3.10. Methodology for Estimating CH_4 Emissions from Enteric Fermentation

Methane emissions from enteric fermentation were estimated for seven livestock categories: cattle, horses, sheep, swine, goats, American bison, and the non-horse equines (mules and asses). Emissions from cattle represent the majority of U.S. emissions from enteric fermentation; consequently, a more detailed IPCC Tier 2 methodology was used to estimate emissions from cattle. The IPCC Tier 1 methodology was used to estimate emissions for the other types of livestock, including horses, goats, sheep, swine, American bison, and mules and asses.

Estimate Methane Emissions from Cattle

This section describes the process used to estimate CH_4 emissions from enteric fermentation from cattle using the Cattle Enteric Fermentation Model (CEFM). The CEFM was developed based on recommendations provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and uses information on population, energy requirements, digestible energy, and CH_4 conversion rates to estimate CH_4 emissions.[73] The emission methodology consists of the following three steps: (1) characterize the cattle population to account for animal population categories with different emission profiles; (2) characterize cattle diets to generate information needed to estimate emission factors; and (3) estimate emissions using these data and the IPCC Tier 2 equations.

Step 1: Characterize U.S. Cattle Population

The state-level cattle population estimates are based on data obtained from the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service Quick Stats database (USDA 2015). A summary of the annual average populations upon which all livestock-related emissions are based is provided in Table A-178. Cattle populations used in the Enteric Fermentation source category were estimated using the cattle transition matrix in the CEFM, which uses January 1 USDA population estimates and weight data to simulate the population of U.S. cattle from birth to slaughter, and results in an estimate of the number of animals in a particular cattle grouping while taking into account the monthly rate of weight gain, the average weight of the animals, and the death and calving rates. The use of supplemental USDA data and the cattle transition matrix in the CEFM results in cattle population estimates for this sector differing slightly from the January 1 or July 1 USDA point estimates and the cattle population data obtained from the Food and Agriculture Organization of the United Nations (FAO).

Table A-178: Cattle Population Estimates from the CEFM Transition Matrix for 1990–2014 (1,000 head)

Livestock Type	1990	1995	2000	2005	2010	2011	2012	2013	2014
Dairy									
Dairy Calves (0–6 months)	5,369	5,091	4,951	4,628	4,666	4,709	4,770	4,758	4,727
Dairy Cows	10,015	9,482	9,183	9,004	9,087	9,156	9,236	9,221	9,208
Dairy Replacements (7–11 months)	1,214	1,216	1,196	1,257	1,351	1,362	1,348	1,341	1,356
Dairy Replacements (12–23 months)	2,915	2,892	2,812	2,905	3,194	3,215	3,233	3,185	3,190
Beef									
Beef Calves (0–6 months)	16,909	18,177	17,431	16,918	16,067	15,817	15,288	14,859	14,946
Bulls	2,160	2,385	2,293	2,214	2,190	2,165	2,100	2,074	2,038
Beef Cows	32,455	35,190	33,575	32,674	31,440	30,913	30,282	29,631	29,085
Beef Replacements (7–11 months)	1,269	1,493	1,313	1,363	1,238	1,232	1,263	1,291	1,342
Beef Replacements (12–23 months)	2,967	3,637	3,097	3,171	3,050	2,889	2,968	3,041	3,113
Steer Stockers	10,321	11,716	8,724	8,185	8,234	7,568	7,173	7,457	7,411
Heifer Stockers	5,946	6,699	5,371	5,015	5,061	4,752	4,456	4,455	4,384
Feedlot Cattle	9,549	11,064	13,006	12,652	13,204	13,601	13,328	13,267	13,222

73 Additional information on the Cattle Enteric Fermentation Model can be found in ICF (2006).

The population transition matrix in the CEFM simulates the U.S. cattle population over time and provides an estimate of the population age and weight structure by cattle type on a monthly basis.[74] Since cattle often do not remain in a single population type for an entire year (e.g., calves become stockers, stockers become feedlot animals), and emission profiles vary both between and within each cattle type, these monthly age groups are tracked in the enteric fermentation model to obtain more accurate emission estimates than would be available from annual point estimates of population (such as available from USDA statistics) and weight for each cattle type.

The transition matrix tracks both dairy and beef populations, and divides the populations into males and females, and subdivides the population further into specific cattle groupings for calves, replacements, stockers, feedlot, and mature animals. The matrix is based primarily on two types of data: population statistics and weight statistics (including target weights, slaughter weights, and weight gain). Using the weight data, the transition matrix simulates the growth of animals over time by month. The matrix also relies on supplementary data, such as feedlot placement statistics, slaughter statistics, death rates, and calving rates.

The basic method for tracking population of animals per category is based on the number of births (or graduates) into the monthly age group minus those animals that die or are slaughtered and those that graduate to the next category (such as stockers to feedlot placements).

Each stage in the cattle lifecycle was modeled to simulate the cattle population from birth to slaughter. This level of detail accounts for the variability in CH_4 emissions associated with each life stage. Given that a stage can last less than one year (e.g., calves are usually weaned between 4 and 6 months of age), each is modeled on a per-month basis. The type of cattle also influences CH_4 emissions (e.g., beef versus dairy). Consequently, there is an independent transition matrix for each of three separate lifecycle phases, 1) calves, 2) replacements and stockers, and 3) feedlot animals. In addition, the number of mature cows and bulls are tabulated for both dairy and beef stock. The transition matrix estimates total monthly populations for all cattle subtypes. These populations are then reallocated to the state level based on the percent of the cattle type reported in each state in the January 1 USDA data. Each lifecycle is discussed separately below, and the categories tracked are listed in Table A-179.

Table A-179: Cattle Population Categories Used for Estimating CH_4 Emissions

Dairy Cattle	Beef Cattle
Calves	Calves
Heifer Replacements	Heifer Replacements
Cows	Heifer and Steer Stockers
	Animals in Feedlots (Heifers & Steer)
	Cows
	Bulls[a]

[a] Bulls (beef and dairy) are accounted for in a single category.

The key variables tracked for each of these cattle population categories are as follows:

Calves. Although enteric emissions are only calculated for 4- to 6-month old calves, it is necessary to calculate populations from birth as emissions from manure management require total calf populations and the estimates of populations for older cattle rely on the available supply of calves from birth. The number of animals born on a monthly basis was used to initiate monthly cohorts and to determine population age structure. The number of calves born each month was obtained by multiplying annual births by the percentage of births per month. Annual birth information for each year was taken from USDA (2015). For dairy cows, the number of births is assumed to be distributed equally throughout the year (approximately 8.3 percent per month) while beef births are distributed according to Table A-180, based on approximations from the National Animal Health Monitoring System (NAHMS) (USDA/APHIS/VS 1998, 1994, 1993). To determine whether calves were born to dairy or beef cows, the dairy cow calving rate (USDA/APHIS/VS 2002, USDA/APHIS/VS 1996) was multiplied by the total dairy cow population to determine the number of births attributable to dairy cows, with the remainder assumed to be attributable to beef cows. Total annual calf births are obtained from USDA, and distributed into monthly cohorts by cattle type (beef or dairy). Calf growth is modeled by month, based on estimated monthly weight gain for each cohort (approximately 61 pounds per month). The total calf population is modified through time to account for veal calf slaughter at 4 months and a calf death loss of 0.35 percent annually (distributed across age cohorts up to 6 months of age). An example of a transition matrix for calves is shown in Table A-181. Note that 1- to 6-month old calves in January of each year have been tracked through the model based on births and death loss from the previous year.

[74] Mature animal populations are not assumed to have significant monthly fluctuations, and therefore the populations utilized are the January estimates downloaded from USDA (2015).

Table A-180: Estimated Beef Cow Births by Month

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7%	15%	28%	22%	9%	3%	2%	2%	3%	4%	3%	3%

Table A-181: Example of Monthly Average Populations from Calf Transition Matrix (1,000 head)

Age (month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6	1,138	1,131	1,389	1,612	1,554	1,538	2,431	4,488	7,755	6,298	2,971	1,522
5	1,131	1,389	1,612	1,554	1,538	2,431	4,488	7,755	6,298	2,971	1,522	1,153
4	1,389	1,612	1,554	1,538	2,431	4,488	7,755	6,298	2,971	1,522	1,153	1,144
3	1,612	1,554	1,538	2,431	4,488	7,755	6,298	2,971	1,522	1,153	1,144	1,402
2	1,554	1,538	2,431	4,488	7,755	6,298	2,971	1,522	1,153	1,144	1,402	1,625
1	1,538	2,431	4,488	7,755	6,298	2,971	1,522	1,153	1,144	1,402	1,625	1,565
0	2,431	4,488	7,755	6,298	2,971	1,522	1,153	1,144	1,402	1,625	1,565	1,547

Note: The cohort starting at age 0 months on January 1 is tracked in order to illustrate how a single cohort moves through the transition matrix. Each month, the cohort reflects the decreases in population due to the estimated 0.35 percent annual death loss, and between months 4 and 5, a more significant loss is seen than in other months due to estimated veal slaughter.

Replacements and Stockers. At 7 months of age, calves "graduate" and are separated into the applicable cattle types. First the number of replacements required for beef and dairy cattle are calculated based on estimated death losses and population changes between beginning and end of year population estimates. Based on the USDA estimates for "replacement beef heifers" and "replacement dairy heifers," the transition matrix for the replacements is back-calculated from the known animal totals from USDA, and the number of calves needed to fill that requirement for each month is subtracted from the known supply of female calves. All female calves remaining after those needed for beef and dairy replacements are removed and become "stockers" that can be placed in feedlots (along with all male calves). During the stocker phase animals are subtracted out of the transition matrix for placement into feedlots based on feedlot placement statistics from USDA (2015).

The data and calculations that occur for the stocker category include matrices that estimate the population of backgrounding heifers and steer, as well as a matrix for total combined stockers. The matrices start with the beginning of year populations in January and model the progression of each cohort. The age structure of the January population is based on estimated births by month from the previous two years, although in order to balance the population properly, an adjustment is added that slightly reduces population percentages in the older populations. The populations are modified through addition of graduating calves (added in month 7, bottom row of Table A-182) and subtraction through death loss and animals placed in feedlots. Eventually, an entire cohort population of stockers may reach zero, indicating that the complete cohort has been transitioned into feedlots. An example of the transition matrix for stockers is shown in Table A-182.

Table A-182: Example of Monthly Average Populations from Stocker Transition Matrix (1,000 head)

Age (month)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
23	185	180	104	37	15	9	8	8	6	3	1	0
22	320	146	49	19	12	9	9	9	6	3	17	181
21	260	69	25	14	11	11	11	8	6	68	218	313
20	123	35	19	14	14	13	10	8	133	331	387	254
19	63	27	19	17	16	13	10	196	472	615	318	120
18	48	27	23	20	16	13	241	610	900	514	149	61
17	47	33	27	19	15	295	709	1,179	759	237	129	47
16	58	38	26	19	363	828	1,380	1,000	348	340	47	46
15	67	36	25	452	977	1,619	1,172	456	603	47	46	57
14	65	36	599	1,172	1,921	1,378	534	862	47	46	57	66
13	64	845	1,478	2,309	1,639	629	1,117	47	46	57	66	63
12	982	1,602	2,556	1,858	755	1,512	214	46	57	66	63	63
11	1,814	2,770	2,056	855	1,872	277	138	76	89	81	80	1,016
10	3,133	2,255	945	2,241	385	189	184	231	209	185	1,135	2,445
9	2,545	1,062	2,502	484	335	341	420	372	371	1,292	2,786	5,299
8	1,200	2,951	664	482	557	759	658	649	1,503	3,247	5,984	4,877
7	3,381	800	794	956	1,160	1,109	1,100	1,876	3,666	6,504	5,243	2,353

Note: The cohort starting at age 7 months on January 1 is tracked in order to illustrate how a single cohort moves through the transition matrix. Each month, the cohort reflects the decreases in population due to the estimated 0.35 percent annual death loss and loss due to placement in feedlots (the latter resulting in the majority of the loss from the matrix).

In order to ensure a balanced population of both stockers and placements, additional data tables are utilized in the stocker matrix calculations. The tables summarize the placement data by weight class and month, and is based on the total number of animals within the population that are available to be placed in feedlots and the actual feedlot placement statistics provided by USDA (2015). In cases where there are discrepancies between the USDA estimated placements by weight class and the calculated animals available by weight, the model pulls available stockers from one higher weight category if available. If there are still not enough animals to fulfill requirements the model pulls animals from one lower weight category. In the current time series, this method was able to ensure that total placement data matched USDA estimates, and no shortfalls have occurred.

In addition, average weights were tracked for each monthly age group using starting weight and monthly weight gain estimates. Weight gain (i.e., pounds per month) was estimated based on weight gain needed to reach a set target weight, divided by the number of months remaining before target weight was achieved. Birth weight was assumed to be 88 pounds for both beef and dairy animals. Weaning weights were estimated at 515 pounds. Other reported target weights were available for 12-, 15-, 24-, and 36-month-old animals, depending on the animal type. Beef cow mature weight was taken from measurements provided by a major British Bos taurus breed (Enns 2008) and increased during the time series through 2007.[75] Bull mature weight was calculated as 1.5 times the beef cow mature weight (Doren et al. 1989). Beef replacement weight was calculated as 70 percent of mature weight at 15 months and 85 percent of mature weight at 24 months. As dairy weights are not a trait that is typically tracked, mature weight for dairy cows was estimated at 1,500 pounds for all years, based on a personal communication with Kris Johnson (2010) and an estimate from Holstein Association USA (2010).[76] Dairy replacement weight at 15 months was assumed to be 875 pounds and 1,300 pounds at 24 months. Live slaughter weights were estimated from dressed slaughter weight (USDA 2015) divided by 0.63. This ratio represents the dressed weight (i.e., weight of the carcass after removal of the internal organs), to the live weight (i.e., weight taken immediately before slaughter). The annual typical animal mass for each livestock type are presented in Table A-183.

Weight gain for stocker animals was based on monthly gain estimates from Johnson (1999) for 1989, and from average daily estimates from Lippke et al. (2000), Pinchack et al. (2004), Platter et al. (2003), and Skogerboe et al. (2000) for 2000. Interim years were calculated linearly, as shown in Table A-184, and weight gain was held constant starting in 2000. Table A-184 provides weight gains that vary by year in the CEFM.

[75] Mature beef weight is held constant after 2007 but future inventory submissions will incorporate known trends through 2007 and extrapolate to future years, as noted in the Planned Improvements section of 5.1 Enteric Fermentation.

[76] Mature dairy weight is based solely on Holstein weight, so could be higher than the national average. Future Inventory submissions will consider other dairy breeds, as noted in the Planned Improvements section of 5.1 Enteric Fermentation.

Table A-183: Typical Animal Mass (lbs)

Year/Cattle Type	Calves	Dairy Cows[a]	Dairy Replacements[b]	Beef Cows[a]	Bulls[a]	Beef Replacements[b]	Steer Stockers[b]	Heifer Stockers[b]	Steer Feedlot[b]	Heifer Feedlot[b]
1990	269	1,500	900	1,221	1,832	820	692	652	923	846
1991	270	1,500	898	1,225	1,838	822	695	656	934	856
1992	269	1,500	897	1,263	1,895	841	714	673	984	878
1993	270	1,500	899	1,280	1,920	852	721	683	930	864
1994	270	1,500	898	1,280	1,920	854	721	689	944	876
1995	270	1,500	898	1,282	1,923	858	735	701	947	880
1996	269	1,500	898	1,285	1,928	859	739	707	940	878
1997	270	1,500	900	1,286	1,929	861	737	708	939	877
1998	270	1,500	897	1,296	1,944	866	736	710	957	892
1999	270	1,500	899	1,292	1,938	862	731	709	960	895
2000	270	1,500	897	1,272	1,908	849	720	702	961	899
2001	270	1,500	898	1,272	1,908	850	726	707	963	901
2002	270	1,500	897	1,276	1,914	852	726	708	982	915
2003	270	1,500	900	1,308	1,962	872	719	702	973	905
2004	270	1,500	897	1,323	1,985	878	719	702	967	905
2005	270	1,500	895	1,327	1,991	880	718	706	975	917
2006	270	1,500	898	1,341	2,012	890	725	713	984	925
2007	270	1,500	897	1,348	2,022	895	721	707	992	928
2008	270	1,500	898	1,348	2,022	895	721	705	1,000	939
2009	270	1,500	896	1,348	2,022	895	731	715	1,007	948
2010	270	1,500	898	1,348	2,022	897	727	714	997	938
2011	270	1,500	898	1,348	2,022	892	721	713	990	932
2012	270	1,500	899	1,348	2,022	892	714	707	1,004	946
2013	270	1,500	899	1,348	2,022	893	719	710	1,017	958
2014	270	1,500	898	1,348	2,022	891	722	713	1,023	962

[a] Input into the model.
[b] Annual average calculated in model based on age distribution.

Table A-184: Weight Gains that Vary by Year (lbs)

Year/Cattle Type	Steer Stockers to 12 months (lbs/day)	Steer Stockers to 24 months (lbs/day)	Heifer Stockers to 12 months (lbs/day)	Heifer Stockers to 24 months (lbs/day)
1990	1.53	1.23	1.23	1.08
1991	1.56	1.29	1.29	1.15
1992	1.59	1.35	1.35	1.23
1993	1.62	1.41	1.41	1.30
1994	1.65	1.47	1.47	1.38
1995	1.68	1.53	1.53	1.45
1996	1.71	1.59	1.59	1.53
1997	1.74	1.65	1.65	1.60
1998	1.77	1.71	1.71	1.68
1999	1.80	1.77	1.77	1.75
2000–onwards	1.83	1.83	1.83	1.83

Sources: Enns (2008), Johnson (1999), Lippke et al. (2000), NRC (1999), Pinchack et al. (2004), Platter et al. (2003), Skogerboe et al. (2000).

Feedlot Animals. Feedlot placement statistics from USDA provide data on the placement of animals from the stocker population into feedlots on a monthly basis by weight class. The model uses these data to shift a sufficient number of animals from the stocker cohorts into the feedlot populations to match the reported placement data. After animals are placed in feedlots they progress through two steps. First, animals spend 25 days on a step-up diet to become acclimated to the new feed type (e.g., more grain than forage, along with new dietary supplements), during this time weight gain is estimated to be 2.7 to 3 pounds per day (Johnson 1999). Animals are then switched to a finishing diet (concentrated, high energy) for a period of time before they are slaughtered. Weight gain during finishing diets is estimated to be 2.9 to 3.3 pounds per day (Johnson 1999). The length of time an animal spends in a feedlot depends on the start weight (i.e., placement weight), the rate of weight gain during the start-up and finishing phase of diet, and the target weight (as determined by weights at slaughter). Additionally, animals remaining in feedlots at the end of the year are tracked for inclusion in the following year's emission and population counts. For 1990 to 1995, only the total placement data were available, therefore placements for each weight category (categories displayed in Table A-185) for those years are based on the average of monthly placements from the 1996 to 1998 reported figures. Placement data is available by weight class for all years from 1996 onward. Table A-185 provides a summary of the reported feedlot placement statistics for 2014.

Table A-185: Feedlot Placements in the United States for 2014 (Number of animals placed/1,000 Head)

Weight Placed	When:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
< 600 lbs		470	390	425	380	435	405	425	410	460	695	555	440
600 – 700 lbs		435	330	290	250	290	245	260	285	350	570	435	365
700 – 800 lbs		559	418	466	393	474	328	354	395	434	463	369	332
> 800 lbs		550	520	620	600	710	490	520	635	770	640	435	400
Total		**2,014**	**1,658**	**1,801**	**1,623**	**1,909**	**1,468**	**1,559**	**1,725**	**2,014**	**2,368**	**1,794**	**1,537**

Source: USDA (2015).
Note: Totals may not sum due to independent rounding.

Mature Animals. Energy requirements and hence, composition of diets, level of intake, and emissions for particular animals, are greatly influenced by whether the animal is pregnant or lactating. Information is therefore needed on the percentage of all mature animals that are pregnant each month, as well as milk production, to estimate CH_4 emissions. A weighted average percent of pregnant cows each month was estimated using information on births by month and average pregnancy term. For beef cattle, a weighted average total milk production per animal per month was estimated using information on typical lactation cycles and amounts (NRC 1999), and data on births by month. This process results in a range of weighted monthly lactation estimates expressed as pounds per animal per month. The monthly estimates for daily milk production by beef cows are shown in Table A-186. Annual estimates for dairy cows were taken from USDA milk production statistics. Dairy lactation estimates for 1990 through 2014 are shown in Table A-187. Beef and dairy cow and bull populations are assumed to remain relatively static throughout the year, as large fluctuations in population size are assumed to not occur. These estimates are taken from the USDA beginning and end of year population datasets.

Table A-186: Estimates of Monthly Milk Production by Beef Cows (lbs/cow)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Beef Cow Milk Production (lbs/ head)	3.3	5.1	8.7	12.0	13.6	13.3	11.7	9.3	6.9	4.4	3.0	2.8

Table A-187: Dairy Lactation Rates by State (lbs/ year/cow)

State/Year	1990	1995	2000	2005	2010	2011	2012	2013	2014
Alabama	12,214	14,176	13,920	14,000	14,182	14,300	13,000	13,000	13,625
Alaska	13,300	17,000	14,500	12,273	11,833	13,800	14,250	10,667	11,667
Arizona	17,500	19,735	21,820	22,679	23,452	23,473	23,979	23,626	24,347
Arkansas	11,841	12,150	12,436	13,545	12,750	11,917	13,300	11,667	13,714
California	18,456	19,573	21,130	21,404	23,025	23,438	23,457	23,178	23,785
Colorado	17,182	18,687	21,618	22,577	23,664	23,430	24,158	24,292	24,951
Connecticut	15,606	16,438	17,778	19,200	19,158	19,000	19,889	20,556	20,158
Delaware	13,667	14,500	14,747	16,622	16,981	18,300	19,542	19,521	20,146
Florida	14,033	14,698	15,688	16,591	18,711	19,067	19,024	19,374	20,382
Georgia	12,973	15,550	16,284	17,259	17,658	18,354	19,138	19,600	20,790
Hawaii	13,604	13,654	14,358	12,889	13,316	14,421	14,200	13,409	13,591
Idaho	16,475	18,147	20,816	22,332	22,647	22,926	23,376	23,440	24,127
Illinois	14,707	15,887	17,450	18,827	18,400	18,510	19,061	19,063	19,681
Indiana	14,590	15,375	16,568	20,295	20,094	20,657	21,440	21,761	21,865
Iowa	15,118	16,124	18,298	20,641	20,676	21,191	22,015	22,149	22,444
Kansas	12,576	14,390	16,923	20,505	20,983	21,016	21,683	21,881	22,064
Kentucky	10,947	12,469	12,841	12,896	14,769	14,342	15,135	15,070	15,905
Louisiana	11,605	11,908	12,034	12,400	11,750	12,889	13,059	12,875	13,600
Maine	14,619	16,025	17,128	18,030	18,344	18,688	18,576	19,548	20,000
Maryland	13,461	14,725	16,083	16,099	18,537	18,654	19,196	19,440	19,740
Massachusetts	14,871	16,000	17,091	17,059	17,286	16,923	18,250	17,692	17,923
Michigan	15,394	17,071	19,017	21,635	23,277	23,164	23,976	24,116	24,638
Minnesota	14,127	15,894	17,777	18,091	19,366	18,996	19,512	19,694	19,841
Mississippi	12,081	12,909	15,028	15,280	13,118	14,571	14,214	13,286	14,462
Missouri	13,632	14,158	14,662	16,026	14,596	14,611	14,979	14,663	15,539
Montana	13,542	15,000	17,789	19,579	20,643	20,571	21,357	21,286	21,500
Nebraska	13,866	14,797	16,513	17,950	19,797	20,579	21,179	21,574	22,130
Nevada	16,400	18,128	19,000	21,680	23,714	22,966	22,931	22,034	23,793
New Hampshire	15,100	16,300	17,333	18,875	19,600	20,429	19,643	20,923	20,143
New Jersey	13,538	13,913	15,250	16,000	17,500	16,875	18,571	18,143	18,143
New Mexico	18,815	18,969	20,944	21,192	24,551	24,854	24,694	24,944	25,093
New York	14,658	16,501	17,378	18,639	20,807	21,046	21,623	22,070	22,330
North Carolina	15,220	16,314	16,746	18,741	19,682	20,089	20,435	20,326	20,891
North Dakota	12,624	13,094	14,292	14,182	18,286	18,158	19,278	18,944	20,250
Ohio	13,767	15,917	17,027	17,567	19,446	19,194	19,833	20,178	20,318
Oklahoma	12,327	13,611	14,440	16,480	17,125	17,415	17,896	17,311	17,425
Oregon	16,273	17,289	18,222	18,876	20,331	20,488	20,431	20,439	20,605
Pennsylvania	14,726	16,492	18,081	18,722	19,847	19,495	19,549	19,797	20,157
Rhode Island	14,250	14,773	15,667	17,000	17,727	17,909	16,636	19,000	19,000
South Carolina	12,771	14,481	16,087	16,000	17,875	17,438	17,250	16,500	16,375
South Dakota	12,257	13,398	15,516	17,741	20,478	20,582	21,391	21,521	21,742
Tennessee	11,825	13,740	14,789	15,743	16,346	16,200	16,100	15,938	16,304
Texas	14,350	15,244	16,503	19,646	21,375	22,232	22,009	21,991	22,268
Utah	15,838	16,739	17,573	18,875	21,898	22,161	22,863	22,432	22,968
Vermont	14,528	16,210	17,199	18,469	18,537	18,940	19,316	19,448	20,197
Virginia	14,213	15,116	15,833	16,990	18,095	17,906	17,990	18,337	19,140
Washington	18,532	20,091	22,644	23,270	23,514	23,727	23,794	23,820	24,117
West Virginia	11,250	12,667	15,588	14,923	15,700	15,700	15,400	15,200	15,556
Wisconsin	13,973	15,397	17,306	18,500	20,630	20,599	21,436	21,693	21,869
Wyoming	12,337	13,197	13,571	14,878	20,067	20,517	20,650	21,367	21,583

Source: USDA (2015).

