 1999b, 2000, 2001, 2002, 2003; Wilson 2001, 2002, 2003) (see Table 6-22 and Table 6-23). The estimates provided for Arkansas and Florida remained constant over the entire 1990 through 2002 period, while the estimates for all other states varied over the time series. For California, it was assumed that the annual percents of rice area burned in the Sacramento Valley are representative of burning in the entire state, because the Sacramento Valley accounts for over 95 percent of the rice acreage in California (Fife 1999). These values declined between 1990 and 2002 because of a legislated reduction in rice straw burning (Lindberg 2002) (see Table 6-23).

All residue/crop product mass ratios except sugarcane were obtained from Strehler and Stützle (1987). The datum for sugarcane is from University of California (1977). Residue dry matter contents for all crops except soybeans and peanuts were obtained from Turn et al. (1997). Soybean dry matter content was obtained from Strehler and Stützle (1987). Peanut dry matter content was obtained through personal communications with Jen Ketzis (1999), who accessed Cornell University's Department of Animal Science's computer model, Cornell Net Carbohydrate and Protein System. The residue carbon contents and nitrogen contents for all crops except soybeans and peanuts are from Turn et al. (1997). The residue carbon content for soybeans and peanuts is the IPCC default (IPCC/UNEP/OECD/IEA 1997). The nitrogen content of soybeans is from Barnard and Kristoferson (1985). The nitrogen content of peanuts is from Ketzis (1999). These data are listed in Table 6-24. The burning efficiency was assumed to be 93 percent, and the combustion efficiency was assumed to be 88 percent, for all crop types (EPA 1994). Emission ratios for all gases (see Table 6-25) were taken from the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

Table 6-21: Agricultural Crop Production (Thousand Metric Tons of Product)

Crop	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Wheat	74,292	61,980	67,534	69,327	62,569	60,758	53,262	43,992
Rice	7,113	7,837	8,346	8,578	9,391	8,703	9,794	9,601
Sugarcane	25,525	26,729	28,766	30,896	32,023	32,762	31,377	32,597
Corn*	201,534	234,518	233,864	247,882	239,549	251,854	241,485	228,805
Barley	9,192	8,544	7,835	7,667	6,103	6,939	5,430	4,940
Soybeans	52,416	64,780	73,176	74,598	72,223	75,055	78,671	74,291
Peanuts	1,635	1,661	1,605	1,798	1,737	1,481	1,940	1,506

*Corn for grain (i.e., excludes corn for silage).

Table 6-22: Percentage of Rice Area Burned by State

State	**Percent Burned 1990-1998**	**Percent Burned 1999**	**Percent Burned 2000**	**Percent Burned 2001**	**Percent Burned 2002**
Arkansas	13	13	13	13	16
California	variable[a]	27	27	23	13
Florida[b]	0	0	0	0	0
Louisiana	6	0	5	4	3
Mississippi	10	40	40	40	8

[16] Rice cultivated in Oklahoma is an exception. As no percent burned data are known, it was assumed that 3 percent (the general crop burning default) of rice residue in Oklahoma is burned annually.

Missouri	5	5	8	5	5
Oklahoma[c]	3	3	3	3	3
Texas	1	2	0	0	0

[a] Values provided in Table 6-23.
[b] Burning of crop residues is illegal in Florida.
[C] Percent of rice burned is unknown in Oklahoma; the general default for percent of crop burned is used to approximate.