Step 2: Characterize U.S. Cattle Population Diets

To support development of digestible energy (DE, the percent of gross energy intake digested by the animal) and CH_4 conversion rate (Y_m, the fraction of gross energy converted to CH_4) values for each of the cattle population categories, data were collected on diets considered representative of different regions. For both grazing animals and animals being fed mixed rations, representative regional diets were estimated using information collected from state livestock specialists, the USDA, expert opinion, and other literature sources. The designated regions for this analysis for dairy cattle for all years and foraging beef cattle from 1990 through 2006 are shown in Table A-188. For foraging beef cattle from 2007 onwards, the regional designations were revised based on data available from the NAHMS 2007–2008 survey on cow-calf system management practices (USDA:APHIS:VS 2010) and are shown in and Table A-189. The data for each of the diets (e.g., proportions of different feed constituents, such as hay or grains) were used to determine feed chemical composition for use in estimating DE and Y_m for each animal type.

Table A-188: Regions used for Characterizing the Diets of Dairy Cattle (all years) and Foraging Cattle from 1990–2006

West	California	Northern Great Plains	Midwestern	Northeast	Southcentral	Southeast
Alaska	California	Colorado	Illinois	Connecticut	Arkansas	Alabama
Arizona		Kansas	Indiana	Delaware	Louisiana	Florida
Hawaii		Montana	Iowa	Maine	Oklahoma	Georgia
Idaho		Nebraska	Michigan	Maryland	Texas	Kentucky
Nevada		North Dakota	Minnesota	Massachusetts		Mississippi
New Mexico		South Dakota	Missouri	New Hampshire		North Carolina
Oregon		Wyoming	Ohio	New Jersey		South Carolina
Utah			Wisconsin	New York		Tennessee
Washington				Pennsylvania		Virginia
				Rhode Island		
				Vermont		
				West Virginia		

Source: USDA (1996).

Table A-189: Regions used for Characterizing the Diets of Foraging Cattle from 2007–2014

West	Central	Northeast	Southeast
Alaska	Illinois	Connecticut	Alabama
Arizona	Indiana	Delaware	**Arkansas**
California	Iowa	Maine	Florida
Colorado	**Kansas**	Maryland	Georgia
Hawaii	Michigan	Massachusetts	Kentucky
Idaho	Minnesota	New Hampshire	**Louisiana**
Montana	Missouri	New Jersey	Mississippi
Nevada	**Nebraska**	New York	North Carolina
New Mexico	**North Dakota**	Pennsylvania	**Oklahoma**
Oregon	Ohio	Rhode Island	South Carolina
Utah	**South Dakota**	Vermont	Tennessee
Washington	Wisconsin	West Virginia	**Texas**
Wyoming			Virginia

Source: Based on data from USDA:APHIS:VS (2010).
Note: States in **bold** represent a change in region from the 1990–2006 assessment.

DE and Y_m vary by diet and animal type. The IPCC recommends Y_m values of 3.0 ± 1.0 percent for feedlot cattle and 6.5 ± 1.0 percent for all other cattle (IPCC 2006). 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 for dairy and beef cattle. Digestible energy and Y_m values were estimated across the time series for each cattle population category based on physiological modeling, published values, and/or expert opinion.

For dairy cows, ruminant digestion models were used to estimate Y_m. The three major categories of input required by the models are animal description (e.g., cattle type, mature weight), animal performance (e.g., initial and final weight, age at start of period), and feed characteristics (e.g., chemical composition, habitat, grain or forage). Data used to simulate ruminant digestion is provided for a particular animal that is then used to represent a group of animals with similar characteristics. The Y_m values were estimated for 1990 using the Donovan and Baldwin model (1999), which represents physiological processes in the ruminant animals, as well as diet characteristics from USDA (1996). The Donovan and Baldwin model is able to account for differing diets (i.e., grain-based or forage-based), so that Y_m values for the variable feeding characteristics within the U.S. cattle population can be estimated. Subsequently, a literature review of dairy diets was conducted and nearly 250 diets were analyzed from 1990 through 2009 across 23 states—the review indicated highly variable diets, both temporally and spatially. Kebreab et al. (2008) conducted an evaluation of models and found that the COWPOLL model was the best model for estimating Y_m for dairy. The statistical analysis of the COWPOLL model showed a trend in predicting Y_m, and inventory team experts determined that the most comprehensive approach was to use the 1990 baseline from Donovan and Baldwin and then scale Y_m values for each of the diets beyond 1990 with the COWPOLL model. A function based on the national trend observed from the analysis of the dairy diets was used to calculate 1991 and beyond regional values based on the regional 1990 Y_m values from Donovan and Baldwin. The resulting scaling factor (incorporating both Donovan and Baldwin (1999) and COWPOLL) is shown below:

$$Y_m = Y_m(1990)EXP\left(\frac{1.22}{(Year - 1980)}\right) / EXP\left(\frac{1.22}{(1990-1980)}\right)$$

DE values for dairy cows were estimated from the literature search based on the annual trends observed in the data collection effort. The regional variability observed in the literature search was not statistically significant, and therefore DE was not varied by region, but did vary over time, and was grouped by the following years 1990–1993, 1994–1998, 1999–2003, 2004–2006, 2007, and 2008 onwards.

Considerably less data was available for dairy heifers and dairy calves. Therefore, for dairy heifers assumptions were based on the relationship of the collected data in the literature on dairy heifers to the data on dairy cow diets. From this relationship, DE was estimated as the mature cow DE minus three percent, and Y_m was estimated as that of the mature dairy cow plus 0.1 percent.

To calculate the DE values for grazing beef cattle, diet composition assumptions were used to estimate weighted DE values for a combination of forage and supplemental diets. The forage portion makes up an estimated 85 to 95 percent of grazing beef cattle diets, and there is considerable variation of both forage type and quality across the United States. Currently there is no comprehensive survey of this data, so for this analysis two regional DE values were developed to account for the generally lower forage quality in the "West" region of the United States versus all other regions in Table A-188 (California, Northern Great Plains, Midwestern, Northeast, Southcentral, Southeast) and Table A-189 (Central, Northeast, and Southeast). For all non-western grazing cattle, the forage DE was an average of the estimated seasonal values for grass pasture diets for a calculated DE of 64.2 percent. For foraging cattle in the west, the forage DE was calculated as the seasonal average for grass pasture, meadow and range diets, for a calculated DE of 61.3 percent. The assumed specific components of each of the broad forage types, along with their corresponding DE value and the calculated regional DE values can be found in Table A-190. In addition, beef cattle are assumed to be fed a supplemental diet, consequently, two sets of supplemental diets were developed, one for 1990 through 2006 (Donovan 1999) and one for 2007 onwards (Preston 2010, Archibeque 2011, USDA:APHIS:VS 2010) as shown in Table A-191 and Table A-192 along with the percent of each total diet that is assumed to be made up of the supplemental portion. By weighting the calculated DE values from the forage and supplemental diets, the DE values for the composite diet were calculated.[77] These values are used for steer and heifer stockers and beef replacements. Finally, for mature beef cows and bulls, the DE value was adjusted downward by two percent to reflect the lower digestibility diets of mature cattle based on Johnson (2002). Y_m values for all grazing beef cattle were set at 6.5 percent based on Johnson (2002). The Y_m values and the resulting final weighted DE values by region for 2007 onwards are shown in Table A-193.

For feedlot animals, DE and Y_m are adjusted over time as diet compositions in actual feedlots are adjusted based on new and improved nutritional information and availability of feed types. Feedlot diets are assumed to not differ significantly by state, and therefore only a single set of national diet values is utilized for each year. The DE and Y_m values for 1990 were estimated by Dr. Don Johnson (1999). In the CEFM, the DE values for 1991 through 1999 were linearly extrapolated based on values for 1990 and 2000. DE and Y_m values from 2000 through the current year were estimated using the MOLLY model as described in Kebreab et al. (2008), based on a series of average diet feed compositions from Galyean and Gleghorn (2001) for 2000 through 2006 and Vasconcelos and Galyean (2007) for 2007 onwards. In addition, feedlot animals are assumed to spend the first 25 days in the feedlot on a "step-up" diet to become accustomed to the higher

[77] For example, the West has a forage DE of 61.3 which makes up 90 percent of the diet and a supplemented diet DE of 67.4 percent was used for 10 percent of the diet, for a total weighted DE of 61.9 percent, as shown in Table A-193

quality feedlot diets. The step-up DE and Y_m are calculated as the average of all state forage and feedlot diet DE and Y_m values.

For calves aged 4 through 6 months, a gradual weaning from milk is simulated, with calf diets at 4 months assumed to be 25 percent forage, increasing to 50 percent forage at age 5 months, and 75 percent forage at age 6 months. The portion of the diet allocated to milk results in zero emissions, as recommended by the IPCC (2006). For calves, the DE for the remainder of the diet is assumed to be similar to that of slightly older replacement heifers (both beef and dairy are calculated separately). The Y_m for beef calves is also assumed to be similar to that of beef replacement heifers (6.5 percent), as literature does not provide an alternative Y_m for use in beef calves. For dairy calves, the Y_m is assumed to be 7.8 percent at 4 months, 8.03 percent at 5 months, and 8.27 percent at 6 months based on estimates provided by Soliva (2006) for Y_m at 4 and 7 months of age and a linear interpolation for 5 and 6 months.

Table A-194 shows the regional DE and Y_m for U.S. cattle in each region for 2014.

Table A-190: Feed Components and Digestible Energy Values Incorporated into Forage Diet Composition Estimates

Forage Type	DE (% of GE)	Grass pasture - Spring	Grass pasture - Summer	Grass pasture - Fall	Range June	Range July	Range August	Range September	Range Winter	Meadow - Spring	Meadow - Fall
Bahiagrass Paspalum notatum, fresh	61.38			x							
Bermudagrass Cynodon dactylon, fresh	66.29		x								
Bremudagrass, Coastal Cynodon dactylon, fresh	65.53		x								
Bluegrass, Canada Poa compressa, fresh, early vegetative	73.99	x									
Bluegrass, Kentucky Poa pratensis, fresh, early vegetative	75.62	x									
Bluegrass, Kentucky Poa pratensis, fresh, mature	59.00		x	x							
Bluestem Andropagon spp, fresh, early vegetative	73.17				x						
Bluestem Andropagon spp, fresh, mature	56.82					x	x	x	x		x
Brome Bromus spp, fresh, early vegetative	78.57	x									
Brome, Smooth Bromus inermis, fresh, early vegetative	75.71	x									
Brome, Smooth Bromus inermis, fresh, mature	57.58		x	x					x		
Buffalograss, Buchloe dactyloides, fresh	64.02				x	x					
Clover, Alsike Trifolium hybridum, fresh, early vegetative	70.62	x									
Clover, Ladino Trifolium repens, fresh, early vegetative	73.22	x									
Clover, Red Trifolium pratense, fresh, early bloom	71.27	x									
Clover, Red Trifolium pratense, fresh, full bloom	67.44		x		x						

Forage Type	DE (% of GE)	Grass pasture - Spring	Grass pasture - Summer	Grass pasture - Fall	Range June	Range July	Range August	Range September	Range Winter	Meadow - Spring	Meadow - Fall
Corn, Dent Yellow Zea mays indentata, aerial part without ears, without husks, sun-cured, (stover)(straw)	55.28			x							
Dropseed, Sand Sporobolus cryptandrus, fresh, stem cured	64.69				x	x	x			x	
Fescue Festuca spp, hay, sun-cured, early vegetative	67.39	x									
Fescue Festuca spp, hay, sun-cured, early bloom	53.57			x							
Grama Bouteloua spp, fresh, early vegetative	67.02	x									
Grama Bouteloua spp, fresh, mature	63.38		x	x						x	
Millet, Foxtail Setaria italica, fresh	68.20	x			x						
Napiergrass Pennisetum purpureum, fresh, late bloom	57.24		x	x							
Needleandthread Stipa comata, fresh, stem cured	60.36					x	x	x			
Orchardgrass Dactylis glomerata, fresh, early vegetative	75.54	x									
Orchardgrass Dactylis glomerata, fresh, midbloom	60.13		x								
Pearlmillet Pennisetum glaucum, fresh	68.04	x									
Prairie plants, Midwest, hay, sun-cured	55.53			x							x
Rape Brassica napus, fresh, early bloom	80.88	x									
Rye Secale cereale, fresh	71.83	x									
Ryegrass, Perennial Lolium perenne, fresh	73.68	x									
Saltgrass Distichlis spp, fresh, post ripe	58.06		x	x							
Sorghum, Sudangrass Sorghum bicolor sudanense, fresh, early vegetative	73.27	x									
Squirreltail Stanion spp, fresh, stem-cured	62.00		x			x					
Summercypress, Gray Kochia vestita, fresh, stem-cured	65.11			x	x	x					

Forage Type	DE (% of GE)	Grass pasture - Spring	Grass pasture - Summer	Grass pasture - Fall	Range June	Range July	Range August	Range September	Range Winter	Meadow - Spring	Meadow - Fall
Timothy Phleum pratense, fresh, late vegetative	73.12	x									
Timothy Phleum pratense, fresh, midbloom	66.87		x								
Trefoil, Birdsfoot Lotus corniculatus, fresh	69.07	x									
Vetch Vicia spp, hay, sun-cured	59.44			x							
Wheat Triticum aestivum, straw	45.77			x							
Wheatgrass, Crested Agropyron desertorum, fresh, early vegetative	79.78	x									
Wheatgrass, Crested Agropyron desertorum, fresh, full bloom	65.89		x			x					
Wheatgrass, Crested Agropyron desertorum, fresh, post ripe	52.99			x					x		x
Winterfat, Common Eurotia lanata, fresh, stem-cured	40.89								x		
Weighted Average DE		**72.99**	**62.45**	**57.26**	**67.11**	**62.70**	**60.62**	**58.59**	**52.07**	**64.03**	**55.11**
Forage Diet for West	**61.3**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**
Forage Diet for All Other Regions	**64.2**	**33.3%**	**33.3%**	**33.3%**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Note that forages marked with an x indicate that the DE from that specific forage type is included in the general forage type for that column (e.g., grass pasture, range, meadow or meadow by month or season).
Sources: Preston (2010) and Archibeque (2011).

Table A-191: DE Values with Representative Regional Diets for the Supplemental Diet of Grazing Beef Cattle for 1990–2006

Feed	Source of DE (NRC 1984)	Unweighted DE (% of GE)	California*	West	Northern Great Plains	Southcentral	Northeast	Midwest	Southeast
Alfalfa Hay	Table 8, feed #006	61.79	65%	30%	30%	29%	12%	30%	
Barley		85.08	10%	15%					
Bermuda	Table 8, feed #030	66.29							35%
Bermuda Hay	Table 8, feed #031	50.79				40%			
Corn	Table 8, feed #089	88.85	10%	10%	25%	11%	13%	13%	
Corn Silage	Table 8, feed #095	72.88			25%		20%	20%	
Cotton Seed Meal						7%			
Grass Hay	Table 8, feed #126, 170, 274	58.37		40%				30%	
Orchard	Table 8, feed #147	60.13							40%
Soybean Meal Supplement		77.15		5%	5%				5%
Sorghum	Table 8, feed #211	84.23							20%
Soybean Hulls		66.86						7%	
Timothy Hay	Table 8, feed #244	60.51					50%		

Whole Cotton Seed		75.75	5%				5%		
Wheat Middlings	Table 8, feed #257	68.09			15%	13%			
Wheat	Table 8, feed #259	87.95	10%						
Weighted Supplement DE (%)			**70.1**	**67.4**	**73.0**	**62.0**	**67.6**	**66.9**	**68.0**
Percent of Diet that is Supplement			**5%**	**10%**	**15%**	**10%**	**15%**	**10%**	**5%**

Source of representative regional diets: Donovan (1999).
[*] Note that emissions are currently calculated on a state-by-state basis, but diets are applied by the regions shown in the table above.

Table A-192: DE Values and Representative Regional Diets for the Supplemental Diet of Grazing Beef Cattle for 2007–2014

Feed	Source of DE (NRC1984)	Unweighted DE (% of GE)	West[a]	Central[a]	Northeast[a]	Southeast[a]
Alfalfa Hay	Table 8, feed #006	61.79	65%	30%	12%	
Bermuda	Table 8, feed #030	66.29				20%
Bermuda Hay	Table 8, feed #031	50.79				20%
Corn	Table 8, feed #089	88.85	10%	15%	13%	10%
Corn Silage	Table 8, feed #095	72.88		35%	20%	
Grass Hay	Table 8, feed #126, 170, 274	58.37	10%			
Orchard	Table 8, feed #147	60.13				30%
Protein supplement (West)	Table 8, feed #082, 134, 225[b]	81.01	10%			
Protein Supplement (Central and Northeast)	Table 8, feed #082, 134, 225[b]	80.76		10%	10%	
Protein Supplement (Southeast)	Table 8, feed #082, 134, 101[b]	77.89				10%
Sorghum	Table 8, feed #211	84.23		5%		10%
Timothy Hay	Table 8, feed #244	60.51			45%	
Wheat Middlings	Table 8, feed #257	68.09		5%		
Wheat	Table 8, feed #259	87.95	5%			
Weighted Supplement DE			**67.4**	**73.1**	**68.9**	**66.6**
Percent of Diet that is Supplement			**10%**	**15%**	**5%**	**15%**

[a] Note that emissions are currently calculated on a state-by-state basis, but diets are applied by the regions shown in the table above.
[b] Not in equal proportions.
Sources of representative regional diets: Donovan (1999), Preston (2010), Archibeque (2011), and USDA:APHIS:VS (2010).

Table A-193: Foraging Animal DE (% of GE) and Y_m Values for Each Region and Animal Type for 2007–2014

Animal Type	Data	West[a]	Central	Northeast	Southeast
Beef Repl. Heifers	DE[b]	61.9	65.6	64.5	64.6
	Y_m[c]	6.5%	6.5%	6.5%	6.5%
Beef Calves (4–6 mo)	DE	61.9	65.6	64.5	64.6
	Y_m	6.5%	6.5%	6.5%	6.5%
Steer Stockers	DE	61.9	65.6	64.5	64.6
	Y_m	6.5%	6.5%	6.5%	6.5%
Heifer Stockers	DE	61.9	65.6	64.5	64.6
	Y_m	6.5%	6.5%	6.5%	6.5%
Beef Cows	DE	59.9	63.6	62.5	62.6
	Y_m	6.5%	6.5%	6.5%	6.5%
Bulls	DE	59.9	63.6	62.5	62.6
	Y_m	6.5%	6.5%	6.5%	6.5%

[a] Note that emissions are currently calculated on a state-by-state basis, but diets are applied by the regions shown in the table above. To see the regional designation per state, please see Table A-189.
[b] DE is the digestible energy in units of percent of GE (MJ/Day).
[c] Y_m is the methane conversion rate, the fraction of GE in feed converted to methane.

Table A-194: Regional DE (% of GE) and Y_m Rates for Dairy and Feedlot Cattle by Animal Type for 2014

Animal Type	Data	California[a]	West	Northern Great Plains	Southcentral	Northeast	Midwest	Southeast
Dairy Repl. Heifers	DE[b]	63.7	63.7	63.7	63.7	63.7	63.7	63.7
	Ym[c]	6.0%	6.0%	5.7%	6.5%	6.4%	5.7%	7.0%
Dairy Calves (4–6 mo)	DE	63.7	63.7	63.7	63.7	63.7	63.7	63.7
	Ym	7.8% (4 mo), 8.03% (5 mo), 8.27% (6 mo)-all regions						
Dairy Cows	DE	66.7	66.7	66.7	66.7	66.7	66.7	66.7
	Ym	5.9%	5.9%	5.6%	6.4%	6.3%	5.6%	6.9%
Steer Feedlot	DE	82.5	82.5	82.5	82.5	82.5	82.5	82.5
	Ym	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%
Heifer Feedlot	DE	82.5	82.5	82.5	82.5	82.5	82.5	82.5
	Ym	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%	3.9%

[a] Note that emissions are currently calculated on a state-by-state basis, but diets are applied in Table A-188 by the regions shown in the table above. To see the regional designation for foraging cattle per state, please see Table A-188.
[b] DE is the digestible energy in units of percent of GE (MJ/Day).
[c] Y_m is the methane conversion rate, the fraction of GE in feed converted to methane.

Step 3: Estimate CH_4 Emissions from Cattle

Emissions by state were estimated in three steps: a) determine gross energy (GE) intake using the Tier 2 IPCC (2006) equations, b) determine an emission factor using the GE values, Y_m and a conversion factor, and c) sum the daily emissions for each animal type. Finally, the state emissions were aggregated to obtain the national emissions estimate. The necessary data values for each state and animal type include:

- Body Weight (kg)
- Weight Gain (kg/day)
- Net Energy for Activity (C_a, MJ/day)[78]
- Standard Reference Weight (kg)[79]
- Milk Production (kg/day)
- Milk Fat (percent of fat in milk = 4)
- Pregnancy (percent of population that is pregnant)
- DE (percent of GE intake digestible)
- Y_m (the fraction of GE converted to CH_4)
- Population

Step 3a: Determine Gross Energy, GE

As shown in the following equation, GE is derived based on the net energy estimates and the feed characteristics. Only variables relevant to each animal category are used (e.g., estimates for feedlot animals do not require the NE_l factor). All net energy equations are provided in IPCC (2006).

$$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} \right) + \left(\frac{NE_g}{REG} \right)}{\frac{DE\%}{100}} \right]$$

where,

GE = Gross energy (MJ/day)
NE_m = Net energy required by the animal for maintenance (MJ/day)

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78 Zero for feedlot conditions, 0.17 for high quality confined pasture conditions, and 0.36 for extensive open range or hilly terrain grazing conditions. C_a factor for dairy cows is weighted to account for the fraction of the population in the region that grazes during the year (IPCC 2006).

79 Standard Reference Weight is the mature weight of a female animal of the animal type being estimated, used in the model to account for breed potential.

NE_a = Net energy for animal activity (MJ/day)
NE_l = Net energy for lactation (MJ/day)
NE_{work} = Net energy for work (MJ/day)
NE_p = Net energy required for pregnancy (MJ/day)
REM = Ratio of net energy available in a diet for maintenance to digestible energy consumed
NE_g = Net energy needed for growth (MJ/day)
REG = Ratio of net energy available for growth in a diet to digestible energy consumed
DE = Digestible energy expressed as a percent of gross energy (percent)

Step 3b: Determine Emission Factor

The daily emission factor (DayEmit) was determined using the GE value and the methane conversion factor (Y_m) for each category. This relationship is shown in the following equation:

$$DayEmit = \frac{GE \times Y_m}{55.65}$$

where,

DayEmit = Emission factor (kg CH_4/head/day)
GE = Gross energy intake (MJ/head/day)
Y_m = CH_4 conversion rate, which is the fraction of GE in feed converted to CH_4 (%)
55.65 = A factor for the energy content of methane (MJ/kg CH_4)

The daily emission factors were estimated for each animal type and state. Calculated annual national emission factors are shown by animal type in Table A-195.

Table A-195: Calculated Annual National Emission Factors for Cattle by Animal Type (kg CH_4/head/year)

Cattle Type	1990	1995	2000	2005	2010	2011	2012	2013	2014
Dairy									
Calves	12	12	12	12	12	12	12	12	12
Cows	124	125	132	133	142	142	144	144	145
Replacements (7–11 months)	48	46	46	45	46	46	46	46	46
Replacements (12–23 months)	73	69	70	67	69	69	69	69	69
Beef									
Calves	11	11	11	11	11	11	11	11	11
Bulls	91	94	94	97	98	98	98	98	98
Cows	89	92	91	94	95	95	95	95	95
Replacements (7–11 months)	54	57	56	59	60	60	60	60	60
Replacements (12–23 months)	63	66	66	68	70	70	70	70	70
Steer Stockers	55	57	58	58	58	58	58	58	58
Heifer Stockers	52	56	60	60	60	60	60	60	60
Feedlot Cattle	39	38	39	39	42	42	42	43	43

Note: To convert to a daily emission factor, the yearly emission factor can be divided by 365 (the number of days in a year).

For quality assurance purposes, U.S. emission factors for each animal type were compared to estimates provided by the other Annex I member countries of the United Nations Framework Convention on Climate Change (UNFCCC) (the most recently available summarized results for Annex I countries are through 2012 only). Results, presented in Table A-196, indicate that U.S. emission factors are comparable to those of other Annex I countries. Results in Table A-196 are presented along with Tier 1 emission factors provided by IPCC (2006). Throughout the time series, beef cattle in the United States generally emit more enteric CH_4 per head than other Annex I member countries, while dairy cattle in the United States generally emit comparable enteric CH_4 per head.

Table A-196: Annex I Countries' Implied Emission Factors for Cattle by Year (kg CH_4/head/year)[80]

	Dairy Cattle		Beef Cattle	
Year	United States Implied Emission Factor	Mean of Implied Emission Factors for Annex I countries (excluding United States)	United States Implied Emission Factor	Mean of Implied Emission Factors for Annex I countries (excluding United States)
1990	107	96	71	53
1991	107	97	71	53
1992	107	96	72	54
1993	106	97	72	54
1994	106	98	73	54
1995	106	98	72	54
1996	105	99	73	54
1997	106	100	73	54
1998	107	101	73	55
1999	110	102	72	55
2000	111	103	72	55
2001	110	104	73	55
2002	111	105	73	55
2003	111	106	73	55
2004	109	107	74	55
2005	110	109	74	55
2006	110	110	74	55
2007	114	111	75	55
2008	115	112	75	55
2009	115	112	75	56
2010	115	113	75	55
2011	116	113	75	55
2012	117	112	75	51
2013	117	NA	75	NA
2014	118	NA	74	NA
Tier I EFs For North America, from IPCC (2006)		**121**		**53**

Step 3c: Estimate Total Emissions

Emissions were summed for each month and for each state population category using the daily emission factor for a representative animal and the number of animals in the category. The following equation was used:

$$Emissions_{state} = DayEmit_{state} \times Days/Month \times SubPop_{state}$$

where,

$Emissions_{state}$	=	Emissions for state during the month (kg CH_4)
DayEmitstate	=	Emission factor for the subcategory and state (kg CH4/head/day)
Days/Month	=	Number of days in the month
$SubPop_{state}$	=	Number of animals in the subcategory and state during the month

This process was repeated for each month, and the monthly totals for each state subcategory were summed to achieve an emission estimate for a state for the entire year and state estimates were summed to obtain the national total. The

[80] Excluding calves.

estimates for each of the 10 subcategories of cattle are listed in Table A-197. The emissions for each subcategory were then aggregated to estimate total emissions from beef cattle and dairy cattle for the entire year.

Table A-197: CH_4 Emissions from Cattle (kt)

Cattle Type	1990	1995	2000	2005	2010	2011	2012	2013	2014
Dairy	**1,574**	**1,498**	**1,519**	**1,503**	**1,627**	**1,645**	**1,670**	**1,664**	**1,677**
Calves (4–6 months)	62	59	59	54	57	57	58	58	58
Cows	1,242	1,183	1,209	1,197	1,287	1,302	1,326	1,325	1,337
Replacements (7–11 months)	58	56	55	56	62	63	62	61	62
Replacements (12–23 months)	212	201	196	196	222	223	224	220	220
Beef	**4,763**	**5,419**	**5,070**	**5,007**	**4,984**	**4,873**	**4,763**	**4,722**	**4,667**
Calves (4–6 months)	182	193	186	179	169	166	161	157	158
Bulls	196	225	215	214	215	212	206	203	200
Cows	2,884	3,222	3,058	3,056	2,976	2,927	2,868	2,806	2,754
Replacements (7–11 months)	69	85	74	80	75	74	76	78	81
Replacements (12–23 months)	188	241	204	217	213	202	208	213	217
Steer Stockers	563	662	509	473	476	436	413	431	428
Heifer Stockers	306	375	323	299	302	283	266	267	262
Feedlot Cattle	375	416	502	488	560	573	565	568	567
Total	**6,338**	**6,917**	**6,589**	**6,510**	**6,612**	**6,518**	**6,433**	**6,386**	**6,344**

Note: Totals may not sum due to independent rounding.

Emission Estimates from Other Livestock

"Other livestock" include horses, sheep, swine, goats, American bison, and mules and asses. All livestock population data, except for American bison for years prior to 2002, were taken from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) agricultural statistics database (USDA 2015) or earlier census data (USDA 1992, 1997). Annex 3.11 Methodology for Estimating CH_4 and N_2O Emissions from Manure Management discusses the methods for obtaining annual average populations and disaggregating into state data where needed and provides the resulting population data for the other livestock that were used for estimating all livestock-related emissions (see Table A-199). For each animal category, the USDA publishes monthly, annual, or multi-year livestock population and production estimates. American bison estimates prior to 2002 were estimated using data from the National Bison Association (1999).

Methane emissions from sheep, goats, swine, horses, mules and asses were estimated by multiplying national population estimates by the default IPCC emission factor (IPCC 2006). For American bison the emission factor for buffalo (IPCC 2006) was used and adjusted based on the ratio of live weights of 300 kilogram for buffalo (IPCC 2006) and 1,130 pounds (513 kg) for American Bison (National Bison Association 2011) to the 0.75 power. This methodology for determining emission factors is recommended by IPCC (2006) for animals with similar digestive systems. Table A-198 shows the emission factors used for these other livestock. National enteric fermentation emissions from all livestock types are shown in Table A-199 and Table A-200. Enteric fermentation emissions from most livestock types, broken down by state, for 2014 are shown in Table A-201 and Table A-202. Livestock populations are shown in Table A-203.

Table A-198: Emission Factors for Other Livestock (kg CH_4/head/year)

Livestock Type	Emission Factor
Swine	1.5
Horses	18
Sheep	8
Goats	5
American Bison	82.2
Mules and Asses	10.0

Source: IPCC (2006), except American Bison, as described in text.

Table A-199: CH_4 Emissions from Enteric Fermentation (MMT CO_2 Eq.)

Livestock Type	1990	1995	2000	2005	2010	2011	2012	2013	2014
Beef Cattle	119.1	135.5	126.7	125.2	124.6	121.8	119.1	118.0	116.7
Dairy Cattle	39.4	37.5	38.0	37.6	40.7	41.1	41.7	41.6	41.9
Swine	2.0	2.2	2.2	2.3	2.4	2.5	2.5	2.5	2.4
Horses	1.0	1.2	1.5	1.7	1.7	1.7	1.6	1.6	1.6
Sheep	2.3	1.8	1.4	1.2	1.1	1.1	1.1	1.1	1.0
Goats	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3
American Bison	0.1	0.2	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Mules and Asses	+	+	+	0.1	0.1	0.1	0.1	0.1	0.1
Total	**164.2**	**178.7**	**170.6**	**168.9**	**171.1**	**168.7**	**166.3**	**164.5**	**164.3**

Notes: Totals may not sum due to independent rounding.
+ Indicates emissions are less than 0.05 MMT CO_2 Eq.

Table A-200: CH_4 Emissions from Enteric Fermentation (kt)

Livestock Type	1990	1995	2000	2005	2010	2011	2012	2013	2014
Beef Cattle	4,763	5,419	5,070	5,007	4,984	4,873	4,763	4,722	4,667
Dairy Cattle	1,574	1,498	1,519	1,503	1,627	1,645	1,670	1,664	1,677
Swine	81	88	88	92	97	98	100	98	96
Horses	40	47	61	70	68	67	65	64	62
Sheep	91	72	56	49	45	44	43	43	42
Goats	13	12	12	14	14	14	13	13	12
American Bison	4	9	16	17	15	14	13	13	12
Mules and Asses	1	1	1	2	3	3	3	3	3
Total	**6,566**	**7,146**	**6,824**	**6,755**	**6,853**	**6,757**	**6,670**	**6,619**	**6,572**

Note: Totals may not sum due to independent rounding.

Table A-201: CH_4 Emissions from Enteric Fermentation from Cattle (metric tons), by State, for 2014

State	Dairy Calves	Dairy Cows	Dairy Repl. Heif. 0-12 Months	Dairy Repl. Heif. 12-24 Months	Bulls	Beef Calves	Beef Cows	Beef Repl. Heif. 0-12 Months	Beef Repl. Heif. 12-24 Months	Steer Stockers	Heifer Stockers	Feedlot	Total
Alabama	56	1,195	63	225	4,866	3,663	64,090	1,587	4,269	1,637	915	249	82,816
Alaska	2	31	1	5	197	25	432	12	33	12	3	1	755
Arizona	1,202	29,450	1,008	3,581	2,078	1,034	17,883	467	1,249	8,956	668	11,844	79,420
Arkansas	50	961	73	260	5,352	4,637	81,125	1,976	5,317	3,956	2,303	598	106,608
California	11,145	267,318	10,215	36,298	7,272	3,484	60,281	1,712	4,581	18,792	7,314	21,784	450,196
Colorado	877	20,629	1,290	4,583	4,675	4,123	71,333	2,334	6,247	22,903	15,583	42,057	196,633
Conn.	119	2,755	130	461	49	22	377	22	58	55	15	7	4,069
Delaware	29	681	37	133	29	15	264	7	19	55	18	7	1,296
Florida	770	20,134	553	1,966	5,839	4,879	85,360	1,659	4,463	682	886	145	127,336
Georgia	501	13,244	395	1,404	2,725	2,690	47,056	1,183	3,183	982	856	184	74,403
Hawaii	14	245	14	48	416	417	7,214	140	375	206	127	32	9,246
Idaho	3,538	86,174	3,678	13,067	4,155	2,700	46,718	1,712	4,581	7,634	6,042	10,298	190,297
Illinois	595	12,138	580	2,062	2,378	1,860	32,662	885	2,387	6,652	2,936	11,171	76,307
Indiana	1,115	24,188	877	3,117	1,617	980	17,205	548	1,477	2,874	1,525	4,527	60,050
Iowa	1,284	28,298	1,548	5,500	5,708	4,690	82,345	2,249	6,061	33,791	18,421	53,578	243,473
Kansas	852	18,581	1,290	4,583	8,562	7,410	130,096	3,373	9,092	47,095	40,295	93,122	364,351
Kentucky	426	9,740	711	2,528	6,812	5,336	93,359	2,164	5,822	5,457	3,690	771	136,815
Louisiana	94	1,795	73	260	2,919	2,421	42,350	1,212	3,260	655	620	121	55,780
Maine	188	4,331	245	870	146	59	1,038	43	117	137	59	20	7,254
Maryland	313	7,164	360	1,280	390	205	3,586	137	370	411	222	433	14,872
Mass.	75	1,629	108	384	98	32	566	29	78	55	15	7	3,075
Michigan	2,386	55,699	2,115	7,516	1,427	624	10,949	408	1,099	4,656	1,353	6,535	94,766
Minn.	2,880	59,049	3,612	12,833	3,330	1,782	31,282	1,124	3,031	13,038	4,893	16,316	153,168
Miss.	81	1,776	95	337	3,698	2,566	44,891	1,313	3,532	1,692	1,270	276	61,526
Missouri	564	10,114	645	2,292	9,513	9,538	167,450	4,287	11,554	10,111	6,188	3,288	235,544
Montana	88	1,883	116	412	10,389	8,571	148,292	6,691	17,908	6,460	6,710	2,271	209,790
Nebraska	332	7,254	258	917	9,038	9,470	166,254	5,622	15,153	61,197	36,842	105,842	418,178
Nevada	182	4,385	123	436	1,351	1,341	23,208	560	1,499	1,292	986	173	35,535
N. Hamp.	85	1,957	101	358	49	16	283	14	39	27	15	4	2,948
N. Jersey	44	956	43	154	98	38	661	14	39	55	30	8	2,139
N. Mexico	2,022	50,489	1,634	5,808	3,636	2,363	40,891	1,089	2,915	2,643	2,226	453	116,170

State	Dairy Calves	Dairy Cows	Dairy Repl. Heif. 0-12 Months	Dairy Repl. Heif. 12-24 Months	Bulls	Beef Calves	Beef Cows	Beef Repl. Heif. 0-12 Months	Beef Repl. Heif. 12-24 Months	Steer Stockers	Heifer Stockers	Feedlot	Total
New York	3,851	94,740	5,116	18,177	1,757	567	9,909	651	1,752	876	1,185	1,012	139,591
N. Car.	282	7,471	316	1,123	2,919	1,910	33,410	1,039	2,794	1,201	709	187	53,360
N. Dakota	106	2,208	129	458	5,232	4,837	84,921	2,389	6,440	7,184	6,044	1,754	121,704
Ohio	1,672	34,747	1,677	5,958	2,378	1,536	26,958	773	2,084	5,188	1,727	6,926	91,623
Oklahoma	282	6,112	292	1,038	12,164	9,656	168,931	4,688	12,614	24,829	10,038	12,140	262,784
Oregon	776	17,197	817	2,904	3,740	2,996	51,842	1,634	4,373	4,698	3,816	3,163	97,957
Penn	3,318	76,855	4,539	16,129	2,440	863	15,100	723	1,946	5,063	2,073	4,837	133,887
R.Island	6	126	7	26	10	8	142	7	19	14	6	2	372
S. Car.	100	2,326	95	337	1,362	909	15,905	433	1,164	327	354	63	23,376
S. Dakota	595	12,866	645	2,292	9,038	8,569	150,429	4,779	12,880	18,359	14,103	16,525	251,079
Tenn.	288	6,673	474	1,685	5,839	4,648	81,313	1,875	5,045	3,683	2,510	130	114,163
Texas	2,755	68,751	3,215	11,423	27,247	21,033	367,978	9,520	25,615	64,665	41,924	108,395	752,521
Utah	595	14,057	627	2,226	2,389	1,974	34,159	1,089	2,915	2,496	2,194	1,125	65,847
Vermont	826	19,163	807	2,867	293	65	1,132	65	175	109	163	27	25,694
Virginia	582	14,695	632	2,247	3,892	3,427	59,949	1,659	4,463	4,638	2,067	891	99,143
Wash.	1,665	40,560	1,703	6,050	1,974	1,243	21,500	778	2,082	4,698	4,134	8,876	95,263
W. Virg.	56	1,133	72	256	1,366	1,031	18,025	506	1,362	1,232	711	208	25,959
Wisconsin	7,952	172,592	8,771	31,166	2,854	1,310	23,001	984	2,652	10,111	2,015	11,255	274,662
Wyoming	38	809	52	183	4,155	4,030	69,725	2,723	7,288	4,404	3,371	3,205	99,984

Table A-202: CH_4 Emissions from Enteric Fermentation from Other Livestock (metric tons), by State, for 2014

State	Swine	Horses	Sheep	Goats	American Bison	Mules and Asses	Total
Alabama	158	978	97	208	17	116	1,574
Alaska	2	23	97	3	143	1	269
Arizona	203	1,833	1,200	417	0	35	3,688
Arkansas	165	971	97	190	14	84	1,520
California	165	2,291	4,720	719	88	65	8,048
Colorado	1,043	1,924	2,920	145	726	63	6,821
Connecticut	4	356	59	22	10	10	460
Delaware	6	127	97	7	8	1	245
Florida	26	2,182	97	249	7	96	2,656
Georgia	230	1,208	97	334	17	88	1,973
Hawaii	14	82	97	73	5	4	274
Idaho	46	1,015	2,000	91	346	39	3,538
Illinois	6,713	1,008	448	153	38	35	8,395
Indiana	5,306	1,870	400	176	89	54	7,895
Iowa	30,263	1,049	1,240	282	117	44	32,994
Kansas	2,603	1,240	600	197	433	37	5,110
Kentucky	488	2,311	392	252	107	130	3,679
Louisiana	12	1,071	97	88	3	73	1,344
Maine	7	215	59	33	18	4	335
Maryland	32	501	97	41	25	12	708
Massachusetts	14	364	59	44	6	5	492
Michigan	1,568	1,489	648	134	99	41	3,979
Minnesota	11,625	1,024	1,080	162	150	30	14,071
Mississippi	833	1,009	97	110	<1	88	2,137
Missouri	3,938	1,882	664	533	112	96	7,224
Montana	264	1,710	1,760	48	1,209	47	5,038
Nebraska	4,613	1,149	608	112	2,077	38	8,596
Nevada	3	434	640	126	4	6	1,213
New Hampshire	5	158	59	26	26	3	277
New Jersey	15	480	97	37	17	9	654
New Mexico	2	892	648	146	435	18	2,142
New York	105	1,660	600	175	54	37	2,631
North Carolina	12,225	1,121	216	268	15	93	13,937
North Dakota	209	819	528	25	578	12	2,170
Ohio	3,101	2,018	936	222	53	71	6,401
Oklahoma	3,000	2,813	472	373	774	136	7,568
Oregon	14	1,131	1,560	156	122	33	3,106
Pennsylvania	1,691	2,184	752	233	62	95	5,016

State	Swine	Horses	Sheep	Goats	American Bison	Mules and Asses	Total
Rhode Island	2	36	59	5	0	1	103
South Carolina	375	1,009	97	184	10	57	1,732
South Dakota	1,853	1,231	2,160	94	2,598	15	7.952
Tennessee	300	1,410	312	380	10	143	2,555
Texas	1,039	6,815	5,840	3,872	310	632	18,508
Utah	1,035	1,056	2,240	68	84	32	4,515
Vermont	5	198	59	61	7	13	343
Virginia	405	1,538	664	230	82	70	2,989
Washington	46	982	440	124	60	35	1,688
West Virginia	6	395	256	76	0	29	762
Wisconsin	450	1,743	664	316	287	58	3,518
Wyoming	126	1,247	2,840	48	688	27	4,975

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3.11. Methodology for Estimating CH_4 and N_2O Emissions from Manure Management

The following steps were used to estimate methane (CH_4) and nitrous oxide (N_2O) emissions from the management of livestock manure.[81]

Step 1: Livestock Population Characterization Data

Annual animal population data for 1990 through 2014 for all livestock types, except American bison, goats, horses, mules and asses were obtained from the USDA National Agricultural Statistics Service (NASS). The population data used in the emissions calculations for cattle, swine, and sheep were downloaded from the USDA NASS Quick Stats Database (USDA 2015a). Poultry population data were obtained from USDA NASS reports (USDA 1995a, 1995b, 1998, 1999, 2004a, 2004b, 2009a, 2009b, 2009c, 2009d, 2010a, 2010b, 2011a, 2011b, 2012a, 2012b, 2013a, 2013b, 2014b, 2014c, 2015b and 2015c). Goat population data for 1992, 1997, 2002, 2007, and 2012 were obtained from the Census of Agriculture (USDA 2014a), as were horse, mule and ass population data for 1987, 1992, 1997, 2002, 2007, and 2012, and American bison population for 2002, 2007, and 2012. American bison population data for 1990-1999 were obtained from the National Bison Association (1999). Additional data sources used and adjustments to these data sets are described below.

Cattle: For all cattle groups (cows, heifers, steers, bulls, and calves), the USDA data provide cattle inventories from January (for each state) and July (as a U. S. total only) of each year. Cattle inventories change over the course of the year, sometimes significantly, as new calves are born and as cattle are moved into feedlots and subsequently slaughtered; therefore, to develop the best estimate for the annual animal population, the populations and the individual characteristics, such as weight and weight gain, pregnancy, and lactation of each animal type were tracked in the Cattle Enteric Fermentation Model (CEFM—see section 5.1 Enteric Fermentation). For animals that have relatively static populations throughout the year, such as mature cows and bulls, the January 1 values were used. For animals that have fluctuating populations throughout the year, such as calves and growing heifers and steer, the populations are modeled based on a transition matrix that uses annual population data from USDA along with USDA data on animal births, placement into feedlots, and slaughter statistics.

Swine: The USDA provides quarterly data for each swine subcategory: breeding, market under 50 pounds (under 23 kg), market 50 to 119 pounds (23 to 54 kg), market 120 to 179 pounds (54 to 81 kg), and market 180 pounds and over (greater than 82 kg). The average of the quarterly data was used in the emission calculations. For states where only December inventory is reported, the December data were used directly.

Sheep: The USDA provides total state-level data annually for lambs and sheep. Population distribution data for lamb and sheep on feed are not available after 1993 (USDA 1994). The number of lamb and sheep on feed for 1994 through 2014 were calculated using the average of the percent of lamb and sheep on feed from 1990 through 1993. In addition, all of the sheep and lamb "on feed" are not necessarily on "feedlots;" they may be on pasture/crop residue supplemented by feed. Data for those animals on feed that are in feedlots versus pasture/crop residue were provided only for lamb in 1993. To calculate the populations of sheep and lamb in feedlots for all years, it was assumed that the percentage of sheep and lamb on feed that are in feedlots versus pasture/crop residue is the same as that for lambs in 1993 (Anderson 2000).

Goats: Annual goat population data by state were available for 1992, 1997, 2002, 2007, and 2012 (USDA 2014a). The data for 1992 were used for 1990 through 1992. Data for 1993 through 1996, 1998 through 2001, 2003 through 2006, 2008 through 2011, and 2013 through 2014 were extrapolated based on the 1992, 1997, 2002, 2007, and 2012 Census data.

Horses: Annual horse population data by state were available for 1987, 1992, 1997, 2002, 2007, and 2012 (USDA 2014a). Data for 1990 through 1991, 1993 through 1996, 1998 through 2001, 2003 through 2006, 2008 through 2011, and 2013 through 2014 were extrapolated based on the 1987, 1992, 1997, 2002, 2007, and 2012 Census data.

Mules and Asses: Annual mule and ass (burro and donkey) population data by state were available for 1987, 1992, 1997, 2002, 2007, and 2012 (USDA 2014a). Data for 1990 through 1991, 1993 through 1996, 1998 through 2001, 2003

[81] Note that direct N_2O emissions from dung and urine spread onto fields either directly as daily spread or after it is removed from manure management systems (e.g., lagoon, pit, etc.) and from livestock dung and urine deposited on pasture, range, or paddock lands are accounted for and discussed in the Agricultural Soil Management source category within the Agriculture sector. Indirect N_2O emissions dung and urine spread onto fields after it is removed from manure management systems (e.g., lagoon, pit, etc.) and from livestock dung and urine deposited on pasture, range, or paddock lands are also included in the Agricultural Soil Management source category.

through 2006, 2008 through 2011, and 2013 through 2014 were extrapolated based on the 1987, 1992, 1997, 2002, 2007, and 2012 Census data.

American Bison: Annual American bison population data by state were available for 2002, 2007, and 2012 (USDA 2014a). Data for 1990 through 1999 were obtained from the Bison Association (1999). Data for 2000, 2001, 2003 through 2006, 2008 through 2011, and 2013 through 2014 were extrapolated based on the Bison Association and 2002 2007, and 2012 Census data.

Poultry: The USDA provides population data for hens (one year old or older), pullets (hens younger than one year old), other chickens, and production (slaughter) data for broilers and turkeys (USDA 1995a, 1995b, 1998, 1999, 2004a, 2004b, 2009b, 2009c, 2009d, 2009e, 2010a, 2010b, 2011a, 2011b, 2012a, 2012b, 2013a, 2013b, 2014b, 2014c, 2015b and 2015c). All poultry population data were adjusted to account for states that report non-disclosed populations to USDA NASS. The combined populations of the states reporting non-disclosed populations are reported as "other" states. State populations for the non-disclosed states were estimated by equally distributing the population attributed to "other" states to each of the non-disclosed states.

Because only production data are available for boilers and turkeys, population data are calculated by dividing the number of animals produced by the number of production cycles per year, or the turnover rate. Based on personal communications with John Lange, an agricultural statistician with USDA NASS, the broiler turnover rate ranges from 3.4 to 5.5 over the course of the inventory (Lange 2000). For turkeys, the turnover rate ranges from 2.4 to 3.0. A summary of the livestock population characterization data used to calculate CH_4 and N_2O emissions is presented in Table A-203.

Step 2: Waste Characteristics Data

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

- Volatile solids (VS) excretion rate;
- Maximum methane producing capacity (B_o) for U.S. animal waste;
- Nitrogen excretion rate (Nex); and
- Typical animal mass (TAM).

Table A-204 presents a summary of the waste characteristics used in the emissions estimates. Published sources were reviewed for U.S.-specific livestock waste characterization data that would be consistent with the animal population data discussed in Step 1. The USDA's *Agricultural Waste Management Field Handbook* (AWMFH; USDA 1996, 2008) is one of the primary sources of waste characteristics for non-cattle animal groups. Data from the 1996 and 2008 USDA AWMFH were used to estimate VS and Nex for most non-cattle animal groups across the time series of the inventory, as shown in Table A-205 (ERG 2010b and 2010c). The 1996 AWMFH data were based on measured values from U.S. farms; the 2008 AWMFH data were developed using the calculation method created by the American Society of Agricultural and Biological Engineers, which is based on U.S. animal dietary intake and performance measures. Since the values from each of the two AWMFHs result from different estimation methods and reflect changes in animal genetics and nutrition over time, both data sources were used to create a time series across the Inventory as neither value would be appropriate to use across the entire span of Inventory years. Although the AWMFH values are lower than the IPCC values, these values are more appropriate for U.S. systems because they have been calculated using U.S.-specific data. Animal-specific notes about VS and Nex are presented below:

- *Swine:* The VS and Nex data for breeding swine are from a combination of the types of animals that make up this animal group, namely gestating and farrowing swine and boars. It is assumed that a group of breeding swine is typically broken out as 80 percent gestating sows, 15 percent farrowing swine, and 5 percent boars (Safley 2000).
- *Poultry:* Due to the change in USDA reporting of hens and pullets in 2005, new nitrogen and VS excretion rates were calculated for the combined population of hens and pullets; a weighted average rate was calculated based on hen and pullet population data from 1990 to 2004.
- *Goats, Sheep, Horses, Mules and Asses:* In cases where data were not available in the USDA documents, data from the American Society of Agricultural Engineers, Standard D384.1 (ASAE 1998) or the *2006 IPCC Guidelines* were used as a supplement.

The method for calculating VS excretion and Nex for cattle (including American bison, beef and dairy cows, bulls, heifers, and steers) is based on the relationship between animal performance characteristics such as diet, lactation, and weight gain and energy utilization. The method used is outlined by the *2006 IPCC Guidelines* Tier II methodology, and is modeled using the CEFM as described in the enteric fermentation portion of the inventory (documented in Moffroid and Pape 2013) in order to take advantage of the detailed diet and animal performance data assembled as part of the Tier II analysis for cattle. For American bison, VS and Nex were assumed to be the same as beef NOF bulls.

The VS content of manure is the fraction of the diet consumed by cattle that is not digested and thus excreted as fecal material; fecal material combined with urinary excretions constitutes manure. The CEFM uses the input of digestible energy (DE) and the energy requirements of cattle to estimate gross energy (GE) intake and enteric CH_4 emissions. GE and DE are used to calculate the indigestible energy per animal as gross energy minus digestible energy plus the amount of gross energy for urinary energy excretion per animal (2 or 4 percent). This value is then converted to VS production per animal using the typical conversion of dietary gross energy to dry organic matter of 18.45 MJ/kg, after subtracting out the ash content of manure. The current equation recommended by the *2006 IPCC Guidelines* is:

$$\text{VS production (kg)} = \left[(\text{GE - DE}) + (\text{UE} \times \text{GE})\right] \times \frac{1 - ASH}{18.45}$$

where,

GE	= Gross energy intake (MJ)
DE	= Digestible energy (MJ)
(UE × GE)	= Urinary energy expressed as fraction of GE, assumed to be 0.04 except for feedlots which are reduced 0.02 as a result of the high grain content of their diet.
ASH	= Ash content of manure calculated as a fraction of the dry matter feed intake (assumed to be 0.08).
18.45	= Conversion factor for dietary GE per kg of dry matter (MJ per kg). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Total nitrogen ingestion in cattle is determined by dietary protein intake. When feed intake of protein exceeds the nutrient requirements of the animal, the excess nitrogen is excreted, primarily through the urine. To calculate the nitrogen excreted by each animal type, the CEFM utilizes the energy balance calculations recommended by the IPCC (2006) for gross energy and the energy required for growth along with inputs of weight gain, milk production, and the percent of crude protein in the diets. The total nitrogen excreted is measured in the CEFM as nitrogen consumed minus nitrogen retained by the animal for growth and in milk. The basic equation for calculating Nex is shown below, followed by the equations for each of the constituent parts.

$$N_{excreted} = N_{consumed} - (N_{growth} + N_{milk})$$

where,

$N_{excreted}$	= Daily N excreted per animal, kg per animal per day.
$N_{consumed}$	= Daily N intake per animal, kg per animal per day
N_{growth}	= Nitrogen retained by the animal for growth, kg per animal per day
N_{milk}	= Nitrogen retained in milk, kg per animal per day

The equation for N consumed is based on the *2006 IPCC Guidelines*, and is estimated as:

$$N_{consumed} = \left[\frac{GE}{18.45} * \left(\frac{\frac{CP\%}{100}}{6.25}\right)\right]$$

where,

$N_{consumed}$	= Daily N intake per animal, kg per animal per day
GE	= Gross energy intake, as calculated in the CEFM, MJ per animal per day
18.45	= Conversion factor for dietary GE per kg of dry matter, MJ per kg.
CP%	= Percent crude protein in diet, input into the CEFM
6.25	= Conversion from kg of dietary protein to kg of dietary N, kg feed per kg N

The portion of consumed N that is retained as product equals the nitrogen required for weight gain plus that in milk. The nitrogen retained in body weight gain by stockers, replacements, or feedlot animals is calculated using the net energy for growth (NEg), weight gain (WG), and other conversion factors and constants. The equation matches current *2006 IPCC Guidelines* recommendations, and is as follows:

$$N_{growth} = \frac{\frac{\left\{ WG * \left[268 - \frac{(7.03 * NEg)}{WG} \right] \right\}}{1000}}{6.25}$$

where,

N_{growth}	= Nitrogen retained by the animal for growth, kg per animal per day
WG	= Daily weight gain of the animal, as input into the CEFM transition matrix, kg per day
268	= Constant from *2006 IPCC Guidelines*
7.03	= Constant from *2006 IPCC Guidelines*
NEg	= Net energy required for growth, as calculated in the CEFM, MJ per animal per day
1,000	= Conversion from grams to kilograms
6.25	= Conversion from kg of dietary protein to kg of dietary N, kg feed per kg N

The N content of milk produced also currently matches the *2006 IPCC Guidelines*, and is calculated using milk production and percent protein, along with conversion factors. Milk N retained as product is calculated using the following equation:

$$N_{milk} = \frac{milk * \left(\frac{pr\%}{100} \right)}{6.38}$$

where,

N_{milk}	= Nitrogen retained in milk, kg per animal per day
milk	= Milk production, kg per day
pr%	= Percent protein in milk, estimated from the fat content as 1.9 + 0.4 * %Fat (Fat assumed to be 4%)
100	= Conversion from percent to value (e.g., 4% to 0.04)
6.38	= Conversion from kg Protein to kg N

The VS and N equations above were used to calculate VS and Nex rates for each state, animal type (heifers and steer on feed, heifers and steer not on feed, bulls and American bison), and year. Table A-206 presents the state-specific VS and Nex production rates used for cattle in 2014.