Table 6-23: Percentage of Rice Area Burned in California

Year	California
1990	75
1996	63
1997	34
1998	33
1999	27
2000	27
2001	23
2002	13

Table 6-24: Key Assumptions for Estimating Emissions from Agricultural Residue Burning

Crop	Residue/Crop Ratio	Fraction of Residue Burned	Dry Matter Fraction	Carbon Fraction	Nitrogen Fraction	Burning Efficiency	Combustion Efficiency
Wheat	1.3	0.03	0.93	0.4428	0.0062	0.93	0.88
Rice	1.4	variable	0.91	0.3806	0.0072	0.93	0.88
Sugarcane	0.8	0.03	0.62	0.4235	0.0040	0.93	0.88
Corn	1.0	0.03	0.91	0.4478	0.0058	0.93	0.88
Barley	1.2	0.03	0.93	0.4485	0.0077	0.93	0.88
Soybeans	2.1	0.03	0.87	0.4500	0.0230	0.93	0.88
Peanuts	1.0	0.03	0.86	0.4500	0.0106	0.93	0.88

Table 6-25: Greenhouse Gas Emission Ratios

Gas	Emission Ratio
CH_4[a]	0.005
CO[a]	0.060
N_2O[b]	0.007
NO_x[b]	0.121

[a] Mass of carbon compound released (units of C) relative to mass of total carbon released from burning (units of C).
[b] Mass of nitrogen compound released (units of N) relative to mass of total nitrogen released from burning (units of N).

Uncertainty

One source of uncertainty in the calculation of non-CO_2 emissions from field burning of agricultural residues is in the estimates of the fraction of residue of each crop type burned each year. Data on the fraction burned, as well as the gross amount of residue burned each year, are not collected at either the national or state level. In addition, burning practices are highly variable among crops, as well as among states. The fractions of residue burned used in these calculations were based upon information collected by state agencies and in published literature. Based on expert judgment, uncertainty in the fraction of crop residue burned ranged from zero to 100 percent depending on the state and crop type.

Based on expert judgment, the uncertainty in production for all crops considered here is estimated to be 5 percent.

Residue/crop product ratios can vary among cultivars. For all crops except sugarcane, generic residue/crop product ratios, rather than ratios specific to the United States, have been used. An uncertainty of 10 percent was applied to the residue/crop product ratios for all crops.

Based on the range given for measurements of soybean dry matter fraction (Strehler and Stützle 1994), residue dry matter contents were assigned an uncertainty of 3.1 percent for all crop types

Burning and combustion efficiencies were assigned an uncertainty of 5 percent based on expert judgment.

The N_2O emission ratio was estimated to have an uncertainty of 28.6 percent based on the range reported in IPCC (2000). The uncertainty estimated for the CH_4 emission ratio was 40 percent based on the range of ratios reported in IPCC (2000).

These uncertainties were combined in a Tier 1 uncertainty analysis, as recommended by IPCC (2000). The 95 percent confidence intervals for CH_4 emissions from the burning of agricultural residues in the United States in 2002 were approximately 70 and 73 percent of the estimated emissions, respectively. Confidence boundaries for the emissions are given in Table 6-26.

Table 6-26: Quantitative Uncertainty Estimates for CH_4 and N_2O Emissions from Field Burning of Agricultural Residues (Tg CO_2 Eq. and Percent)

IPCC Source Category	**Gas**	**Year 2002 Emissions (Tg CO_2 Eq.)**	**Uncertainty (%)**	**Uncertainty Range Relative to 2002 Emission Estimate (Tg CO_2 Eq.)**	
				Lower Bound	**Upper Bound**
Field Burning of Agricultural Residues	CH_4	0.7	70%	0.2	1.2
Field Burning of Agricultural Residues	N_2O	0.4	73%	0.1	0.7

Recalculations Discussion

This year, it was determined that Oklahoma was a rice-growing state. As a consequence, the activity data used to estimate greenhouse gas emissions from field burning of agricultural residues have been revised to include rice residues from that state. Additionally, Florida rice production is now estimated using current, state-specific yield figures from the published literature, rather than industry estimates. These changes together caused less than a 1 percent average annual increase in emissions. These changes resulted an average annual increase of less than 0.01 Tg CO_2 Eq. (0.8 percent) in CH_4 emissions and an average annual increase of less than 0.01 Tg CO_2 Eq. (0.7 percent) in N_2O emissions for the period 1990 through 2001.