Step 3: Waste Management System Usage Data

Table A-207 summarizes 2014 manure distribution data among waste management systems (WMS) at beef feedlots, dairies, dairy heifer facilities, and swine, layer, broiler, and turkey operations. Manure from the remaining animal types (beef cattle not on feed, American bison, goats, horses, mules and asses and sheep) is managed on pasture, range, or paddocks, on drylot, or with solids storage systems. Additional information on the development of the manure distribution estimates for each animal type is presented below. Definitions of each WMS type are presented in Table A-208.

Beef Cattle, Dairy Heifers and American Bison: The beef feedlot and dairy heifer WMS data were developed using information from EPA's Office of Water's engineering cost analyses conducted to support the development of effluent limitations guidelines for Concentrated Animal Feeding Operations (EPA 2002b). Based on EPA site visits and state contacts supporting this work and additional personal communication with the national USDA office to estimate the percent of beef steers and heifers in feedlots (Milton 2000), feedlot manure is almost exclusively managed in drylots. Therefore, for these animal groups, the percent of manure deposited in drylots is assumed to be 100 percent. In addition, there is a small amount of manure contained in runoff, which may or may not be collected in runoff ponds. Using EPA and USDA data and expert opinions (documented in ERG 2000a), the runoff from feedlots was calculated by region in *Calculations: Percent Distribution of Manure for Waste Management Systems* and was used to estimate the percentage of manure managed in runoff ponds in addition to drylots; this percentage ranges from 0.4 to 1.3 percent (ERG 2000a). The percentage of manure generating emissions from beef feedlots is therefore greater than 100 percent. The remaining population categories of beef cattle outside of feedlots are managed through pasture, range, or paddock systems, which are utilized for the majority of the population of beef cattle in the country. American bison WMS data were assumed to be the same as beef cattle NOF.

Dairy Cows: The WMS data for dairy cows were developed using data from the Census of Agriculture, EPA's Office of Water, USDA, and the expert sources noted below. Farm-size distribution data are reported in the 1992, 1997, 2002, and 2007 Census of Agriculture (USDA 2014a). It was assumed that the Census data provided for 1992 were the same as that for 1990 and 1991, and data provided for 2007 were the same as that for 2008 through 2014. Data for 1993 through 1996, 1998 through 2001, and 2003 through 2006, and 2008 through 2014 were extrapolated using the 1992, 1997, 2002, and 2007 data. The percent of waste by system was estimated using the USDA data broken out by geographic region and farm size.

Based on EPA site visits and the expert opinion of state contacts, manure from dairy cows at medium (200 through 700 head) and large (greater than 700 head) operations are managed using either flush systems or scrape/slurry systems. In addition, they may have a solids separator in place prior to their storage component. Estimates of the percent of farms that use each type of system (by geographic region) were developed by EPA's Office of Water, and were used to estimate the percent of waste managed in lagoons (flush systems), liquid/slurry systems (scrape systems), and solid storage (separated solids) (EPA 2002b).

Manure management system data for small (fewer than 200 head) dairies were obtained from USDA's Animal and Plant Health Inspection Service (APHIS)'s National Animal Health Monitoring System (Ott 2000). These data are based on a statistical sample of farms in the 20 U.S. states with the most dairy cows. Small operations are more likely to use liquid/slurry and solid storage management systems than anaerobic lagoon systems. The reported manure management systems were deep pit, liquid/slurry (includes slurry tank, slurry earth-basin, and aerated lagoon), anaerobic lagoon, and solid storage (includes manure pack, outside storage, and inside storage).

Data regarding the use of daily spread and pasture, range, or paddock systems for dairy cattle were obtained from personal communications with personnel from several organizations. These organizations include state NRCS offices, state extension services, state universities, USDA NASS, and other experts (Deal 2000, Johnson 2000, Miller 2000, Stettler 2000, Sweeten 2000, and Wright 2000). Contacts at Cornell University provided survey data on dairy manure management practices in New York (Poe et al. 1999). Census of Agriculture population data for 1992, 1997, 2002, and 2007 (USDA 2014a) were used in conjunction with the state data obtained from personal communications to determine regional percentages of total dairy cattle and dairy waste that are managed using these systems. These percentages were applied to the total annual dairy cow and heifer state population data for 1990 through 2014, which were obtained from the USDA NASS (USDA 2015a).

Of the dairies using systems other than daily spread and pasture, range, or paddock systems, some dairies reported using more than one type of manure management system. Due to limitations in how USDA APHIS collects the manure management data, the total percent of systems for a region and farm size is greater than 100 percent. However, manure is typically partitioned to use only one manure management system, rather than transferred between several different systems. Emissions estimates are only calculated for the final manure management system used for each portion of manure. To avoid double counting emissions, the reported percentages of systems in use were adjusted to equal a total of 100 percent using the same distribution of systems. For example, if USDA reported that 65 percent of dairies use deep pits to manage manure and 55 percent of dairies use anaerobic lagoons to manage manure, it was assumed that 54 percent (i.e., 65 percent divided by 120 percent) of the manure is managed with deep pits and 46 percent (i.e., 55 percent divided by 120 percent) of the manure is managed with anaerobic lagoons (ERG 2000a).

Finally, the percentage of manure managed with anaerobic digestion (AD) systems with methane capture and combustion was added to the WMS distributions. AD system data were obtained from EPA's AgSTAR Program's project database (EPA 2012). This database includes basic information for AD systems in the United States, based on publically available data and data submitted by farm operators, project developers, financiers, and others involved in the development of farm AD projects.

Swine: The distribution of manure managed in each WMS was estimated using data from a USDA APHIS report and EPA's Office of Water site visits (Bush 1998, ERG 2000a). The USDA APHIS data are based on a statistical sample of farms in the 16 U.S. states with the most hogs. For operations with less than 200 head, manure management system data were obtained from USDA APHIS (Bush 1998), it was assumed that those operations use pasture, range, or paddock systems. For swine operations with greater than 200 head, the percent of waste managed in each system was estimated using the EPA and USDA data broken out by geographic region and farm size. Farm-size distribution data reported in the 1992, 1997, 2002, and 2007 Census of Agriculture (USDA 2014a) were used to determine the percentage of all swine utilizing the various manure management systems. It was assumed that the swine farm size data provided for 1992 were the same as that for 1990 and 1991, and data provided for 2007 were the same as that for 2008 through 2014. Data for 1993 through 1996, 1998 through 2001, and 2003 through 2006 were extrapolated using the 1992, 1997, 2002, and 2007 data. The manure management systems reported in the census were deep pit, liquid/slurry (includes above- and below-ground slurry), anaerobic lagoon, and solid storage (includes solids separated from liquids).

Some swine operations reported using more than one management system; therefore, the total percent of systems reported by USDA for a region and farm size was greater than 100 percent. Typically, this means that a portion of the manure at a swine operation is handled in one system (e.g., liquid system), and a separate portion of the manure is handled in another system (e.g., dry system). However, it is unlikely that the same manure is moved from one system to another, which could result in increased emissions, so reported systems data were normalized to 100 percent for incorporation into the WMS distribution, using the same method as described above for dairy operations. As with dairy, AD WMS were added to the WMS distribution based on data from EPA's AgSTAR database (EPA 2012).

Sheep: WMS data for sheep were obtained from USDA NASS sheep report for years 1990 through 1993 (USDA 1994). Data for 2001 are obtained from USDA APHIS's national sheep report (USDA, APHIS 2003). The USDA APHIS data are based on a statistical sampled of farms in the 22 U.S. states with the most sheep. The data for years 1994-2000 are calculated assuming a linear progression from 1993 to 2001. Due to lack of additional data, data for years 2002 and beyond are assumed to be the same as 2001. Based on expert opinion, it was assumed that all sheep manure not deposited in feedlots was deposited on pasture, range, or paddock lands (Anderson 2000).

Goats, Horses, and Mules and Asses: WMS data for 1990 to 2014 were obtained from Appendix H of *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). This report presents state WMS usage in percentages for the major animal types in the United States, based on information obtained from extension service personnel in each state. It was assumed that all manure not deposited in pasture, range, or paddock lands was managed in dry systems. For mules and asses, the WMS was assumed to be the same as horses.

Poultry—Hens (one year old or older), Pullets (hens less than one year old), and Other Chickens: WMS data for 1992 were obtained from *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). These data were also used to represent 1990 and 1991. The percentage of layer operations using a shallow pit flush house with anaerobic lagoon or high-rise house without bedding was obtained for 1999 from a United Egg Producers voluntary survey (UEP 1999). These data were augmented for key poultry states (AL, AR, CA, FL, GA, IA, IN, MN, MO, NC, NE, OH, PA, TX, and WA) with USDA data (USDA, APHIS 2000). It was assumed that the change in system usage between 1990 and 1999 is proportionally distributed among those years of the inventory. It was also assumed that system usage in 2000 through 2014 was equal to that estimated for 1999. Data collected for EPA's Office of Water, including information collected during site visits (EPA 2002b), were used to estimate the distribution of waste by management system and animal type. As with dairy and swine, using information about AD WMS from EPA's AgSTAR database (EPA 2012), AD was added to the WMS distribution for poultry operations.

Poultry—Broilers and Turkeys: The percentage of turkeys and broilers on pasture was obtained from the Office of Air and Radiation's *Global Methane Emissions from Livestock and Poultry Manure* (EPA 1992). It was assumed that one percent of poultry waste is deposited in pastures, ranges, and paddocks (EPA 1992). The remainder of waste is assumed to be deposited in operations with bedding management. As with dairy, swine, and other poultry, AD systems were added to the WMS distributions based on information from EPA's AgSTAR database (EPA 2012).

Step 4: Emission Factor Calculations

Methane conversion factors (MCFs) and N_2O emission factors (EFs) used in the emission calculations were determined using the methodologies presented below.

Methane Conversion Factors (MCFs)

Climate-based IPCC default MCFs (IPCC 2006) were used for all dry systems; these factors are presented in Table A-209. A U.S.-specific methodology was used to develop MCFs for all lagoon and liquid systems.

For animal waste managed in dry systems, the appropriate IPCC default MCF was applied based on annual average temperature data. The average county and state temperature data were obtained from the National Climate Data Center

(NOAA 2014) and each state and year in the inventory was assigned a climate classification of cool, temperate or warm. Although there are some specific locations in the United States that may be included in the warm climate category, no aggregated state-level annual average temperatures are included in this category. In addition, some counties in a particular state may be included in the cool climate category, although the aggregated state-level annual average temperature may be included in the temperate category. Although considering the temperatures at a state level instead of a county level may be causing some specific locations to be classified into an inappropriate climate category, using the state level annual average temperature provides an estimate that is appropriate for calculating the national average.

For anaerobic lagoons and other liquid systems a climate-based approach based on the van't Hoff-Arrhenius equation was developed to estimate MCFs that reflects the seasonal changes in temperatures, and also accounts for long-term retention time. This approach is consistent with the latest guidelines from IPCC (IPCC 2006). The van't Hoff-Arrhenius equation, with a base temperature of 30°C, is shown in the following equation (Safley and Westerman 1990):

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

where,

f	= van't Hoff-Arrhenius f factor, the proportion of VS that are biologically available for conversion to CH_4 based on the temperature of the system
T_1	= 303.15K
T_2	= Ambient temperature (K) for climate zone (in this case, a weighted value for each state)
E	= Activation energy constant (15,175 cal/mol)
R	= Ideal gas constant (1.987 cal/K mol)

For those animal populations using liquid manure management systems or manure runoff ponds (i.e., dairy cow, dairy heifer, layers, beef in feedlots, and swine) monthly average state temperatures were based on the counties where the specific animal population resides (i.e., the temperatures were weighted based on the percent of animals located in each county). County population data were calculated from state-level population data from NASS and county-state distribution data from the 1992, 1997, 2002, and 2007 Census data (USDA 2014a). County population distribution data for 1990 and 1991 were assumed to be the same as 1992; county population distribution data for 1993 through 1996 were extrapolated based on 1992 and 1997 data; county population data for 1998 through 2001 were extrapolated based on 1997 and 2002 data; county population data for 2003 through 2006 were extrapolated based on 2002 and 2007 data; and county population data for 2008 to 2014 were assumed to be the same as 2007.

Annual MCFs for liquid systems are calculated as follows for each animal type, state, and year of the inventory:

- The weighted-average temperature for a state is calculated using the county population estimates and average monthly temperature in each county. Monthly temperatures are used to calculate a monthly van't Hoff-Arrhenius f factor, using the equation presented above. A minimum temperature of 5°C is used for uncovered anaerobic lagoons and 7.5°C is used for liquid/slurry and deep pit systems due to the biological activity in the lagoon which keeps the temperature above freezing.
- Monthly production of VS added to the system is estimated based on the animal type, number of animals present, and the volatile solids excretion rate of the animals.
- For lagoon systems, the calculation of methane includes a management and design practices (MDP) factor. This factor, equal to 0.8, was developed based on model comparisons to empirical CH_4 measurement data from anaerobic lagoon systems in the United States (ERG 2001). The MDP factor represents management and design factors which cause a system to operate at a less than optimal level.
- For all systems other than anaerobic lagoons, the amount of VS available for conversion to CH_4 each month is assumed to be equal to the amount of VS produced during the month (from Step 3). For anaerobic lagoons, the amount of VS available also includes VS that may remain in the system from previous months.
- The amount of VS consumed during the month is equal to the amount available for conversion multiplied by the f factor.

- For anaerobic lagoons, the amount of VS carried over from one month to the next is equal to the amount available for conversion minus the amount consumed. Lagoons are also modeled to have a solids clean-out once per year, occurring in the month of October.
- The estimated amount of CH_4 generated during the month is equal to the monthly VS consumed multiplied by the maximum CH_4 potential of the waste (B_o).

  The annual MCF is then calculated as:

$$MCF_{annual} = \frac{CH_4 \text{ generated}_{annual}}{\text{VS produced}_{annual} \times B_o}$$

where,

MCF_{annual}	= Methane conversion factor
VS produced $_{annual}$	= Volatile solids excreted annually
B_o	= Maximum CH_4 producing potential of the waste

In order to account for the carry-over of VS from one year to the next, it is assumed that a portion of the VS from the previous year are available in the lagoon system in the next year. For example, the VS from October, November, and December of 2005 are available in the lagoon system starting January of 2006 in the MCF calculation for lagoons in 2006. Following this procedure, the resulting MCF for lagoons accounts for temperature variation throughout the year, residual VS in a system (carry-over), and management and design practices that may reduce the VS available for conversion to CH_4. It is assumed that liquid-slurry systems have a retention time less than 30 days, so the liquid-slurry MCF calculation doesn't reflect the VS carry-over.

The liquid system MCFs are presented in Table A-210 by state, WMS, and animal group for 2014.

Nitrous Oxide Emission Factors

Direct N_2O EFs for manure management systems (kg N_2O-N/kg excreted N) were set equal to the most recent default IPCC factors (IPCC 2006), presented in Table A-211.

Indirect N_2O EFs account for two fractions of nitrogen losses: volatilization of ammonia (NH_3) and NO_X ($Frac_{gas}$) and runoff/leaching ($Frac_{runoff/leach}$). IPCC default indirect N_2O EFs were used to estimate indirect N_2O emissions. These factors are 0.010 kg N_2O-N/kg N for volatilization and 0.0075 kg N_2O/kg N for runoff/leaching.

Country-specific estimates of N losses were developed for $Frac_{gas}$ and $Frac_{runoff/leach}$ for the United States. The vast majority of volatilization losses are NH_3. Although there are also some small losses of NO_X, no quantified estimates were available for use and those losses are believed to be small (about 1 percent) in comparison to the NH_3 losses. Therefore, $Frac_{gas}$ values were based on WMS-specific volatilization values estimated from U.S. EPA's *National Emission Inventory - Ammonia Emissions from Animal Agriculture Operations* (EPA 2005). To estimate $Frac_{runoff/leach}$, data from EPA's Office of Water were used that estimate the amount of runoff from beef, dairy, and heifer operations in five geographic regions of the country (EPA 2002b). These estimates were used to develop U.S. runoff factors by animal type, WMS, and region. Nitrogen losses from leaching are believed to be small in comparison to the runoff losses and there are a lack of data to quantify these losses. Therefore, leaching losses were assumed to be zero and $Frac_{runoff/leach}$ was set equal to the runoff loss factor. Nitrogen losses from volatilization and runoff/leaching are presented in Table A-212.

Step 5: CH_4 Emission Calculations

To calculate CH_4 emissions for animals other than cattle, first the amount of VS excreted in manure that is managed in each WMS was estimated:

$$\text{VS excreted}_{State,\,Animal,\,WMS} = Population_{State,\,Animal} \times \frac{TAM}{1000} \times VS \times WMS \times 365.25$$

where,

VS excreted $_{State, Animal, WMS}$	= Amount of VS excreted in manure managed in each WMS for each animal type (kg/yr)
Population $_{State, Animal}$	= Annual average state animal population by animal type (head)

TAM	= Typical animal mass (kg)
VS	= Volatile solids production rate (kg VS/1000 kg animal mass/day)
WMS	= Distribution of manure by WMS for each animal type in a state (percent)
365.25	= Days per year

Using the CEFM VS data for cattle, the amount of VS excreted in manure that is managed in each WMS was estimated using the following equation:

$$\text{VS excreted}_{\text{State, Animal, WMS}} = \text{Population}_{\text{State, Animal}} \text{ x VS x WMS}$$

where,

VS excreted $_{\text{State, Animal, WMS}}$	= Amount of VS excreted in manure managed in each WMS for each animal type (kg/yr)
Population $_{\text{State, Animal}}$	= Annual average state animal population by animal type (head)
VS	= Volatile solids production rate (kg VS/animal/year)
WMS	= Distribution of manure by WMS for each animal type in a state (percent)

For all animals, the estimated amount of VS excreted into a WMS was used to calculate CH_4 emissions using the following equation:

$$CH_4 = \sum_{\text{State, Animal, WMS}} \left(\text{VS excreted}_{\text{State, Animal, WMS}} \times B_o \times MCF \times 0.662 \right)$$

where,

CH_4	= CH_4 emissions (kg CH_4/yr)
VS excreted $_{\text{WMS, State}}$	= Amount of VS excreted in manure managed in each WMS (kg/yr)
B_o	= Maximum CH_4 producing capacity (m^3 CH_4/kg VS)
MCF $_{\text{animal, state, WMS}}$	= MCF for the animal group, state and WMS (percent)
0.662	= Density of methane at 25^o C (kg CH_4/m^3 CH_4)

A calculation was developed to estimate the amount of CH_4 emitted from AD systems utilizing CH_4 capture and combustion technology. First, AD systems were assumed to produce 90 percent of the maximum CH_4 producing capacity (B_0) of the manure. This value is applied for all climate regions and AD system types. However, this is a conservative assumption as the actual amount of CH_4 produced by each AD system is very variable and will change based on operational and climate conditions and an assumption of 90 percent is likely overestimating CH_4 production from some systems and underestimating CH_4 production in other systems. The CH_4 production of AD systems is calculated using the equation below:

$$CH_4\ ProductionAD_{ADSystem} = ProductionAD_{ADSystem} \times \frac{TAM}{1000} \times VS \times B_O \times 0.662 \times 365.25 \times 0.90$$

where,

CH_4 Production $AD_{\text{AD system}}$	=	CH_4 production from a particular AD system, (kg/yr)
Population AD $_{\text{state}}$	=	Number of animals on a particular AD system
VS	=	Volatile solids production rate (kg VS/1000 kg animal mass-day)
TAM	=	Typical Animal Mass (kg/head)
B_o	=	Maximum CH_4 producing capacity (CH4 m^3/kg VS)
0.662	=	Density of CH_4 at 25^o C (kg CH_4/m^3 CH_4)
365.25	=	Days/year
0.90	=	CH_4 production factor for AD systems

The total amount of CH_4 produced by AD is calculated only as a means to estimate the emissions from AD; i.e., only the estimated amount of CH_4 actually entering the atmosphere from AD is reported in the inventory. The emissions to the atmosphere from AD are a result of leakage from the system (e.g. from the cover, piping, tank, etc.) and incomplete combustion and are calculated using the collection efficiency (CE) and destruction efficiency (DE) of the AD system. The three primary types of AD systems in the United States are covered lagoons, complete mix and plug flow systems. The CE of covered lagoon systems was assumed to be 75 percent, and the CE of complete mix and plug flow AD systems was assumed to be 99 percent (EPA 2008). The CH_4 DE from flaring or burning in an engine was assumed to be 98 percent; therefore, the amount of CH_4 that would not be flared or combusted was assumed to be 2 percent (EPA 2008). The amount of CH_4 produced by systems with AD was calculated with the following equation:

$$\text{CH}_4 \text{ Emissions AD} = \sum_{\text{State, Animal, AD Systems}} \left(\begin{array}{l} \left[\text{CH}_4 \text{ Production AD}_{\text{AD system}} \times \text{CE}_{\text{AD system}} \times (1-\text{DE})\right] \\ + \left[\text{CH}_4 \text{ Production AD}_{\text{AD system}} \times (1-\text{CE}_{\text{AD system}})\right] \end{array} \right)$$

where,

CH_4 Emissions AD	=	CH_4 emissions from AD systems, (kg/yr)
CH_4 Production $AD_{AD\ system}$	=	CH_4 production from a particular AD system, (kg/yr)
$CE_{AD\ system}$	=	Collection efficiency of the AD system, varies by AD system type
DE	=	Destruction efficiency of the AD system, 0.98 for all systems

Step 6: N_2O Emission Calculations

Total N_2O emissions from manure management systems were calculated by summing direct and indirect N_2O emissions. The first step in estimating direct and indirect N_2O emissions was calculating the amount of N excreted in manure and managed in each WMS. For calves and animals other than cattle the following equation was used:

$$\text{N excreted}_{\text{State, Animal, WMS}} = \text{Population}_{\text{State, Animal}} \times \text{WMS} \times \frac{\text{TAM}}{1000} \times \text{Nex} \times 365.25$$

where,

N excreted $_{State,\ Animal,\ WMS}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
Population $_{state}$	= Annual average state animal population by animal type (head)
WMS	= Distribution of manure by waste management system for each animal type in a state (percent)
TAM	= Typical animal mass (kg)
Nex	= Total Kjeldahl nitrogen excretion rate (kg N/1000 kg animal mass/day)
365.25	= Days per year

Using the CEFM Nex data for cattle other than calves, the amount of N excreted was calculated using the following equation:

$$\text{N excreted}_{\text{State, Animal, WMS}} = \text{Population}_{\text{State, Animal}} \times \text{WMS} \times \text{Nex}$$

where,

N excreted $_{State,\ Animal,\ WMS}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
Population $_{state}$	= Annual average state animal population by animal type (head)
WMS	= Distribution of manure by waste management system for each animal type in a state (percent)
Nex	= Total Kjeldahl N excretion rate (kg N/animal/year)

For all animals, direct N_2O emissions were calculated as follows:

$$\text{Direct N}_2\text{O} = \sum_{\text{State, Animal, WMS}} \left(\text{N excreted}_{\text{State, Animal, WMS}} \times \text{EF}_{\text{WMS}} \times \frac{44}{28} \right)$$

where,

Direct N_2O	= Direct N_2O emissions (kg N_2O/yr)

N excreted $_{State, Animal, WMS}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
EF_{WMS}	= Direct N_2O emission factor from IPCC guidelines (kg N_2O-N /kg N)
44/28	= Conversion factor of N_2O-N to N_2O

Indirect N_2O emissions were calculated for all animals with the following equation:

$$\text{Indirect } N_2O = \sum_{\text{State, Animal, WMS}} \left(\left[\text{N excreted}_{\text{State, Animal, WMS}} \times \frac{\text{Frac}_{\text{gas, WMS}}}{100} \times EF_{\text{volatilization}} \times \frac{44}{28} \right] + \left[\text{N excreted}_{\text{State, Animal, WMS}} \times \frac{\text{Frac}_{\text{runoff/leach, WMS}}}{100} \times EF_{\text{runnoff/leach}} \times \frac{44}{28} \right] \right)$$

where,

Indirect N_2O	= Indirect N_2O emissions (kg N_2O/yr)
N excreted $_{State, Animal, WMS}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
$Frac_{gas,WMS}$	= Nitrogen lost through volatilization in each WMS
$Frac_{runoff/leach,WMS}$	= Nitrogen lost through runoff and leaching in each WMS (data were not available for leaching so the value reflects only runoff)
$EF_{volatilization}$	= Emission factor for volatilization (0.010 kg N_2O-N/kg N)
$EF_{runoff/leach}$	= Emission factor for runoff/leaching (0.0075 kg N_2O-N/kg N)
44/28	= Conversion factor of N_2O-N to N_2O

Emission estimates of CH_4 and N_2O by animal type are presented for all years of the inventory in Table A-213 and Table A-214 respectively. Emission estimates for 2014 are presented by animal type and state in Table A-215 and Table A-216 respectively.

Table A-203: Livestock Population (1,000 Head)

Animal Type	1990	1995	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Dairy Cattle	19,512	18,681	17,927	17,833	17,919	17,642	17,793	18,078	18,190	18,423	18,560	18,298	18,442	18,587	18,505	18,481
Dairy Cows	*10,015*	*9,482*	*9,172*	*9,106*	*9,142*	*8,988*	*9,004*	*9,104*	*9,145*	*9,257*	*9,333*	*9,087*	*9,156*	*9,236*	*9,221*	*9,208*
Dairy Heifer	*4,129*	*4,108*	*4,045*	*4,060*	*4,073*	*4,033*	*4,162*	*4,294*	*4,343*	*4,401*	*4,437*	*4,545*	*4,577*	*4,581*	*4,525*	*4,546*
Dairy Calves	*5,369*	*5,091*	*4,710*	*4,668*	*4,704*	*4,621*	*4,628*	*4,680*	*4,703*	*4,765*	*4,791*	*4,666*	*4,709*	*4,770*	*4,758*	*4,727*
Swine[a]	53,941	58,899	58,913	60,028	59,827	60,735	61,073	61,887	65,417	67,183	65,842	64,723	65,572	66,363	65,437	64,230
Market <50 lb.	*18,359*	*19,656*	*19,659*	*19,863*	*19,929*	*20,222*	*20,228*	*20,514*	*21,812*	*19,933*	*19,411*	*19,067*	*19,285*	*19,472*	*19,002*	*18,900*
Market 50-119 lb.	*11,734*	*12,836*	*12,900*	*13,284*	*13,138*	*13,400*	*13,519*	*13,727*	*14,557*	*17,163*	*16,942*	*16,645*	*16,904*	*17,140*	*16,834*	*16,560*
Market 120-179 lb.	*9,440*	*10,545*	*10,708*	*11,013*	*11,050*	*11,227*	*11,336*	*11,443*	*12,185*	*12,825*	*12,517*	*12,377*	*12,514*	*12,714*	*12,674*	*12,314*
Market >180 lb.	*7,510*	*8,937*	*9,465*	*9,738*	*9,701*	*9,922*	*9,997*	*10,113*	*10,673*	*11,161*	*11,067*	*10,856*	*11,078*	*11,199*	*11,116*	*10,548*
Breeding	*6,899*	*6,926*	*6,181*	*6,129*	*6,011*	*5,963*	*5,993*	*6,090*	*6,190*	*6,102*	*5,905*	*5,778*	*5,791*	*5,839*	*5,812*	*5,908*
Beef Cattle[b]	81,576	90,361	84,237	84,260	83,361	81,672	82,193	83,263	82,801	81,528	80,993	80,485	78,937	76,858	76,075	75,540
Feedlot Steers	*6,357*	*7,233*	*7,932*	*8,116*	*8,416*	*8,018*	*8,116*	*8,724*	*8,674*	*8,474*	*8,434*	*8,584*	*8,771*	*8,586*	*8,614*	*8,685*
Feedlot Heifers	*3,192*	*3,831*	*4,569*	*4,557*	*4,676*	*4,521*	*4,536*	*4,801*	*4,730*	*4,585*	*4,493*	*4,620*	*4,830*	*4,742*	*4,653*	*4,537*
NOF Bulls	*2,160*	*2,385*	*2,274*	*2,244*	*2,248*	*2,201*	*2,214*	*2,258*	*2,214*	*2,207*	*2,188*	*2,190*	*2,165*	*2,100*	*2,074*	*2,038*
Beef Calves	*16,909*	*18,177*	*17,508*	*17,483*	*17,126*	*17,013*	*16,918*	*16,814*	*16,644*	*16,229*	*16,051*	*16,067*	*15,817*	*15,288*	*14,859*	*14,946*
NOF Heifers	*10,182*	*11,829*	*9,832*	*9,843*	*9,564*	*9,321*	*9,550*	*9,716*	*9,592*	*9,356*	*9,473*	*9,350*	*8,874*	*8,687*	*8,787*	*8,838*
NOF Steers	*10,321*	*11,716*	*8,724*	*8,883*	*8,347*	*8,067*	*8,185*	*8,248*	*8,302*	*8,243*	*8,560*	*8,234*	*7,568*	*7,173*	*7,457*	*7,411*
NOF Cows	*32,455*	*35,190*	*33,398*	*33,134*	*32,983*	*32,531*	*32,674*	*32,703*	*32,644*	*32,435*	*31,794*	*31,440*	*30,913*	*30,282*	*29,631*	*29,085*
Sheep	11,358	8,989	6,908	6,623	6,321	6,065	6,135	6,200	6,120	5,950	5,747	5,620	5,470	5,375	5,335	5,245
Sheep On Feed	*1,180*	*1,771*	*3,256*	*3,143*	*3,049*	*2,923*	*2,971*	*3,026*	*3,000*	*2,911*	*2,806*	*2,778*	*2,687*	*2,666*	*2,626*	*2,593*
Sheep NOF	*10,178*	*7,218*	*3,652*	*3,480*	*3,272*	*3,142*	*3,164*	*3,174*	*3,120*	*3,039*	*2,941*	*2,842*	*2,783*	*2,709*	*2,709*	*2,652*
Goats	2,516	2,357	2,475	2,530	2,652	2,774	2,897	3,019	3,141	3,037	2,933	2,829	2,725	2,622	2,518	2,414
Poultry[c]	1,537,074	1,826,977	2,060,398	2,097,691	2,085,268	2,130,877	2,150,410	2,154,236	2,166,936	2,175,990	2,088,828	2,104,335	2,095,951	2,168,697	2,106,502	2,111,689
Hens >1 yr.	*273,467*	*299,071*	*340,317*	*340,209*	*340,979*	*343,922*	*348,203*	*349,888*	*346,613*	*339,859*	*341,005*	*341,884*	*338,944*	*346,965*	*361,403*	*366,045*
Pullets	*73,167*	*81,369*	*95,656*	*95,289*	*100,346*	*101,429*	*96,809*	*96,596*	*103,816*	*99,458*	*102,301*	*105,738*	*102,233*	*104,460*	*106,646*	*106,602*
Chickens	*6,545*	*7,637*	*8,126*	*8,353*	*8,439*	*8,248*	*8,289*	*7,938*	*8,164*	*7,589*	*8,487*	*7,390*	*6,922*	*6,827*	*6,853*	*6,403*
Broilers	*1,066,209*	*1,331,940*	*1,525,413*	*1,562,015*	*1,544,155*	*1,589,209*	*1,613,091*	*1,612,327*	*1,619,400*	*1,638,055*	*1,554,582*	*1,567,927*	*1,565,018*	*1,625,945*	*1,551,600*	*1,553,473*
Turkeys	*117,685*	*106,960*	*90,887*	*91,826*	*91,349*	*88,069*	*84,018*	*87,487*	*88,943*	*91,029*	*82,453*	*81,396*	*82,833*	*84,500*	*80,000*	*79,167*
Horses	2,212	2,632	3,519	3,644	3,721	3,798	3,875	3,952	4,029	3,947	3,866	3,784	3,703	3,621	3,540	3,458
Mules and Asses	63	101	109	105	141	177	212	248	284	286	287	289	291	293	294	296
American Bison	47	104	213	232	225	218	212	205	198	191	184	177	169	162	155	148

[a] Prior to 2008, the Market <50 lbs category was <60 lbs and the Market 50-119 lbs category was Market 60-119 lbs; USDA updated the categories to be more consistent with international animal categories.
[b] NOF - Not on Feed
[c] Pullets includes laying pullets, pullets younger than 3 months, and pullets older than 3 months.
Note: Totals may not sum due to independent rounding.

Table A-204: Waste Characteristics Data

	Typical Animal Mass, TAM		Total Kjeldahl Nitrogen Excreted, Nex[a]		Maximum Methane Generation Potential, B_0		Volatile Solids Excreted, VS[a]	
Animal Group	Value (kg)	Source	Value	Source	Value (m^3 CH_4/kg VS added)	Source	Value	Source
Dairy Cows	680	CEFM	Table A-206	CEFM	0.24	Morris 1976	Table A-206	CEFM
Dairy Heifers	406-408	CEFM	Table A-206	CEFM	0.17	Bryant et al. 1976	Table A-206	CEFM
Feedlot Steers	419-457	CEFM	Table A-206	CEFM	0.33	Hashimoto 1981	Table A-206	CEFM
Feedlot Heifers	384-430	CEFM	Table A-206	CEFM	0.33	Hashimoto 1981	Table A-206	CEFM
NOF Bulls	831-917	CEFM	Table A-206	CEFM	0.17	Hashimoto 1981	Table A-206	CEFM
NOF Calves	118	ERG 2003b	Table A-205	USDA 1996, 2008	0.17	Hashimoto 1981	Table A-205	USDA 1996, 2008
NOF Heifers	296-407	CEFM	Table A-206	CEFM	0.17	Hashimoto 1981	Table A-206	CEFM
NOF Steers	314-335	CEFM	Table A-206	CEFM	0.17	Hashimoto 1981	Table A-206	CEFM
NOF Cows	554-611	CEFM	Table A-206	CEFM	0.17	Hashimoto 1981	Table A-206	CEFM
American Bison	578.5	Meagher 1986	Table A-206	CEFM	0.17	Hashimoto 1981	Table A-206	CEFM
Market Swine <50 lbs.	13	ERG 2010a	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Market Swine <60 lbs.	16	Safley 2000	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Market Swine 50-119 lbs.	39	ERG 2010a	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Market Swine 60-119 lbs.	41	Safley 2000	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Market Swine 120-179 lbs.	68	Safley 2000	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Market Swine >180 lbs.	91	Safley 2000	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Breeding Swine	198	Safley 2000	Table A-205	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-205	USDA 1996, 2008
Feedlot Sheep	25	EPA 1992	Table A-205	ASAE 1998, USDA 2008	0.36	EPA 1992	Table A-205	ASAE 1998, USDA 2008
NOF Sheep	80	EPA 1992	Table A-205	ASAE 1998, USDA 2008	0.19	EPA 1992	Table A-205	ASAE 1998, USDA 2008
Goats	64	ASAE 1998	Table A-205	ASAE 1998	0.17	EPA 1992	Table A-205	ASAE 1998
Horses	450	ASAE 1998	Table A-205	ASAE 1998, USDA 2008	0.33	EPA 1992	Table A-205	ASAE 1998, USDA 2008
Mules and Asses	130	IPCC 2006	Table A-205	IPCC 2006	0.33	EPA 1992	Table A-205	IPCC 2006
Hens >/= 1 yr	1.8	ASAE 1998	Table A-205	USDA 1996, 2008	0.39	Hill 1982	Table A-205	USDA 1996, 2008
Pullets	1.8	ASAE 1998	Table A-205	USDA 1996, 2008	0.39	Hill 1982	Table A-205	USDA 1996, 2008

Other Chickens	1.8	ASAE 1998	Table A-205	USDA 1996, 2008	0.39	Hill 1982	Table A-205	USDA 1996, 2008
Broilers	0.9	ASAE 1998	Table A-205	USDA 1996, 2008	0.36	Hill 1984	Table A-205	USDA 1996, 2008
Turkeys	6.8	ASAE 1998	Table A-205	USDA 1996, 2008	0.36	Hill 1984	Table A-205	USDA 1996, 2008

[a] Nex and VS values vary by year; Table A-206 shows state-level values for 2014 only.

Table A-205: Estimated Volatile Solids (VS) and Total Kjeldahl Nitrogen Excreted (Nex) Production Rates by year for Swine, Poultry, Sheep, Goats, Horses, Mules and Asses, and Cattle Calves (kg/day/1000 kg animal mass)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
VS																									
Swine, Market <50 lbs.	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Swine, Market 50-119 lbs.	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Swine, Market 120-179 lbs.	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Swine, Market >180 lbs.	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Swine, Breeding	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
NOF Cattle Calves	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.5	6.6	6.7	6.8	6.9	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Sheep	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.0	8.9	8.8	8.8	8.7	8.6	8.5	8.4	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Goats	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Hens >1yr.	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
Pullets	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
Chickens	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.9	10.9	10.9	10.9	10.9	10.9	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Broilers	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.2	15.3	15.5	15.7	15.8	16.0	16.2	16.3	16.5	16.7	16.8	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Turkeys	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.6	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Horses	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.6	9.2	8.8	8.4	8.1	7.7	7.3	6.9	6.5	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Mules and Asses	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Nex																									
Swine, Market <50 lbs.	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.63	0.65	0.68	0.71	0.73	0.76	0.79	0.81	0.84	0.87	0.89	0.92	0.92	0.92	0.92	0.92	0.92	0.92

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Swine, Market 50-119 lbs.	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Swine, Market 120-179 lbs.	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Swine, Market >180 lbs.	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Swine, Breeding	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20
NOF Cattle Calves	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.31	0.33	0.34	0.35	0.36	0.38	0.39	0.40	0.41	0.43	0.44	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sheep	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43	0.43	0.43	0.44	0.44	0.44	0.44	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Goats	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Hens >1yr.	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.71	0.72	0.73	0.73	0.74	0.75	0.76	0.77	0.77	0.78	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Pullets	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.71	0.72	0.73	0.73	0.74	0.75	0.76	0.77	0.77	0.78	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Chickens	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.85	0.88	0.90	0.92	0.94	0.97	0.99	1.01	1.03	1.06	1.08	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Broilers	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.09	1.08	1.07	1.05	1.04	1.03	1.02	1.01	1.00	0.98	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Turkeys	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.73	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Horses	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mules and Asses	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Table A-206: Estimated Volatile Solids (VS) and Total Kjeldahl Nitrogen Excreted (Nex) Production Rates by State for Cattle (other than Calves) and American Bison[a] for 2014 (kg/animal/year)

	Volatile Solids									Nitrogen Excreted								
State	Dairy Cow	Dairy Heifers	Beef NOF Cow	Beef NOF Heifers	Beef NOF Steer	Beef OF Heifers	Beef OF Steer	Beef NOF Bull	American Bison	Dairy Cow	Dairy Heifers	Beef NOF Cow	Beef NOF Heifers	Beef NOF Steer	Beef OF Heifers	Beef OF Steer	Beef NOF Bull	American Bison
Alabama	2,171	1,252	1,664	1,100	971	682	663	1,721	1,721	132	69	73	51	42	55	56	83	83
Alaska	1,971	1,252	1,891	1,272	1,116	682	663	1,956	1,956	121	69	59	42	33	55	56	69	69
Arizona	2,918	1,252	1,891	1,244	1,116	682	663	1,956	1,956	162	69	59	40	33	55	56	69	69
Arkansas	2,128	1,252	1,664	1,088	971	682	663	1,721	1,721	128	69	73	50	42	55	56	83	83
California	2,857	1,252	1,891	1,211	1,116	682	663	1,956	1,956	159	69	59	39	33	55	56	69	69
Colorado	2,963	1,252	1,891	1,198	1,116	682	663	1,956	1,956	164	69	59	38	33	55	56	69	69
Connecticut	2,605	1,252	1,674	1,104	977	682	664	1,731	1,731	148	69	74	51	42	55	56	84	84
Delaware	2,604	1,252	1,674	1,076	977	682	663	1,731	1,731	148	69	74	49	42	55	56	84	84
Florida	2,676	1,252	1,664	1,101	971	682	662	1,721	1,721	153	69	73	51	42	55	56	83	83
Georgia	2,707	1,252	1,664	1,097	971	682	664	1,721	1,721	155	69	73	50	42	55	57	83	83
Hawaii	2,114	1,252	1,891	1,254	1,116	682	664	1,956	1,956	127	69	59	41	33	55	57	69	69
Idaho	2,902	1,252	1,891	1,217	1,116	682	663	1,956	1,956	161	69	59	39	33	55	56	69	69
Illinois	2,569	1,252	1,589	1,009	923	682	663	1,643	1,643	147	69	75	49	43	55	56	85	85
Indiana	2,733	1,252	1,589	1,014	923	682	662	1,643	1,643	154	69	75	50	43	55	56	85	85
Iowa	2,776	1,252	1,589	987	923	682	663	1,643	1,643	156	69	75	48	43	55	56	85	85
Kansas	2,747	1,252	1,589	979	923	682	663	1,643	1,643	155	69	75	47	43	55	56	85	85
Kentucky	2,342	1,252	1,664	1,079	971	682	663	1,721	1,721	139	69	73	49	42	55	56	83	83
Louisiana	2,120	1,252	1,664	1,102	971	682	663	1,721	1,721	128	69	73	51	42	55	56	83	83
Maine	2,593	1,252	1,674	1,091	977	682	664	1,731	1,731	148	69	74	50	42	55	57	84	84
Maryland	2,574	1,252	1,674	1,087	977	682	663	1,731	1,731	147	69	74	50	42	55	56	84	84
Massachusetts	2,438	1,252	1,674	1,108	977	682	664	1,731	1,731	141	69	74	52	42	55	57	84	84
Michigan	2,940	1,252	1,589	1,009	923	682	663	1,643	1,643	163	69	75	49	43	55	56	85	85
Minnesota	2,581	1,252	1,589	1,002	923	682	663	1,643	1,643	147	69	75	49	43	55	56	85	85
Mississippi	2,234	1,252	1,664	1,092	971	682	662	1,721	1,721	134	69	73	50	42	55	56	83	83
Missouri	2,260	1,252	1,589	1,030	923	682	663	1,643	1,643	134	69	75	51	43	55	56	85	85
Montana	2,705	1,252	1,891	1,252	1,116	682	662	1,956	1,956	153	69	59	41	33	55	56	69	69
Nebraska	2,752	1,252	1,589	992	923	682	663	1,643	1,643	155	69	75	48	43	55	56	85	85
Nevada	2,877	1,252	1,891	1,238	1,116	682	663	1,956	1,956	160	69	59	40	33	55	56	69	69
New Hampshire	2,604	1,252	1,674	1,097	977	682	664	1,731	1,731	148	69	74	51	42	55	57	84	84
New Jersey	2,454	1,252	1,674	1,081	977	682	664	1,731	1,731	142	69	74	50	42	55	56	84	84
New Mexico	2,974	1,252	1,891	1,234	1,116	682	664	1,956	1,956	164	69	59	40	33	55	57	69	69
New York	2,767	1,252	1,674	1,084	977	682	663	1,731	1,731	155	69	74	50	42	55	56	84	84
North Carolina	2,714	1,252	1,664	1,098	971	682	663	1,721	1,721	155	69	73	50	42	55	56	83	83

	Volatile Solids									Nitrogen Excreted								
State	Dairy Cow	Dairy Heifers	Beef NOF Cow	Beef NOF Heifers	Beef NOF Steer	Beef OF Heifers	Beef OF Steer	Beef NOF Bull	American Bison	Dairy Cow	Dairy Heifers	Beef NOF Cow	Beef NOF Heifers	Beef NOF Steer	Beef OF Heifers	Beef OF Steer	Beef NOF Bull	American Bison
North Dakota	2,612	1,252	1,589	1,016	923	682	664	1,643	1,643	149	69	75	50	43	55	57	85	85
Ohio	2,617	1,252	1,589	1,020	923	682	663	1,643	1,643	149	69	75	50	43	55	56	85	85
Oklahoma	2,405	1,252	1,664	1,073	971	682	664	1,721	1,721	140	69	73	49	42	55	57	83	83
Oregon	2,638	1,252	1,891	1,230	1,116	682	662	1,956	1,956	150	69	59	40	33	55	56	69	69
Pennsylvania	2,605	1,252	1,674	1,072	977	682	663	1,731	1,731	148	69	74	49	42	55	56	84	84
Rhode Island	2,519	1,252	1,674	1,101	977	682	662	1,731	1,731	145	69	74	51	42	54	56	84	84
South Carolina	2,377	1,252	1,664	1,095	971	682	662	1,721	1,721	140	69	73	50	42	55	56	83	83
South Dakota	2,723	1,252	1,589	1,012	923	682	663	1,643	1,643	154	69	75	50	43	55	56	85	85
Tennessee	2,372	1,252	1,664	1,085	971	682	663	1,721	1,721	140	69	73	50	42	55	56	83	83
Texas	2,767	1,252	1,664	1,053	971	682	663	1,721	1,721	156	69	73	47	42	55	56	83	83
Utah	2,815	1,252	1,891	1,234	1,116	682	663	1,956	1,956	157	69	59	40	33	55	56	69	69
Vermont	2,608	1,252	1,674	1,075	977	682	664	1,731	1,731	149	69	74	49	42	55	57	84	84
Virginia	2,584	1,252	1,664	1,086	971	682	663	1,721	1,721	149	69	73	50	42	55	56	83	83
Washington	2,901	1,252	1,891	1,204	1,116	682	664	1,956	1,956	161	69	59	38	33	55	57	69	69
West Virginia	2,261	1,252	1,674	1,090	977	682	662	1,731	1,731	134	69	74	50	42	55	56	84	84
Wisconsin	2,733	1,252	1,589	1,022	923	682	663	1,643	1,643	154	69	75	50	43	55	56	85	85
Wyoming	2,712	1,252	1,891	1,247	1,116	682	663	1,956	1,956	153	69	59	40	33	55	56	69	69

[a] Beef NOF Bull values were used for American bison Nex and VS.
Source: CEFM. NA: Not available; no population exists in this state.

Table A-207: 2014 Manure Distribution Among Waste Management Systems by Operation (Percent)

	Beef Feedlots		Beef Not on Feed Operations	Dairy Cow Farms[a]						Dairy Heifer Facilities				Swine Operations[a]					Layer Operations		Broiler and Turkey Operations	
State	Dry Lot[b]	Liquid/ Slurry[b]	Pasture, Range, Paddock	Pasture, Range, Paddock	Daily Spread	Solid Storage	Liquid/ Slurry	Anaerobic Lagoon	Deep Pit	Daily Spread[b]	Dry Lot[b]	Liquid/ Slurry[b]	Pasture, Range, Paddock[b]	Pasture, Range, Paddock	Solid Storage	Liquid/ Slurry	Anaerobic Lagoon	Deep Pit	Anaerobic Lagoon	Poultry without Litter	Pasture, Range, Paddock	Poultry with Litter
Alabama	100	1	100	51	16	7	10	16	0	17	38	0	45	5	4	7	54	31	42	58	1	99
Alaska	100	1	100	5	9	34	19	24	9	6	90	1	4	64	2	10	7	17	25	75	1	99
Arizona	100	0	100	0	10	9	19	61	0	10	90	0	0	6	3	6	55	29	60	40	1	99
Arkansas	100	1	100	60	14	10	7	9	0	15	28	0	57	4	4	13	45	35	0	100	1	99
California	100	1	100	1	11	9	20	59	0	11	88	1	1	10	3	7	50	29	12	88	1	99
Colorado	100	0	100	1	1	11	23	64	0	1	98	0	1	1	6	26	17	50	60	40	1	99
Connecticut	100	1	100	6	43	16	20	13	2	43	51	0	6	78	1	6	5	11	5	95	1	99
Delaware	100	1	100	6	44	19	19	10	2	44	50	0	6	8	5	25	17	46	5	95	1	99
Florida	100	1	100	13	22	7	15	43	0	22	61	1	17	72	1	8	6	13	42	58	1	99
Georgia	100	1	100	37	18	9	12	23	0	18	42	0	40	4	4	8	53	31	42	58	1	99
Hawaii	100	1	100	10	0	9	23	57	0	0	99	1	1	31	3	19	14	32	25	75	1	99
Idaho	100	0	100	0	0	11	23	65	0	1	99	0	0	12	5	23	15	44	60	40	1	99
Illinois	100	1	100	4	6	39	31	16	5	8	87	0	5	1	5	29	14	52	2	98	1	99
Indiana	100	1	100	5	8	29	31	24	3	13	79	0	8	1	5	28	14	52	0	100	1	99
Iowa	100	1	100	4	8	34	30	20	4	10	83	0	6	1	4	9	54	33	0	100	1	99
Kansas	100	1	100	2	3	21	37	36	2	5	92	0	3	2	5	28	13	52	2	98	1	99
Kentucky	100	1	100	60	14	14	7	3	2	14	24	0	61	5	4	10	48	33	5	95	1	99
Louisiana	100	1	100	59	15	10	7	9	1	14	26	0	60	88	1	3	3	6	60	40	1	99
Maine	100	1	100	7	45	20	17	10	2	45	48	0	7	65	2	10	7	16	5	95	1	99
Maryland	100	1	100	7	44	22	16	8	3	44	49	0	7	7	5	25	17	47	5	95	1	99
Massachusetts	100	1	100	7	44	22	16	8	3	45	47	0	7	56	2	12	9	20	5	95	1	99
Michigan	100	1	100	2	4	24	38	29	3	6	91	0	3	4	5	26	17	48	2	98	1	99
Minnesota	100	1	100	5	8	39	28	17	4	10	84	0	6	1	5	26	18	50	0	100	1	99
Mississippi	100	1	100	54	15	10	8	12	0	15	28	0	57	2	4	6	58	31	60	40	1	99
Missouri	100	1	100	7	12	42	22	11	5	14	77	0	8	2	5	28	13	52	0	100	1	99
Montana	100	0	100	2	4	19	28	42	4	4	93	0	3	3	5	25	17	49	60	40	1	99
Nebraska	100	1	100	2	4	26	35	29	3	6	90	0	4	1	5	28	14	51	2	98	1	99
Nevada	100	0	100	0	0	10	24	65	0	0	99	0	0	34	3	18	14	31	0	100	1	99
New Hampshire	100	1	100	7	44	19	18	10	2	44	49	0	7	64	2	10	8	17	5	95	1	99
New Jersey	100	1	100	7	45	25	13	6	3	45	47	0	8	36	3	18	14	30	5	95	1	99
New Mexico	100	0	100	0	10	9	19	61	0	10	90	0	0	100	0	0	0	0	60	40	1	99

	Beef Feedlots		Beef Not on Feed Operations	Dairy Cow Farms[a]						Dairy Heifer Facilities				Swine Operations[a]					Layer Operations		Broiler and Turkey Operations	
State	Dry Lot[b]	Liquid/ Slurry[b]	Pasture, Range, Paddock	Pasture, Range, Paddock	Daily Spread	Solid Storage	Liquid/ Slurry	Anaerobic Lagoon	Deep Pit	Daily Spread[b]	Dry Lot[b]	Liquid/ Slurry[b]	Pasture, Range, Paddock[b]	Pasture, Range, Paddock	Solid Storage	Liquid/ Slurry	Anaerobic Lagoon	Deep Pit	Anaerobic Lagoon	Poultry without Litter	Pasture, Range, Paddock	Poultry with Litter
New York	100	1	100	6	44	17	18	13	2	45	48	0	7	13	5	23	15	44	5	95	1	99
North Carolina	100	1	100	46	17	11	15	10	2	15	31	0	54	0	4	7	57	32	42	58	1	99
North Dakota	100	1	100	7	11	38	26	15	4	11	83	0	6	5	5	25	17	48	2	98	1	99
Ohio	100	1	100	6	11	38	26	15	4	14	78	0	8	3	5	28	14	51	0	100	1	99
Oklahoma	100	0	100	0	7	21	22	45	4	6	94	0	0	1	4	6	58	31	60	40	1	99
Oregon	100	1	100	16	0	11	22	50	1	0	80	1	20	48	2	14	11	24	25	75	1	99
Pennsylvania	100	1	100	8	46	24	12	6	2	47	44	0	9	4	5	26	18	48	0	100	1	99
Rhode Island	100	1	100	9	47	25	13	5	2	47	44	0	9	72	1	8	6	13	5	95	1	99
South Carolina	100	1	100	47	17	8	11	18	0	15	31	0	54	3	4	7	55	31	60	40	1	99
South Dakota	100	1	100	3	4	24	36	31	2	8	87	0	5	1	5	26	17	50	2	98	1	99
Tennessee	100	1	100	58	15	12	9	4	2	15	26	0	59	13	3	11	41	32	5	95	1	99
Texas	100	0	100	0	9	11	22	58	1	8	92	0	0	3	4	6	57	30	12	88	1	99
Utah	100	0	100	1	1	15	26	56	2	1	98	0	1	1	6	26	17	51	60	40	1	99
Vermont	100	1	100	6	44	17	19	13	2	44	49	0	7	63	2	10	8	18	5	95	1	99
Virginia	100	1	100	56	15	11	10	5	2	15	28	0	57	4	4	7	54	31	5	95	1	99
Washington	100	1	100	11	0	11	22	56	1	0	83	1	17	43	3	15	11	28	12	88	1	99
West Virginia	100	1	100	8	46	23	14	7	2	45	48	0	7	59	2	11	7	20	5	95	1	99
Wisconsin	100	1	100	5	9	38	28	17	4	12	82	0	7	13	4	23	17	42	2	98	1	99
Wyoming	100	0	100	4	6	19	23	43	4	12	81	0	7	4	5	25	16	49	60	40	1	99

[a] In the methane inventory for manure management, the percent of dairy cows and swine with AD systems is estimated using data from EPA's AgSTAR Program.