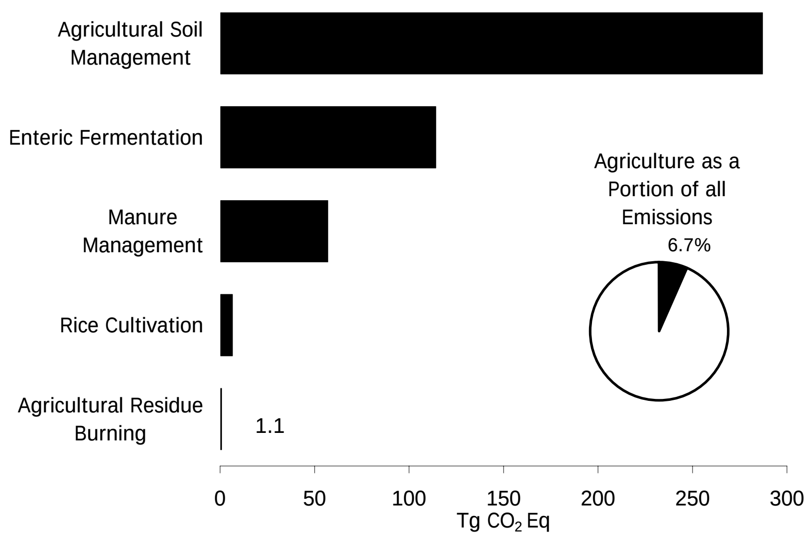
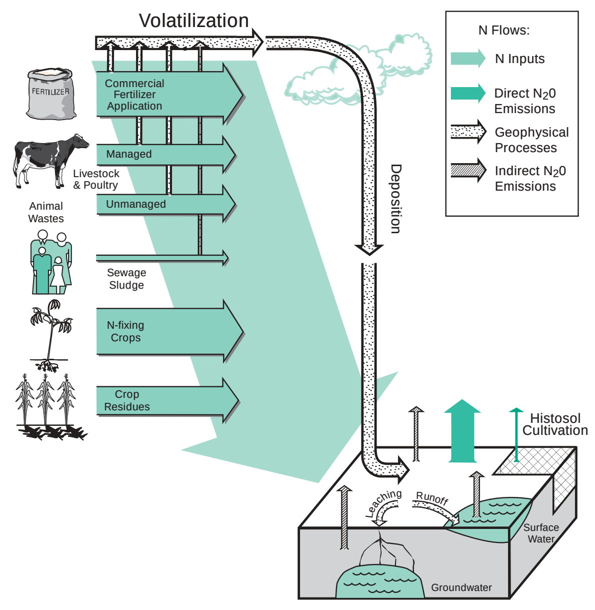


Figure 6-1: 2002 Agriculture Chapter Greenhouse Gas Sources

Figure 6-2

Direct and Indirect N_2O Emissions from Agricultural Soils



This graphic illustrates the sources and pathways of nitrogen that result in direct and indirect N_2O emissions from agricultural soils in the United States. Sources of nitrogen applied to, or deposited on, soils are respresented with arrows on the left-hand side of the graphic. Emissions pathways are also shown with arrows. On the lower right-hand side is a cut-away view of a representative section of a managed soil; histosol cultivation is represented here.

Descriptions of Figures: Agriculture

Figure 6-1 illustrates the data presented in Table 6-1. In addition, there is a pie chart that indicates that agriculture processes made up 6.7 % of U.S. greenhouse gas emissions in 2002.

Figure 6-2 illustrates the sources and pathways of nitrogen that result in direct and indirect N_2O emissions from agricultural soils in the U.S. Sources of nitrogen applied to, or deposited on, soils are represented with arrows on the left-hand side of the graphic. Emissions pathways are also shown with arrows. On the lower right-hand side is a cut-away view of a representative section of a managed soil; histosol cultivation is represented here.