[b] Because manure from beef feedlots and dairy heifers may be managed for long periods of time in multiple systems (i.e., both drylot and runoff collection pond), the percent of manure that generates emissions is greater than 100 percent.

Table A-208: Manure Management System Descriptions

Manure Management System	Description[a]
Pasture, Range, Paddock	The manure from pasture and range grazing animals is allowed to lie as is, and is not managed. Methane emissions are accounted for under Manure Management, but the N_2O emissions from manure deposited on PRP are included under the Agricultural Soil Management category.
Daily Spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. Methane and indirect N_2O emissions are accounted for under Manure Management. Direct N_2O emissions from land application are covered under the Agricultural Soil Management category.
Solid Storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry Lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. Dry lots are most typically found in dry climates but also are used in humid climates.
Liquid/ Slurry	Manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds, usually for periods less than one year.
Anaerobic Lagoon	Uncovered anaerobic lagoons are designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the VS loading rate, and other operational factors. Anaerobic lagoons accumulate sludge over time, diminishing treatment capacity. Lagoons must be cleaned out once every 5 to 15 years, and the sludge is typically applied to agricultural lands. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields. Lagoons are sometimes used in combination with a solids separator, typically for dairy waste. Solids separators help control the buildup of nondegradable material such as straw or other bedding materials.
Anaerobic Digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel (complete mix or plug flow digester) or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Deep Pit	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility. Typical storage periods range from 5 to 12 months, after which manure is removed from the pit and transferred to a treatment system or applied to land.
Poultry with Litter	Enclosed poultry houses use bedding derived from wood shavings, rice hulls, chopped straw, peanut hulls, or other products, depending on availability. The bedding absorbs moisture and dilutes the manure produced by the birds. Litter is typically cleaned out completely once a year. These manure systems are typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.
Poultry without Litter	In high-rise cages or scrape-out/belt systems, manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored. When designed and operated properly, this high-rise system is a form of passive windrow composting.

[a] Manure management system descriptions are based on the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Volume 4: Agriculture, Forestry and Other Land Use, Chapter 10: Emissions from Livestock and Manure Management, Tables 10.18 and 10.21) and the *Development Document for the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations* (EPA-821-R-03-001, December 2002).

Table A-209: Methane Conversion Factors (percent) for Dry Systems

Waste Management System	Cool Climate MCF	Temperate Climate MCF	Warm Climate MCF
Aerobic Treatment	0	0	0
Anaerobic Digester	0	0	0
Cattle Deep Litter (<1 month)	3	3	30
Cattle Deep Litter (>1 month)	21	44	76

Waste Management System	Cool Climate MCF	Temperate Climate MCF	Warm Climate MCF
Composting - In Vessel	0.5	0.5	0.5
Composting - Static Pile	0.5	0.5	0.5
Composting-Extensive/ Passive	0.5	1	1.5
Composting-Intensive	0.5	1	1.5
Daily Spread	0.1	0.5	1
Dry Lot	1	1.5	5
Fuel	10	10	10
Pasture	1	1.5	2
Poultry with bedding	1.5	1.5	1.5
Poultry without bedding	1.5	1.5	1.5
Solid Storage	2	4	5

Source: IPCC 2006

Table A-210: Methane Conversion Factors by State for Liquid Systems for 2014 (percent)

	Dairy		Swine		Beef	Poultry
State	Anaerobic Lagoon	Liquid/Slurry and Deep Pit	Anaerobic Lagoon	Liquid/Slurry and Deep Pit	Liquid/Slurry	Anaerobic Lagoon
Alabama	75	37	75	36	38	75
Alaska	47	15	47	15	15	47
Arizona	78	57	77	47	52	74
Arkansas	75	34	76	37	35	75
California	73	32	72	31	41	74
Colorado	65	22	68	24	24	65
Connecticut	69	25	69	26	26	69
Delaware	73	31	73	31	31	73
Florida	79	55	79	53	53	79
Georgia	76	39	75	38	37	75
Hawaii	76	57	76	57	57	76
Idaho	69	25	66	22	22	68
Illinois	72	29	72	28	27	72
Indiana	70	27	71	27	27	71
Iowa	70	25	70	26	26	70
Kansas	74	32	74	32	32	74
Kentucky	73	31	73	31	30	73
Louisiana	77	45	77	46	46	77
Maine	63	21	63	21	21	64
Maryland	72	30	72	30	31	73
Massachusetts	67	24	68	25	25	68
Michigan	67	23	67	24	24	67
Minnesota	68	24	69	24	24	67
Mississippi	76	40	76	38	41	76
Missouri	73	30	73	30	30	74
Montana	61	19	64	21	21	64
Nebraska	72	27	72	27	27	72
Nevada	70	26	71	27	25	70
New Hampshire	64	22	65	22	22	65
New Jersey	71	28	71	29	28	71
New Mexico	73	31	71	28	30	70
New York	65	23	66	23	23	66
North Carolina	73	31	75	36	30	73
North Dakota	66	22	66	22	22	66
Ohio	69	26	70	27	27	70
Oklahoma	76	37	75	35	36	76
Oregon	64	21	63	21	22	63
Pennsylvania	69	26	70	27	27	70
Rhode Island	69	26	69	26	26	69

State	Dairy		Swine		Beef	Poultry
	Anaerobic Lagoon	Liquid/Slurry and Deep Pit	Anaerobic Lagoon	Liquid/Slurry and Deep Pit	Liquid/Slurry	Anaerobic Lagoon
South Carolina	75	37	76	38	36	75
South Dakota	69	24	70	25	25	70
Tennessee	73	31	74	32	31	73
Texas	76	41	76	44	38	77
Utah	65	22	69	25	24	65
Vermont	63	21	63	21	21	63
Virginia	71	28	72	31	29	71
Washington	64	21	66	22	23	65
West Virginia	69	26	70	27	26	69
Wisconsin	66	23	68	24	23	67
Wyoming	63	20	64	21	22	64

Note: MCFs developed using Tier 2 methods described in IPCC 2006, Section 10.4.2.

Table A-211: Direct Nitrous Oxide Emission Factors for 2014 (kg N_2O-N/kg Kjdl N)

Waste Management System	Direct N_2O Emission Factor
Aerobic Treatment (forced aeration)	0.005
Aerobic Treatment (natural aeration)	0.01
Anaerobic Digester	0
Anaerobic Lagoon	0
Cattle Deep Bed (active mix)	0.07
Cattle Deep Bed (no mix)	0.01
Composting_in vessel	0.006
Composting_intensive	0.1
Composting_passive	0.01
Composting_static	0.006
Daily Spread	0
Deep Pit	0.002
Dry Lot	0.02
Fuel	0
Liquid/Slurry	0.005
Pasture	0
Poultry with bedding	0.001
Poultry without bedding	0.001
Solid Storage	0.005

Source: IPCC 2006

Table A-212: Indirect Nitrous Oxide Loss Factors (percent)

Animal Type	Waste Management System	Volatilization Nitrogen Loss	Runoff/Leaching Nitrogen Loss[a]				
			Central	Pacific	Mid-Atlantic	Midwest	South
Beef Cattle	Dry Lot	23	1.1	3.9	3.6	1.9	4.3
Beef Cattle	Liquid/Slurry	26	0	0	0	0	0
Beef Cattle	Pasture	0	0	0	0	0	0
Dairy Cattle	Anaerobic Lagoon	43	0.2	0.8	0.7	0.4	0.9
Dairy Cattle	Daily Spread	10	0	0	0	0	0
Dairy Cattle	Deep Pit	24	0	0	0	0	0
Dairy Cattle	Dry Lot	15	0.6	2	1.8	0.9	2.2
Dairy Cattle	Liquid/Slurry	26	0.2	0.8	0.7	0.4	0.9
Dairy Cattle	Pasture	0	0	0	0	0	0

Animal Type	Waste Management System	Volatilization Nitrogen Loss	Runoff/Leaching Nitrogen Loss[a]				
			Central	Pacific	Mid-Atlantic	Midwest	South
Dairy Cattle	Solid Storage	27	0.2	0	0	0	0
American Bison	Pasture	0	0	0	0	0	0
Goats	Dry Lot	23	1.1	3.9	3.6	1.9	4.3
Goats	Pasture	0	0	0	0	0	0
Horses	Dry Lot	23	0	0	0	0	0
Horses	Pasture	0	0	0	0	0	0
Mules and Asses	Dry Lot	23	0	0	0	0	0
Mules and Asses	Pasture	0	0	0	0	0	0
Poultry	Anaerobic Lagoon	54	0.2	0.8	0.7	0.4	0.9
Poultry	Liquid/Slurry	26	0.2	0.8	0.7	0.4	0.9
Poultry	Pasture	0	0	0	0	0	0
Poultry	Poultry with bedding	26	0	0	0	0	0
Poultry	Poultry without bedding	34	0	0	0	0	0
Poultry	Solid Storage	8	0	0	0	0	0
Sheep	Dry Lot	23	1.1	3.9	3.6	1.9	4.3
Sheep	Pasture	0	0	0	0	0	0
Swine	Anaerobic Lagoon	58	0.2	0.8	0.7	0.4	0.9
Swine	Deep Pit	34	0	0	0	0	0
Swine	Liquid/Slurry	26	0.2	0.8	0.7	0.4	0.9
Swine	Pasture	0	0	0	0	0	0
Swine	Solid Storage	45	0	0	0	0	0

[a] Data for nitrogen losses due to leaching were not available, so the values represent only nitrogen losses due to runoff.
Source: EPA 2002b, 2005.

Table A-213: Methane Emissions from Livestock Manure Management (kt)[a]

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Dairy Cattle	**590**	**607**	**591**	**614**	**656**	**685**	**695**	**725**	**771**	**841**	**889**	**951**	**985**	**1,036**	**988**	**1,057**	**1,091**	**1,212**	**1,230**	**1,218**	**1,217**	**1,245**	**1,306**	**1,271**	**1,289**
Dairy Cows	*581*	*598*	*583*	*606*	*647*	*676*	*687*	*716*	*763*	*832*	*880*	*942*	*977*	*1,027*	*980*	*1,049*	*1,083*	*1,202*	*1,220*	*1,208*	*1,207*	*1,236*	*1,295*	*1,261*	*1,278*
Dairy Heifer	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*6*	*7*	*7*	*7*	*7*	*7*	*6*	*7*	*7*	*8*	*8*	*8*	*8*	*8*	*9*	*8*	*8*
Dairy Calves	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
Swine	**622**	**674**	**637**	**678**	**740**	**763**	**729**	**782**	**891**	**849**	**835**	**854**	**877**	**859**	**858**	**916**	**902**	**984**	**936**	**896**	**945**	**942**	**972**	**920**	**896**
Market Swine	483	522	499	533	584	608	581	625	720	693	681	697	719	705	707	755	742	816	779	748	790	788	814	771	744
Market <50 lbs.	*102*	*110*	*103*	*108*	*119*	*121*	*116*	*125*	*140*	*133*	*131*	*134*	*137*	*135*	*135*	*142*	*141*	*155*	*109*	*103*	*110*	*109*	*113*	*105*	*104*
Market 50-119 lbs.	*101*	*110*	*104*	*110*	*119*	*123*	*117*	*127*	*144*	*138*	*136*	*138*	*144*	*140*	*141*	*150*	*148*	*163*	*174*	*167*	*176*	*0*	*0*	*0*	*0*
Market 120-179 lbs.	*136*	*147*	*139*	*150*	*164*	*170*	*163*	*175*	*201*	*193*	*189*	*192*	*199*	*196*	*196*	*210*	*206*	*228*	*228*	*218*	*232*	*230*	*238*	*228*	*221*
Market >180 lbs.	*144*	*156*	*152*	*164*	*182*	*193*	*184*	*198*	*234*	*229*	*225*	*232*	*240*	*234*	*235*	*252*	*247*	*270*	*268*	*259*	*272*	*274*	*281*	*266*	*250*
Breeding Swine	139	151	138	146	156	155	148	157	171	157	155	158	158	154	151	161	160	168	157	148	155	154	158	150	152
Beef Cattle	**126**	**126**	**129**	**130**	**135**	**139**	**136**	**134**	**137**	**137**	**131**	**134**	**131**	**131**	**129**	**133**	**137**	**134**	**130**	**130**	**132**	**131**	**128**	**121**	**120**
Feedlot Steers	*14*	*14*	*14*	*13*	*14*	*14*	*14*	*13*	*13*	*14*	*15*	*15*	*15*	*16*	*15*	*15*	*16*	*16*	*16*	*16*	*16*	*17*	*16*	*16*	*16*
Feedlot Heifers	*7*	*7*	*7*	*7*	*8*	*8*	*8*	*8*	*8*	*8*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
NOF Bulls	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*
Beef Calves	*6*	*6*	*6*	*6*	*7*	*7*	*6*	*6*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*6*	*6*
NOF Heifers	*12*	*12*	*13*	*14*	*14*	*15*	*15*	*14*	*15*	*14*	*13*	*13*	*13*	*13*	*12*	*13*	*13*	*13*	*13*	*13*	*13*	*12*	*12*	*12*	*12*
NOF Steers	*12*	*12*	*13*	*14*	*13*	*14*	*14*	*13*	*13*	*12*	*11*	*11*	*11*	*10*	*10*	*10*	*11*	*10*	*10*	*11*	*10*	*10*	*9*	*9*	*9*
NOF Cows	*69*	*69*	*70*	*71*	*74*	*76*	*75*	*74*	*76*	*76*	*71*	*73*	*71*	*71*	*71*	*73*	*75*	*73*	*70*	*70*	*71*	*71*	*69*	*64*	*63*
Sheep	**7**	**7**	**7**	**6**	**6**	**5**	**5**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Goats	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Poultry	**131**	**131**	**127**	**131**	**131**	**128**	**125**	**128**	**130**	**126**	**127**	**131**	**129**	**130**	**129**	**129**	**131**	**134**	**129**	**128**	**129**	**127**	**128**	**128**	**130**
Hens >1 yr.	*73*	*72*	*70*	*73*	*72*	*69*	*68*	*67*	*70*	*66*	*66*	*70*	*67*	*68*	*66*	*66*	*66*	*67*	*64*	*64*	*64*	*64*	*63*	*65*	*66*
Total Pullets	*25*	*26*	*23*	*23*	*23*	*22*	*21*	*23*	*23*	*21*	*22*	*22*	*22*	*22*	*23*	*22*	*23*	*25*	*23*	*23*	*24*	*23*	*23*	*24*	*24*
Chickens	*4*	*4*	*4*	*4*	*4*	*4*	*3*	*3*	*4*	*4*	*3*	*3*	*4*	*4*	*3*	*3*	*3*	*3*	*3*	*4*	*3*	*3*	*3*	*3*	*3*
Broilers	*19*	*20*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*28*	*29*	*29*	*30*	*31*	*32*	*32*	*33*	*31*	*31*	*31*	*32*	*31*	*31*
Turkeys	*10*	*10*	*10*	*10*	*9*	*9*	*9*	*9*	*8*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*6*	*6*	*6*	*6*	*6*	*6*
Horses	**9**	**9**	**9**	**9**	**10**	**11**	**11**	**12**	**13**	**13**	**13**	**13**	**13**	**13**	**12**	**12**	**12**	**11**	**10**	**10**	**10**	**10**	**10**	**9**	**9**
Mules and Asses	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**
American Bison	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**

+ Does not exceed 0.5 kt.

[a] Accounts for CH_4 reductions due to capture and destruction of CH_4 at facilities using anaerobic digesters.

Table A-214: Total (Direct and Indirect) Nitrous Oxide Emissions from Livestock Manure Management (kt)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Dairy Cattle	**17.7**	**17.6**	**17.7**	**17.9**	**18.0**	**18.2**	**18.3**	**18.4**	**18.5**	**18.1**	**18.4**	**18.7**	**18.9**	**19.1**	**18.2**	**18.7**	**19.3**	**19.3**	**19.0**	**19.2**	**19.3**	**19.5**	**19.7**	**19.6**	**19.7**
Dairy Cows	*10.6*	*10.6*	*10.5*	*10.5*	*10.6*	*10.7*	*10.8*	*10.9*	*10.9*	*10.6*	*10.8*	*10.9*	*11.0*	*11.1*	*10.6*	*10.8*	*11.1*	*11.1*	*10.9*	*11.1*	*10.9*	*11.1*	*11.3*	*11.3*	*11.4*
Dairy Heifer	*7.1*	*7.0*	*7.2*	*7.3*	*7.4*	*7.5*	*7.5*	*7.5*	*7.6*	*7.5*	*7.6*	*7.8*	*7.9*	*8.0*	*7.6*	*7.8*	*8.2*	*8.2*	*8.0*	*8.1*	*8.3*	*8.4*	*8.5*	*8.3*	*8.3*
Dairy Calves	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Swine	**4.0**	**4.2**	**4.3**	**4.4**	**4.6**	**4.5**	**4.4**	**4.7**	**5.1**	**5.0**	**5.0**	**5.1**	**5.3**	**5.4**	**5.6**	**5.7**	**5.9**	**6.3**	**6.4**	**6.3**	**6.2**	**6.3**	**6.4**	**6.3**	**6.2**
Market Swine	*3.0*	*3.1*	*3.3*	*3.3*	*3.5*	*3.5*	*3.3*	*3.6*	*4.0*	*4.1*	*4.1*	*4.2*	*4.4*	*4.5*	*4.7*	*4.9*	*5.0*	*5.5*	*5.6*	*5.5*	*5.4*	*5.5*	*5.6*	*5.5*	*5.4*
Market <50 lbs.	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*	*0.7*	*0.7*	*0.7*	*0.8*	*0.8*	*0.8*	*0.9*	*0.9*	*0.9*	*1.0*	*1.1*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Market 50-119 lbs.	*0.6*	*0.7*	*0.7*	*0.7*	*0.7*	*0.7*	*0.7*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.9*	*0.9*	*0.9*	*1.0*	*1.0*	*1.1*	*1.3*	*1.2*	*1.2*	*1.2*	*1.3*	*1.2*	*1.2*
Market 120-179 lbs.	*0.9*	*0.9*	*0.9*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.1*	*1.1*	*1.1*	*1.2*	*1.2*	*1.3*	*1.3*	*1.4*	*1.4*	*1.5*	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*	*1.6*
Market >180 lbs.	*0.9*	*1.0*	*1.0*	*1.0*	*1.1*	*1.1*	*1.1*	*1.2*	*1.3*	*1.3*	*1.3*	*1.4*	*1.5*	*1.5*	*1.6*	*1.6*	*1.6*	*1.8*	*1.9*	*1.9*	*1.8*	*1.9*	*1.9*	*1.9*	*1.8*
Breeding Swine	*1.0*	*1.1*	*1.1*	*1.1*	*1.1*	*1.1*	*1.0*	*1.1*	*1.1*	*1.0*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Beef Cattle	**19.8**	**20.3**	**20.1**	**19.1**	**20.9**	**21.8**	**21.4**	**21.5**	**21.6**	**24.0**	**25.0**	**24.1**	**24.8**	**25.0**	**23.6**	**24.0**	**25.7**	**25.6**	**25.1**	**25.1**	**25.3**	**25.9**	**25.8**	**26.0**	**26.0**
Feedlot Steers	*13.4*	*13.6*	*13.5*	*12.8*	*13.9*	*14.4*	*14.0*	*13.9*	*14.1*	*15.5*	*16.1*	*15.4*	*16.0*	*16.3*	*15.3*	*15.5*	*16.7*	*16.7*	*16.5*	*16.5*	*16.6*	*16.9*	*16.7*	*17.0*	*17.3*
Feedlot Heifers	*6.4*	*6.6*	*6.6*	*6.3*	*7.0*	*7.4*	*7.4*	*7.6*	*7.6*	*8.5*	*8.9*	*8.6*	*8.7*	*8.8*	*8.4*	*8.5*	*9.0*	*8.9*	*8.7*	*8.6*	*8.7*	*9.1*	*9.0*	*9.0*	*8.8*
Sheep	**0.4**	**0.4**	**0.4**	**0.4**	**0.6**	**0.7**	**0.8**	**0.9**	**0.9**	**1.0**	**1.1**	**1.2**	**1.2**	**1.2**	**1.1**	**1.2**	**1.2**	**1.2**	**1.2**	**1.1**	**1.1**	**1.1**	**1.1**	**1.0**	**1.0**
Goats	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Poultry	**4.7**	**4.8**	**4.9**	**5.0**	**5.1**	**5.1**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.4**	**5.3**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.2**	**5.2**	**5.2**	**5.3**	**5.2**	**5.2**
Hens >1 yr.	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.1*	*1.1*	*1.1*	*1.1*	*1.2*	*1.2*	*1.2*	*1.2*	*1.3*	*1.3*	*1.3*	*1.3*	*1.3*	*1.3*	*1.3*	*1.3*	*1.3*	*1.4*
Total Pullets	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Chickens	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Broilers	*2.2*	*2.3*	*2.4*	*2.5*	*2.6*	*2.7*	*2.8*	*2.8*	*2.9*	*2.9*	*2.9*	*2.9*	*3.0*	*2.9*	*2.9*	*3.0*	*2.9*	*2.9*	*2.9*	*2.7*	*2.8*	*2.8*	*2.9*	*2.7*	*2.7*
Turkeys	*1.2*	*1.2*	*1.2*	*1.1*	*1.1*	*1.1*	*1.1*	*1.1*	*1.0*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.7*	*0.7*	*0.7*	*0.7*	*0.7*	*0.7*
Horses	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Mules and Asses	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**
American Bison	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

+ Does not exceed 0.5 kt.
NA (Not applicable)
Note: American bison are maintained entirely on unmanaged WMS; there are no American bison N_2O emissions from managed systems.

Table A-215: Methane Emissions by State from Livestock Manure Management for 2014 (kt)[a]

State	Beef on Feedlots	Beef Not on Feed[b]	Dairy Cow	Dairy Heifer	Swine—Market	Swine—Breeding	Layer	Broiler	Turkey	Sheep	Goats	Horses	Mules and Asses	American Bison
Alabama	0.0170	2.4961	0.5233	0.0106	1.6284	0.4402	8.9934	3.8556	0.0211	0.0085	0.0156	0.1785	0.0131	0.0006
Alaska	0.0001	0.0154	0.0154	0.0002	0.0018	0.0015	0.1926	+	0.0210	0.0057	0.0002	0.0029	+	0.0038
Arizona	0.6906	1.0848	52.7906	0.1741	1.9359	0.7272	0.6745	+	0.0211	0.1057	0.0313	0.3346	0.0039	+
Arkansas	0.0296	2.1448	0.2667	0.0094	0.6193	1.9556	0.5434	3.5225	0.7503	0.0085	0.0143	0.1772	0.0094	0.0003
California	1.5156	3.8144	402.0657	1.9264	1.6039	0.1800	3.0921	0.1985	0.2751	0.4158	0.0539	0.4182	0.0073	0.0035
Colorado	1.5724	2.7254	31.0978	0.1501	4.0379	2.8453	4.0236	+	0.0210	0.1715	0.0073	0.2341	0.0047	0.0194
Connecticut	0.0003	0.0158	1.0347	0.0153	0.0049	0.0036	0.2501	+	0.0210	0.0034	0.0011	0.0433	0.0007	0.0002
Delaware	0.0003	0.0092	0.2790	0.0046	0.0269	0.0218	0.0754	0.8837	0.0210	0.0057	0.0003	0.0154	0.0001	0.0002
Florida	0.0108	3.2376	22.1675	0.1010	0.0635	0.0424	6.4911	0.2423	0.0211	0.0085	0.0187	0.3982	0.0108	0.0003
Georgia	0.0124	1.8294	7.6846	0.0667	1.9133	0.9216	15.6498	4.8098	0.0211	0.0085	0.0250	0.2205	0.0099	0.0006
Hawaii	0.0024	0.2895	0.4264	0.0029	0.0686	0.0639	0.3014	+	0.0211	0.0085	0.0054	0.0149	0.0005	0.0002
Idaho	0.3828	1.6793	125.0109	0.4087	0.1619	0.0987	0.6159	+	0.0210	0.1175	0.0046	0.1235	0.0029	0.0093
Illinois	0.4437	1.0049	8.1855	0.0725	40.2193	10.3785	0.2649	0.1978	0.0210	0.0263	0.0077	0.1227	0.0027	0.0008
Indiana	0.1800	0.5545	14.3566	0.1086	32.9344	5.5527	0.8942	0.1978	0.4736	0.0235	0.0088	0.2275	0.0040	0.0020
Iowa	2.1095	3.0403	20.9373	0.1904	293.3499	31.0226	1.9147	0.1978	0.2617	0.0728	0.0141	0.1277	0.0033	0.0026
Kansas	3.7901	4.8366	23.3681	0.1634	18.5299	3.8114	0.0440	+	0.0210	0.0352	0.0099	0.1508	0.0028	0.0097
Kentucky	0.0343	2.5216	1.4173	0.0789	4.0954	1.2243	0.6210	1.1150	0.0210	0.0230	0.0126	0.2812	0.0097	0.0025
Louisiana	0.0087	1.6486	0.5940	0.0138	0.0130	0.0093	2.3022	0.1985	0.0211	0.0085	0.0066	0.1955	0.0082	0.0001
Maine	0.0008	0.0383	1.3343	0.0280	0.0102	0.0068	0.2830	+	0.0210	0.0034	0.0017	0.0261	0.0003	0.0004
Maryland	0.0193	0.1179	2.4502	0.0436	0.1827	0.0640	0.3077	1.0419	0.0210	0.0057	0.0021	0.0610	0.0009	0.0006
Massachusetts	0.0003	0.0201	0.4851	0.0126	0.0303	0.0186	0.0127	+	0.0210	0.0034	0.0022	0.0443	0.0004	0.0002
Michigan	0.2545	0.4752	48.2147	0.2582	8.7176	1.9544	0.7766	0.1978	0.1271	0.0381	0.0067	0.1812	0.0031	0.0022
Minnesota	0.6363	1.2341	31.5912	0.4408	63.2767	10.6950	0.3802	0.1694	1.1341	0.0634	0.0081	0.1246	0.0022	0.0034
Mississippi	0.0191	1.8134	0.5460	0.0161	8.7714	1.6819	7.6425	2.6413	0.0211	0.0085	0.0083	0.1841	0.0099	+
Missouri	0.1323	4.3993	5.6464	0.0811	19.5727	7.7160	0.3223	1.0444	0.4237	0.0390	0.0266	0.2290	0.0072	0.0025
Montana	0.0841	4.4117	1.7741	0.0134	1.1634	0.3959	0.4143	+	0.0210	0.1034	0.0024	0.2081	0.0035	0.0324
Nebraska	4.1931	5.9583	7.3544	0.0320	25.7524	7.9160	0.5798	0.1978	0.0210	0.0357	0.0056	0.1398	0.0029	0.0467
Nevada	0.0065	0.6579	6.8818	0.0137	0.0126	0.0073	0.0224	+	0.0210	0.0376	0.0063	0.0528	0.0004	0.0001
New Hampshire	0.0002	0.0116	0.6205	0.0116	0.0103	0.0057	0.0693	+	0.0210	0.0034	0.0013	0.0192	0.0002	0.0006
New Jersey	0.0004	0.0204	0.2564	0.0052	0.0671	0.0150	0.0744	+	0.0210	0.0057	0.0018	0.0584	0.0007	0.0004
New Mexico	0.0173	1.2629	77.5423	0.1849	0.0002	0.0003	0.6320	+	0.0210	0.0381	0.0073	0.1086	0.0014	0.0117
New York	0.0425	0.4557	31.2877	0.5901	0.4865	0.1467	0.5324	0.1978	0.0210	0.0352	0.0088	0.2020	0.0028	0.0013
North Carolina	0.0083	0.9086	2.4938	0.0352	119.6529	30.7160	11.8916	2.8787	0.7104	0.0127	0.0134	0.1364	0.0070	0.0003
North Dakota	0.0677	2.3399	1.2266	0.0157	0.7321	0.6034	0.0416	+	0.0210	0.0310	0.0012	0.0996	0.0009	0.0130
Ohio	0.2740	0.8580	19.7712	0.2071	17.8795	3.2873	1.0144	0.2737	0.1271	0.0550	0.0111	0.2455	0.0053	0.0012
Oklahoma	0.4728	4.9499	7.8066	0.0454	25.9088	15.5288	3.5335	0.7432	0.0210	0.0277	0.0186	0.3423	0.0102	0.0182

State	Beef on Feedlots	Beef Not on Feed[b]	Dairy Cow	Dairy Heifer	Swine—Market	Swine—Breeding	Layer	Broiler	Turkey	Sheep	Goats	Horses	Mules and Asses	American Bison
Oregon	0.1394	1.5941	17.9099	0.1025	0.0301	0.0195	0.8158	0.1978	0.0210	0.0916	0.0078	0.1376	0.0025	0.0033
Pennsylvania	0.2089	0.6687	16.7144	0.5361	10.2501	1.9201	0.7949	0.6563	0.1745	0.0442	0.0116	0.2657	0.0071	0.0015
Rhode Island	0.0001	0.0044	0.0290	0.0009	0.0032	0.0032	0.0729	+	0.0210	0.0034	0.0002	0.0044	0.0001	+
South Carolina	0.0042	0.6335	1.1129	0.0158	4.7818	0.4586	4.5615	0.8445	0.0211	0.0085	0.0138	0.1841	0.0065	0.0004
South Dakota	0.6473	4.3569	12.3807	0.0790	10.1884	3.3233	0.1697	+	0.1122	0.1269	0.0047	0.1498	0.0012	0.0584
Tennessee	0.0058	2.1576	1.2620	0.0527	2.5978	0.5478	0.2375	0.6538	0.0210	0.0183	0.0190	0.1716	0.0107	0.0002
Texas	6.1094	17.0779	100.3698	0.5029	10.2790	3.1653	4.5570	2.1495	0.0211	0.5145	0.2903	1.2439	0.0711	0.0110
Utah	0.0420	1.0336	18.1451	0.0691	5.3791	1.2998	3.5876	+	0.0997	0.1316	0.0034	0.1285	0.0024	0.0023
Vermont	0.0011	0.0658	5.9194	0.0921	0.0084	0.0072	0.0121	+	0.0210	0.0034	0.0030	0.0241	0.0010	0.0002
Virginia	0.0391	1.6537	2.8422	0.0689	4.5280	0.1581	0.3495	0.9485	0.4187	0.0390	0.0115	0.1871	0.0053	0.0019
Washington	0.3929	0.8259	47.0772	0.2127	0.1092	0.0651	1.3173	0.1978	0.0210	0.0258	0.0062	0.1195	0.0027	0.0016
West Virginia	0.0089	0.4978	0.3084	0.0085	0.0154	0.0088	0.1706	0.3450	0.0773	0.0150	0.0038	0.0481	0.0022	+
Wisconsin	0.4381	1.0851	93.9587	1.0665	2.1879	0.6948	0.3439	0.1933	0.0210	0.0390	0.0158	0.2121	0.0043	0.0065
Wyoming	0.1190	2.0593	0.8553	0.0060	0.1890	0.3462	0.5771	+	0.0210	0.1668	0.0024	0.1517	0.0020	0.0184

+ Does not exceed 0.00005 kt.

[a] Accounts for CH_4 reductions due to capture and destruction of CH_4 at facilities using anaerobic digesters.

[b] Beef Not on Feed includes calves.

Table A-216: Nitrous Oxide Emissions by State from Livestock Manure Management for 2014 (kt)

	Beef Feedlot-Heifer	Beef Feedlot-Steers	Dairy Cow	Dairy Heifer	Swine-Market	Swine-Breeding	Layer	Broiler	Turkey	Sheep	Goats	Horses	Mules and Asses
Alabama	0.0039	0.0077	0.0040	0.0037	0.0085	0.0017	0.0650	0.3411	0.0024	0.0046	0.0012	0.0061	0.0005
Alaska	+	+	0.0003	0.0002	+	+	0.0033	+	0.0024	0.0015	+	0.0001	+
Arizona	0.1828	0.3594	0.2417	0.1565	0.0091	0.0026	0.0035	+	0.0024	0.0165	0.0025	0.0115	0.0001
Arkansas	0.0094	0.0184	0.0029	0.0034	0.0036	0.0084	0.0766	0.3116	0.0869	0.0040	0.0011	0.0061	0.0003
California	0.3396	0.6690	2.1973	1.5656	0.0090	0.0007	0.0651	0.0176	0.0319	0.0735	0.0043	0.0144	0.0003
Colorado	0.6505	1.2767	0.1943	0.2294	0.0429	0.0223	0.0242	+	0.0024	0.0402	0.0009	0.0121	0.0003
Connecticut	0.0001	0.0002	0.0172	0.0112	+	+	0.0109	+	0.0024	0.0028	0.0001	0.0022	+
Delaware	0.0001	0.0002	0.0042	0.0032	0.0002	0.0001	0.0031	0.0784	0.0024	0.0046	+	0.0008	+
Florida	0.0023	0.0045	0.1122	0.0512	0.0003	0.0002	0.0439	0.0214	0.0024	0.0046	0.0015	0.0137	0.0004
Georgia	0.0029	0.0057	0.0552	0.0252	0.0100	0.0036	0.1128	0.4255	0.0024	0.0046	0.0020	0.0076	0.0004
Hawaii	0.0005	0.0010	0.0022	0.0023	0.0004	0.0002	0.0033	+	0.0024	0.0015	0.0004	0.0005	+
Idaho	0.1593	0.3126	0.7753	0.6240	0.0018	0.0008	0.0035	+	0.0024	0.0276	0.0005	0.0064	0.0002
Illinois	0.1728	0.3401	0.1380	0.0920	0.3798	0.0716	0.0190	0.0176	0.0024	0.0184	0.0009	0.0063	0.0001
Indiana	0.0695	0.1377	0.2528	0.1261	0.3206	0.0396	0.1242	0.0176	0.0551	0.0164	0.0010	0.0117	0.0002
Iowa	0.8306	1.6316	0.3025	0.2352	1.7882	0.1387	0.2658	0.0176	0.0304	0.0508	0.0017	0.0066	0.0002
Kansas	1.4446	2.8361	0.1995	0.2154	0.1617	0.0246	0.0031	+	0.0024	0.0246	0.0012	0.0078	0.0001
Kentucky	0.0120	0.0236	0.0296	0.0265	0.0240	0.0053	0.0259	0.0990	0.0024	0.0187	0.0015	0.0145	0.0005
Louisiana	0.0019	0.0037	0.0057	0.0031	0.0001	+	0.0118	0.0176	0.0024	0.0040	0.0005	0.0067	0.0003
Maine	0.0003	0.0006	0.0263	0.0200	0.0001	0.0001	0.0129	+	0.0024	0.0028	0.0002	0.0013	+
Maryland	0.0068	0.0133	0.0443	0.0300	0.0016	0.0004	0.0128	0.0925	0.0024	0.0046	0.0002	0.0031	+
Massachusetts	0.0001	0.0002	0.0103	0.0087	0.0003	0.0001	0.0006	+	0.0024	0.0028	0.0003	0.0023	+
Michigan	0.1013	0.1990	0.5981	0.3485	0.0915	0.0153	0.0578	0.0176	0.0148	0.0266	0.0008	0.0093	0.0002
Minnesota	0.2529	0.4969	0.6511	0.5530	0.6434	0.0801	0.0528	0.0150	0.1319	0.0443	0.0010	0.0064	0.0001
Mississippi	0.0043	0.0085	0.0058	0.0041	0.0448	0.0062	0.0399	0.2337	0.0024	0.0046	0.0007	0.0063	0.0004
Missouri	0.0510	0.1002	0.1086	0.0910	0.1885	0.0542	0.0449	0.0927	0.0493	0.0272	0.0032	0.0118	0.0004
Montana	0.0349	0.0689	0.0191	0.0196	0.0134	0.0034	0.0025	+	0.0024	0.0243	0.0003	0.0107	0.0002
Nebraska	1.6420	3.2236	0.0792	0.0423	0.2495	0.0564	0.0417	0.0176	0.0024	0.0249	0.0007	0.0072	0.0002
Nevada	0.0027	0.0053	0.0398	0.0209	0.0001	+	0.0031	+	0.0024	0.0088	0.0007	0.0027	+
New Hampshire	0.0001	0.0001	0.0120	0.0084	0.0001	+	0.0031	+	0.0024	0.0028	0.0002	0.0010	+
New Jersey	0.0001	0.0003	0.0059	0.0035	0.0006	0.0001	0.0031	+	0.0024	0.0046	0.0002	0.0030	+
New Mexico	0.0070	0.0138	0.4120	0.2537	+	+	0.0035	+	0.0024	0.0089	0.0009	0.0056	0.0001
New York	0.0158	0.0311	0.5698	0.4185	0.0051	0.0011	0.0237	0.0176	0.0024	0.0286	0.0010	0.0104	0.0001
North Carolina	0.0029	0.0057	0.0288	0.0147	0.6303	0.1194	0.0875	0.2555	0.0826	0.0103	0.0016	0.0070	0.0004
North Dakota	0.0275	0.0535	0.0229	0.0194	0.0079	0.0048	0.0031	+	0.0024	0.0217	0.0001	0.0051	+
Ohio	0.1073	0.2109	0.3649	0.2401	0.1756	0.0237	0.1407	0.0243	0.0148	0.0443	0.0013	0.0127	0.0003

Oklahoma	0.1892	0.3689	0.0547	0.0438	0.1336	0.0584	0.0184	0.0660	0.0024	0.0193	0.0022	0.0176	0.0005
Oregon	0.0492	0.0971	0.1396	0.1126	0.0003	0.0002	0.0107	0.0176	0.0024	0.0243	0.0009	0.0071	0.0001
Pennsylvania	0.0756	0.1484	0.4531	0.3435	0.0984	0.0138	0.1105	0.0583	0.0203	0.0358	0.0014	0.0137	0.0004
Rhode Island	+	0.0001	0.0008	0.0005	+	+	0.0031	+	0.0024	0.0028	+	0.0002	+
South Carolina	0.0010	0.0019	0.0084	0.0044	0.0245	0.0017	0.0239	0.0747	0.0024	0.0046	0.0011	0.0063	0.0002
South Dakota	0.2567	0.5034	0.1393	0.1025	0.1012	0.0243	0.0124	+	0.0130	0.0886	0.0006	0.0077	0.0001
Tennessee	0.0020	0.0040	0.0208	0.0190	0.0155	0.0024	0.0100	0.0580	0.0024	0.0149	0.0023	0.0088	0.0006
Texas	1.6794	3.2913	0.5474	0.4745	0.0583	0.0132	0.0930	0.1902	0.0024	0.0805	0.0229	0.0427	0.0025
Utah	0.0174	0.0342	0.1320	0.1051	0.0546	0.0108	0.0214	+	0.0116	0.0309	0.0004	0.0066	0.0001
Vermont	0.0004	0.0008	0.1176	0.0671	0.0001	0.0001	0.0006	+	0.0024	0.0028	0.0004	0.0012	0.0001
Virginia	0.0140	0.0273	0.0462	0.0267	0.0254	0.0007	0.0149	0.0842	0.0487	0.0316	0.0014	0.0096	0.0003
Washington	0.1399	0.2730	0.3354	0.2451	0.0011	0.0005	0.0311	0.0176	0.0024	0.0068	0.0007	0.0062	0.0001
West Virginia	0.0032	0.0064	0.0070	0.0059	0.0001	0.0001	0.0075	0.0306	0.0090	0.0122	0.0005	0.0025	0.0001
Wisconsin	0.1743	0.3427	1.8468	1.3065	0.0220	0.0051	0.0256	0.0172	0.0024	0.0272	0.0019	0.0109	0.0002
Wyoming	0.0493	0.0972	0.0077	0.0076	0.0034	0.0046	0.0035	+	0.0024	0.0391	0.0003	0.0078	0.0001

+ Does not exceed 0.00005 kt.

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3.12. Methodology for Estimating N_2O Emissions, CH_4 Emissions and Soil Organic C Stock Changes from Agricultural Lands (Cropland and Grassland)

Nitrous oxide (N_2O) is produced in soils through the microbial processes of nitrification and denitrification[82] Management influences these processes by modifying the availability of mineral nitrogen (N), which is a key control on the N_2O emissions rates (Mosier et al. 1998). Emissions can occur directly in the soil where the N is made available or can be transported to another location following volatilization, leaching, or runoff, and then converted into N_2O. Management practices influence soil organic C stocks in agricultural soils by modifying the natural processes of photosynthesis (i.e., crop and forage production) and microbial decomposition. CH_4 emissions from rice cultivation occur under flooded conditions through the process of methanogenesis. This sub-annex describes the methodologies used to calculate N_2O emissions from agricultural soil management and annual carbon (C) stock changes from mineral and organic soils classified as *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*[83], and CH_4 emissions from *Rice Cultivation.* This annex provides the underlying methodologies for these three emission sources because there is considerable overlap in the methods with the majority of emissions estimated using the DAYCENT biogeochemical[84] simulation model.

A combination of Tier 1, 2 and 3 approaches are used to estimate direct and indirect N_2O emissions and C stock changes in agricultural soils.

More specifically, the methodologies used to estimate soil N_2O emissions include:

1) A Tier 3 method using the DAYCENT biogeochemical simulation model to estimate direct emissions from mineral soils that have less than 35 percent coarse fragments by volume and are used to produce alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat, as well as non-federal grasslands and land use change between grassland and cropland (with the crops listed above and less than 35 percent coarse fragments);
2) A combination of the Tier 3 and 1 methods to estimate indirect N_2O emissions associated with management of cropland and grassland simulated with DAYCENT in Item 1;
3) A Tier 1 method to estimate direct and indirect N_2O emissions from mineral soils that are not simulated with DAYCENT, including very gravelly, cobbly, or shaley soils (greater than 35 percent coarse fragments by volume); mineral soils with less than 35 percent coarse fragments that are used to produce crops that are not simulated by DAYCENT; and crops that are rotated with the crops that are not simulated with DAYCENTPasture/Range/Paddock (PRP) manure N deposited on federal grasslands; and
4) A Tier 1 method to estimate direct N_2O emissions due to partial or complete drainage of organic soils in croplands and grasslands.

The methodologies used to estimate soil CH_4 emissions from rice cultivation include:

1) A Tier 3 method using the DAYCENT biogeochemical simulation model to estimate CH_4emissions from mineral soils that have less than 35 percent coarse fragments by volume and rice grown continuously or in rotation with a crop listed in (1) for soil N_2O emissions; and
2) A Tier 1 method to estimate CH_4 emissions from all other soils used to produce rice that are not estimated with the Tier 3 method, including rice grown on organic soils (i.e., *Histosols*), mineral soils with very gravelly, cobbly, or shaley soils (greater than 35 percent coarse fragments by volume), and rice grown in rotation with crops that are not simulated by DAYCENT.

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[82] Nitrification and denitrification are driven by the activity of 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 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).

[83] Soil C stock change methods for forestland are described in the *Forestland Remaining Forestland* section.

[84] Biogeochemical cycles are the flow of chemical elements and compounds between living organisms and the physical environment.

The methodologies used to estimate soil organic C stock changes include:

1) A Tier 3 method using the DAYCENT biogeochemical simulation model to estimate soil organic C stock changes in mineral soils as described in Item 1 for N_2O emissions;
2) Tier 2 methods with country-specific stock change factors for estimating mineral soil organic C stock changes for mineral soils that are very gravelly, cobbly, or shaley (greater than 35 percent coarse fragments by volume), are used to produce crops or have land use changes to cropland and grassland (other than the conversions between cropland and grassland that are included in Item 1) that are not simulated with DAYCENT;
3) Tier 2 methods with country-specific stock change factors for estimating mineral soil organic C stock changes on federal lands;
4) Tier 2 methods with country-specific emission factors for estimating losses of C from organic soils that are partly or completely drained for agricultural production; and
5) Tier 2 methods for estimating additional changes in mineral soil C stocks due to sewage sludge additions to soils and enrollment changes in the Conservation Reserve Program (CRP) after 2010.

As described above, the Inventory uses a Tier 3 approach to estimate direct soil N_2O emissions, CH_4 emissions from rice cultivation, and C stock changes for the majority of agricultural lands. This approach has the following advantages over the IPCC Tier 1 or 2 approaches:

1) It utilizes actual weather data at sub-county scales enabling quantification of inter-annual variability in N_2O emissions and C stock changes at finer spatial scales, as opposed to a single emission factor for the entire country for soil N_2O or broad climate region classification for soil C stock changes;
2) The model uses a more detailed characterization of spatially-mapped soil properties that influence soil C and N dynamics, as opposed to the broad soil taxonomic classifications of the IPCC methodology;
3) The simulation approach provides a more detailed representation of management influences and their interactions than are represented by a discrete factor-based approach in the Tier 1 and 2 methods; and
4) Soil N_2O and CH_4 emissions, and C stock changes are estimated on a more continuous, daily basis as a function of the interaction of climate, soil, and land management, compared with the linear rate changes that are estimated with the Tier 1 and 2 methods.

The DAYCENT process-based simulation model (daily time-step version of the Century model) has been selected for the Tier 3 approach based on the following criteria:

1) The model has been developed in the U.S. and extensively tested and verified for U.S. conditions (e.g., Parton et al. 1987, 1993). In addition, the model has been widely used by researchers and agencies in many other parts of the world for simulating soil C dynamics at local, regional and national scales (e.g., Brazil, Canada, India, Jordan, Kenya, Mexico), soil N_2O emissions (e.g., Canada, China, Ireland, New Zealand) (Abdalla et al. 2010; Li et al. 2005; Smith et al. 2008; Stehfest and Muller 2004; Cheng et al. 2014), and CH_4 emissions (Cheng et al. 2013).
2) The model is capable of simulating cropland, grassland, forest, and savanna ecosystems, and land-use transitions between these different land uses. It is, thus, well suited to model land-use change effects.
3) The model is designed to simulate management practices that influence soil C dynamics, CH_4 emissions and direct N_2O emissions, with the exception of cultivated organic soils; cobbly, gravelly, or shaley soils; and crops that have not been parameterized for DAYCENT simulations (e.g., some vegetables, tobacco, perennial/horticultural crops, and crops that are rotated with these crops). For these latter cases, an IPCC Tier 2 method has been used for soil C stock changes and IPCC Tier 1 method for CH_4 and N_2O emissions. The model can also be used estimate the amount of N leaching and runoff, as well as volatilization of N, which is subject to indirect N_2O emissions.
4) Much of the data needed for the model is available from existing national databases. The exceptions are CRP enrollment after 2010, management of federal grasslands, and sewage sludge amendments to soils, which are not known at a sufficient resolution to use the Tier 3 model. Soil N_2O emissions and C stock changes associated with these practices are addressed with a Tier 1 and 2 method, respectively.

Overall, the Tier 3 approach is used to estimate approximately 89 percent of direct soil N_2O emissions 94 percent of the rice cultivation, and 88 percent of the land area associated with estimation of soil organic C stock changes under agricultural management in the United States.

Tier 3 Method Description and Model Evaluation

The DAYCENT biogeochemical model (Parton et al. 1998; Del Grosso et al. 2001, 2011) simulates biogeochemical C and N fluxes between the atmosphere, vegetation, and soil; and provides a more complete estimation of soil C stock changes and N_2O emissions than IPCC Tier 1 or 2 methods by more thoroughly accounting for the influence of environmental conditions. These conditions include soil characteristics, weather patterns, crop and forage characteristics, and management practices. The DAYCENT model utilizes the soil C modeling framework developed in the Century model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), but has been refined to simulate dynamics at a daily time-step. Carbon and N dynamics are linked in plant-soil systems through biogeochemical processes of microbial decomposition and plant production (McGill and Cole 1981). Coupling the three source categories (i.e., agricultural soil C, rice CH_4 and soil N_2O) in a single inventory analysis ensures that there is a consistent treatment of the processes and interactions between C and N cycling in soils. For example, plant growth is controlled by nutrient availability, water, and temperature stress. Plant growth, along with residue management, determines C inputs to soils, which influence C stock changes, and removal of mineral N from the soil where plant growth influences the amount of N that can be converted into N_2O. Nutrient supply is a function of external nutrient additions as well as litter and soil organic matter (SOM) decomposition rates, and increasing decomposition can lead to a reduction in soil organic C stocks due to microbial respiration, and greater N_2O emissions by enhancing mineral N availability in soils.

Key processes simulated by DAYCENT include (1) plant growth; (2) organic matter formation and decomposition; (3) soil water and temperature regimes by layer; (4) nitrification and denitrification processes; and (5) methanogenesis (Figure A-7). Each of these submodels will be described separately below.

1) The plant-growth submodel simulates C assimilation through photosynthesis; N uptake; dry matter production; partitioning of C within the crop or forage; senescence; and mortality. The primary function of the growth submodel is to estimate the amount, type, and timing of organic matter inputs to soil, and to represent the influence of the plant on soil water, temperature, and N balance. Yield and removal of harvested biomass are also simulated. Separate submodels are designed to simulate herbaceous plants (i.e., agricultural crops and grasses) and woody vegetation (i.e., trees and scrub). Maximum daily net primary production (NPP) is estimated using the NASA-CASA production algorithm (Potter et al.1993, 2007) and MODIS Enhanced Vegetation Index (EVI) products, MOD13Q1 and MYD13Q1, or an approximation of EVI data derived from the MODIS products (Gurung et al. 2009). The NASA-CASA production algorithm is only used for the following major crops: corn, soybeans, sorghum, cotton and wheat.[85] Other regions and crops are simulated with a single value for the maximum daily NPP, instead of the more dynamic NASA-CASA algorithm. The maximum daily NPP rate is modified by air temperature and available water (to capture temperature and moisture stress). If the NASA-CASA algorithm is not used in the simulation, then production is further subject to nutrient limitations (i.e., nitrogen). Model evaluation has shown that the NASA-CASA algorithm improves the precision of NPP estimates using the EVI products to inform the production model. The r^2 is 83 percent for the NASA-CASA algorithm and 64 percent for the single parameter value approach. See Figure A-8.

2) Dynamics of soil organic C and N (Figure A-7) are simulated for the surface and belowground litter pools and soil organic matter in the top 20 cm of the soil profile; mineral N dynamics are simulated through the whole soil profile. Organic C and N stocks are represented by two plant litter pools (metabolic and structural) and three soil organic matter (SOM) pools (active, slow, and passive). The metabolic litter pool represents the easily decomposable constituents of plant residues, while the structural litter pool is composed of more recalcitrant, ligno-cellulose plant materials. The three SOM pools represent a gradient in decomposability, from active SOM (representing microbial biomass and associated metabolites) having a rapid turnover (months to years), to passive SOM (representing highly processed, humified, condensed decomposition products), which is highly recalcitrant, with mean residence times on the order of several hundred years. The slow pool represents decomposition products of intermediate stability, having a mean residence time on the order of decades and is the fraction that tends to change the most in response to changes in land use and management. Soil texture influences turnover rates of the slow and passive pools. The clay and silt-sized mineral fraction of the soil provides physical protection from microbial decomposition, leading to enhanced SOM stabilization in finely textured soils. Soil temperature and moisture, tillage disturbance, aeration, and other factors influence decomposition and loss of C from the soil organic matter pools.

3) The soil-water balance submodel calculates water balance components and changes in soil water availability, which influences both plant growth and decomposition/nutrient cycling processes. The moisture content of soils are simulated

[85] It is a planned improvement to estimate NPP for additional crops and grass forage with the NASA-CASA method in the future.

through a multi-layer profile based on precipitation, snow accumulation and melting, interception, soil and canopy evaporation, transpiration, soil water movement, runoff, and drainage.

Figure A-7: DAYCENT Model Flow Diagram

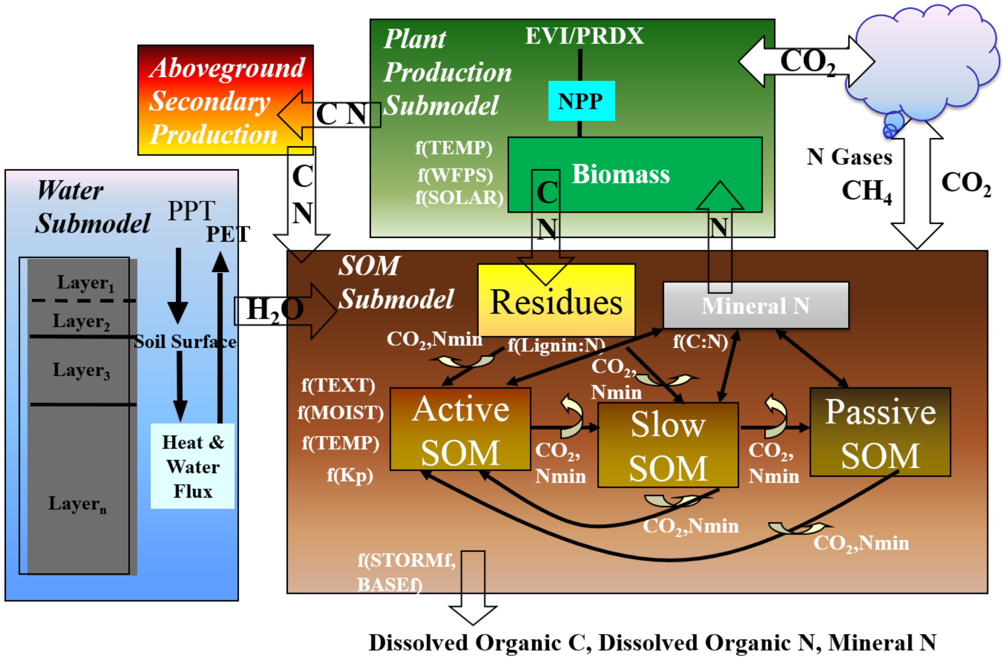
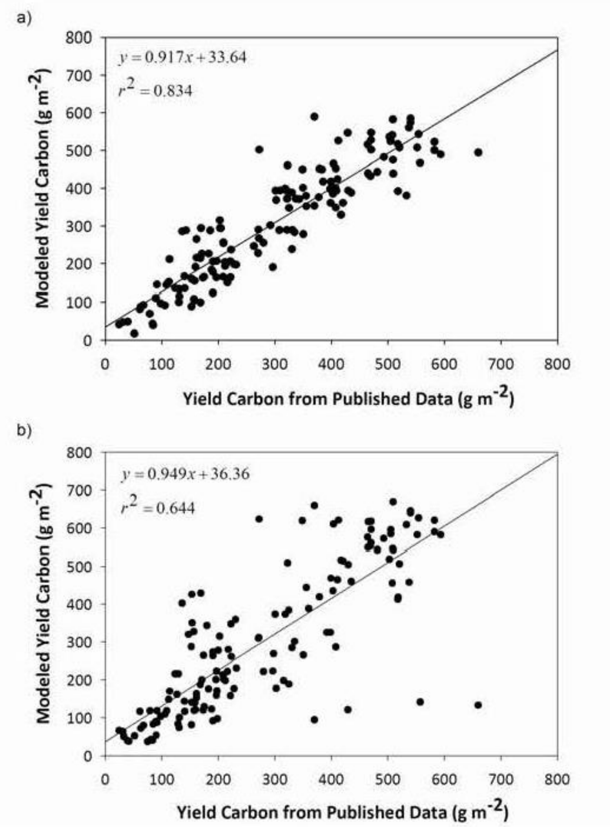


Figure A-8: Modeled versus measured net primary production (g C m^{-2})



Part a) presents results of the NASA-CASA algorithm (r^2 = 83%) and part b) presents the results of a single parameter value for maximum net primary production (r^2 = 64%).

4) Soil mineral N dynamics are modeled based on N inputs from fertilizer inputs (synthetic and organic), residue N inputs, soil organic matter mineralization in addition to symbiotic and asymbiotic N fixation. Mineral N is available for plant and microbial uptake, and is largely controlled by the specified stoichiometric limits for these organisms (i.e., C:N ratios). Mineral and organic N losses are simulated with leaching and runoff, and nitrogen can be volatilized and lost from the soil through ammonia volatilization, nitrification and denitrification. N_2O emissions occur through nitrification and denitrification. Denitrification is a function of soil NO_3^- concentration, water filled pore space (WFPS), heterotrophic (i.e., microbial) respiration, and texture. Nitrification is controlled by soil ammonium (NH_4^+) concentration, water filled pore space, temperature, and pH (See Box 2 for more information).

5) Methanogenesis is modeled under anaerobic conditions and is controlled by carbon substrate availability, temperature, and redox potential (Cheng et al. 2013). Carbon substrate supply is determined by decomposition of residues and soil organic matter, in addition to root exudation. The transport of CH_4 to the atmosphere occurs through the rice plant and via ebullition (i.e., bubbles). CH_4 can be oxidized (methanotrophy) as it moves through a flooded soil and the oxidation rates are higher as the plants mature and in soils with more clay (Sass et al. 1994).

The model allows for a variety of management options to be simulated, including specifying different crop types, crop sequences (e.g., rotation), tillage practices, fertilization, organic matter addition (e.g., manure amendments), harvest events (with variable residue removal), drainage, flooding, irrigation, burning, and grazing intensity. An input "schedule" file is used to simulate the timing of management activities and temporal trends; schedules can be organized into discrete time blocks to define a repeated sequence of events (e.g., a crop rotation or a frequency of disturbance such as a burning cycle for perennial grassland). Management options can be specified for any day of a year within a scheduling block, where management codes point to operation-specific parameter files (referred to as *.100 files), which contain the information used to simulate management effects with the model algorithms. User-specified management activities can be defined by adding to or editing the contents of the *.100 files. Additional details of the model formulation are given in Parton et al. (1987, 1988, 1994, 1998), Del Grosso et al. (2001, 2011), Cheng et al. (2013) and Metherell et al. (1993), and archived copies of the model source code are available.

[BEGIN TEXT BOX]

Box 2. DAYCENT Model Simulation of Nitrification and Denitrification

The DAYCENT model simulates the two biogeochemical processes, nitrification and denitrification, that result in N_2O emissions from soils (Del Grosso et al. 2000, Parton et al. 2001). Nitrification is calculated for the top 15 cm of soil (where nitrification mostly occurs) while denitrification is calculated for the entire soil profile (accounting for denitrification near the surface and subsurface as nitrate leaches through the profile). The equations and key parameters controlling N_2O emissions from nitrification and denitrification are described below.

Nitrification is controlled by soil ammonium (NH_4^+) concentration, temperature (t), Water Filled Pore Space (WFPS) and pH according to the following equation:

$$Nit = NH_{4+} \times K_{max} \times F(t) \times F(WFPS) \times F(pH)$$

where,

Nit	=	the soil nitrification rate (g N/m^2/day)
NH_{4+}	=	the model-derived soil ammonium concentration (g N/m^2)
K_{max}	=	the maximum fraction of NH_4^+ nitrified (K_{max} = 0.10/day)
F(t)	=	the effect of soil temperature on nitrification (Figure A-9a)
F(WFPS)	=	the effect of soil water content and soil texture on nitrification (Figure A-9b)
F(pH)	=	the effect of soil pH on nitrification (Figure A-9c)

The current parameterization used in the model assumes that 1.2 percent of nitrified N is converted to N_2O.

The model assumes that denitrification rates are controlled by the availability of soil NO_3^- (electron acceptor), labile C compounds (electron donor) and oxygen (competing electron acceptor). Heterotrophic soil respiration is used as a proxy for labile C availability, while oxygen availability is a function of soil physical properties that influence gas diffusivity, soil WFPS, and oxygen demand. The model selects the minimum of the NO_3^- and CO_2 functions to establish a maximum potential denitrification rate. These rates vary for particular levels of electron acceptor and C substrate, and account for limitations of oxygen availability to estimate daily denitrification rates according to the following equation:

$$Den = \min[F(CO_2), F(NO_3)] \times F(WFPS)$$

where,

Den	=	the soil denitrification rate (μg N/g soil/day)
$F(NO_3)$	=	a function relating N gas flux to nitrate levels (Figure A-10a)
$F(CO_2)$	=	a function relating N gas flux to soil respiration (Figure A-10b)

F(WFPS)	=	a dimensionless multiplier (Figure A-10c).

The x inflection point of F(WFPS) is a function of respiration and soil gas diffusivity at field capacity (D_{FC}):

$$x \text{ inflection} = 0.90 - M(CO_2)$$

where,

M	=	a multiplier that is a function of D_{FC}. In technical terms, the inflection point is the domain where either F(WFPS) is not differentiable or its derivative is 0. In this case, the inflection point can be interpreted as the WFPS value at which denitrification reaches half of its maximum rate.

Respiration has a much stronger effect on the water curve in clay soils with low D_{FC} than in loam or sandy soils with high D_{FC} (Figure A-9b). The model assumes that microsites in fine-textured soils can become anaerobic at relatively low water contents when oxygen demand is high. After calculating total N gas flux, the ratio of N_2/N_2O is estimated so that total N gas emissions can be partitioned between N_2O and N_2:

$$R_{N2/N2O} = F_r(NO_3/CO_2) \times F_r(WFPS).$$

where,

$R_{N2/N2O}$	=	the ratio of N_2/N_2O
$F_r(NO_3/CO_2)$	=	a function estimating the impact of the availability of electron donor relative to substrate
$F_r(WFPS)$	=	a multiplier to account for the effect of soil water on N_2:N_2O.

For $F_r(NO_3/CO_2)$, as the ratio of electron donor to substrate increases, a higher portion of N gas is assumed to be in the form of N_2O. For $F_r(WFPS)$, as WFPS increases, a higher portion of N gas is assumed to be in the form of N_2.

[End Box]

Comparison of model results and plot level data show that DAYCENT reliably simulates soil organic matter levels (Ogle et al. 2007). The model was tested and shown to capture the general trends in C storage across 908 treatment observations from over 80 experimental sites (Figure A-11). Some bias and imprecision occur in predictions of soil organic C, which is reflected in the uncertainty associated with DAYCENT model results. Regardless, the Tier 3 approach has considerably less uncertainty than Tier 1 and 2 methods (Del Grosso et al. 2010; Figure A-12).

Similarly, DAYCENT model results have been compared to trace gas N_2O fluxes for a number of native and managed systems (Del Grosso et al. 2001, 2005, 2010) (Figure A-13). In general, the model simulates accurate emissions, but some bias and imprecision does occur in predictions, which is reflected in the uncertainty associated with DAYCENT model results. Comparisons with measured data showed that DAYCENT estimated N_2O emissions more accurately and precisely than the IPCC Tier 1 methodology (IPCC 2006) (See Agricultural Soil Management, QA/QC and Verification Section). The linear regression of simulated vs. measured emissions for DAYCENT had higher r^2 values and a fitted line closer to a perfect 1:1 relationship between measured and modeled N_2O emissions compared to the IPCC Tier 1 approach (Del Grosso et al. 2005, 2008). This is not surprising, since DAYCENT includes site-specific factors (climate, soil properties, and previous management) that influence N_2O emissions. Furthermore, DAYCENT also simulated NO_3- leaching (root mean square error = 20 percent) more accurately than IPCC Tier 1 methodology (root mean square error = 69 percent) (Del Grosso et al. 2005). Volatilization of N gases that contribute to indirect soil N_2O emissions is the only component that has not been thoroughly tested, which is due to a lack of measurement data. Overall, the Tier 3 approach has reduced uncertainties in the agricultural soil C stock changes and N_2O emissions compared to using lower Tier methods.

DAYCENT predictions of soil CH_4 emissions have also been compared to experimental measurements from sites in California, Texas, Arkansas and Louisiana (Figure A-14). There are 10 experiments and 126 treatment observations. In general, the model estimates CH_4 emissions in most states with no apparent bias, but there is a lack of precision, which is addressed in the uncertainty analysis. The exception is California where the model tends to over-estimate low emission rates, and this additional uncertainty is captured in the error propagation associated with the inventory analysis for California.

Figure A-9: Effect of Soil Temperature (a) , Water-Filled Pore Space (b) , and pH (c) on Nitrification Rates

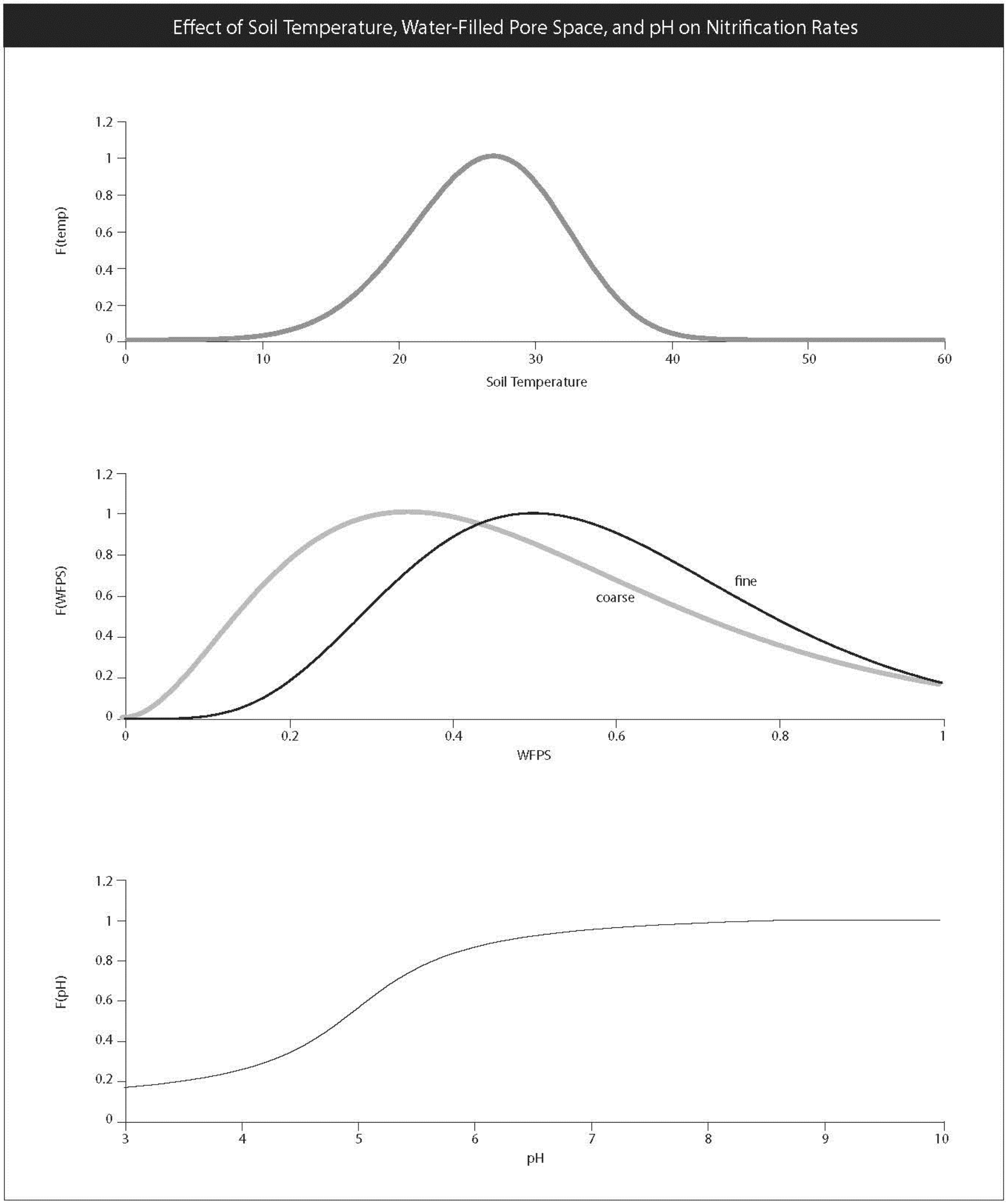


Figure A-10: Effect of Soil Nitrite Concentration (a), Heterotrophic Respiration Rates (b), and Water-Filled Pore Space (c) on Denitrification Rates

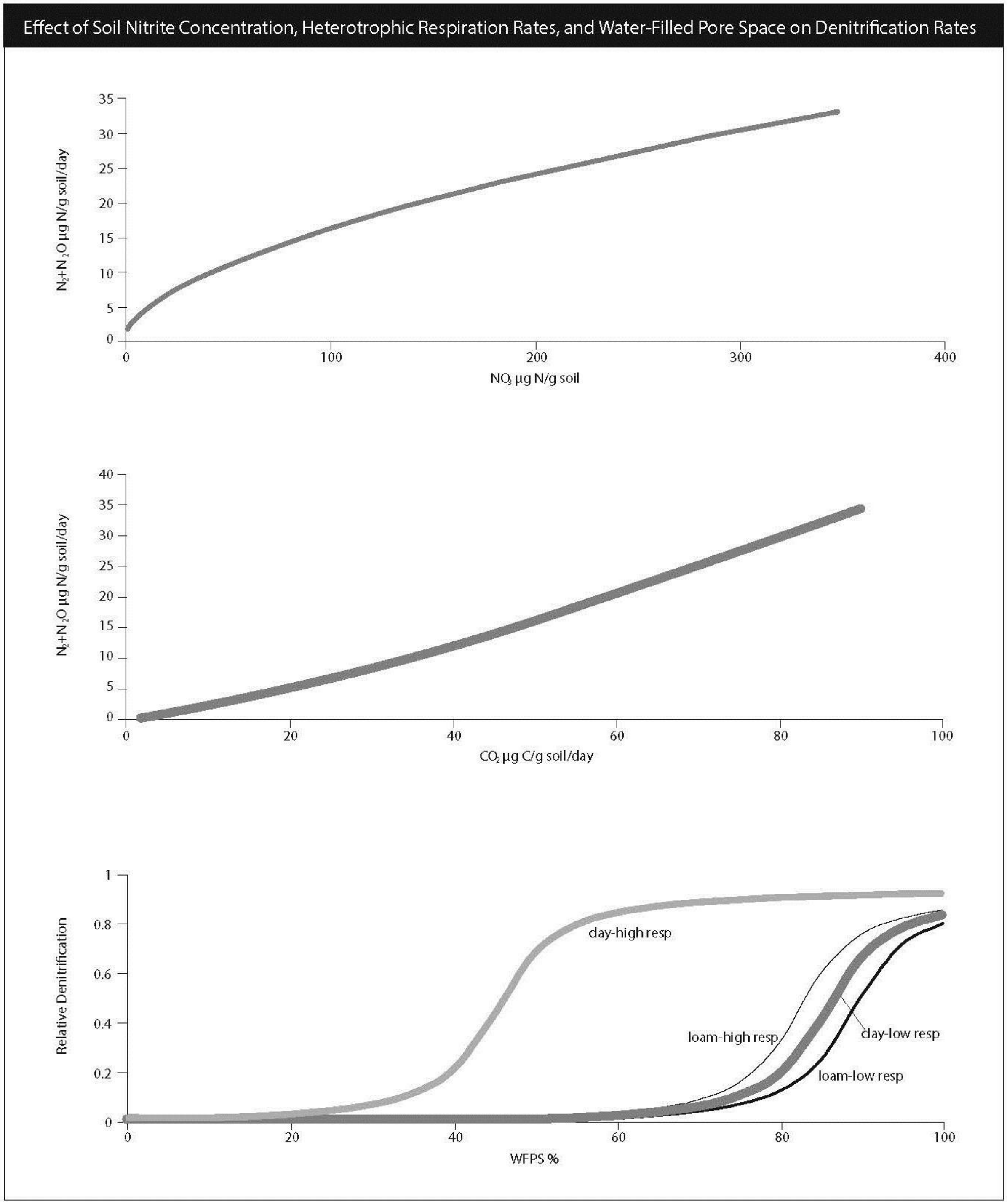


Figure A-11: Comparisons of Results from DAYCENT Model and Measurements of Soil Organic C Stocks

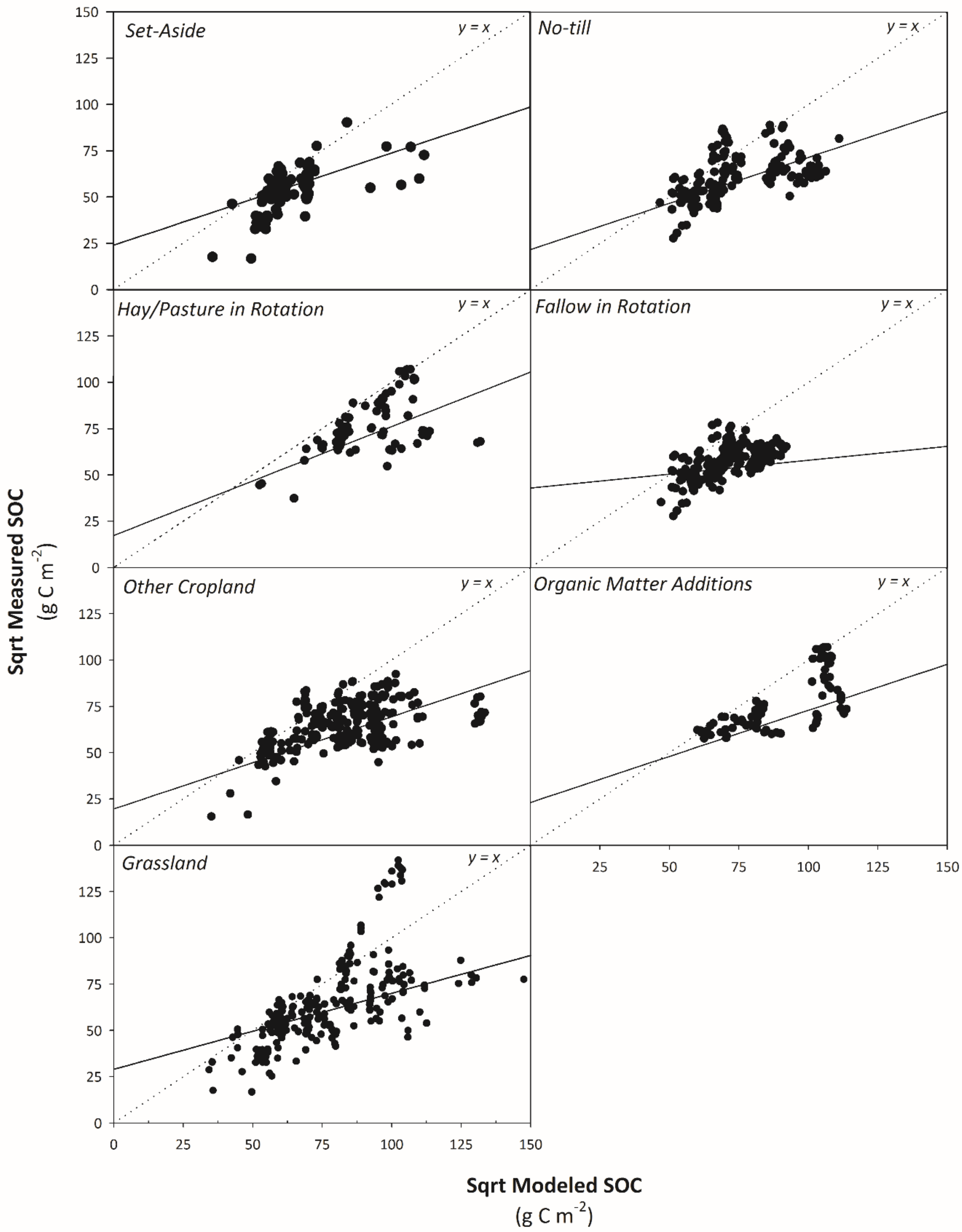
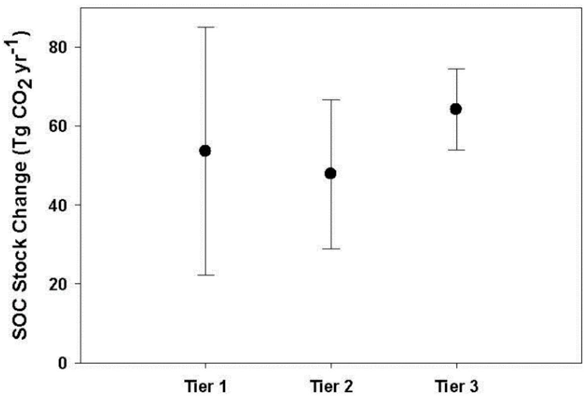


Figure A-12: Comparison of Estimated Soil Organic C Stock Changes and Uncertainties using Tier 1 (IPCC 2006), Tier 2 (Ogle et al. 2003, 2006) and Tier 3 Methods



Source: Tier 1 (IPCC 2007), Tier 2 (Ogle et al. 2003, 2006), Tier 3 (Ogle et al. 2010).

Figure A-13: Comparisons of Results from DAYCENT Model and Measurements of Soil Nitrous Oxide Emissions

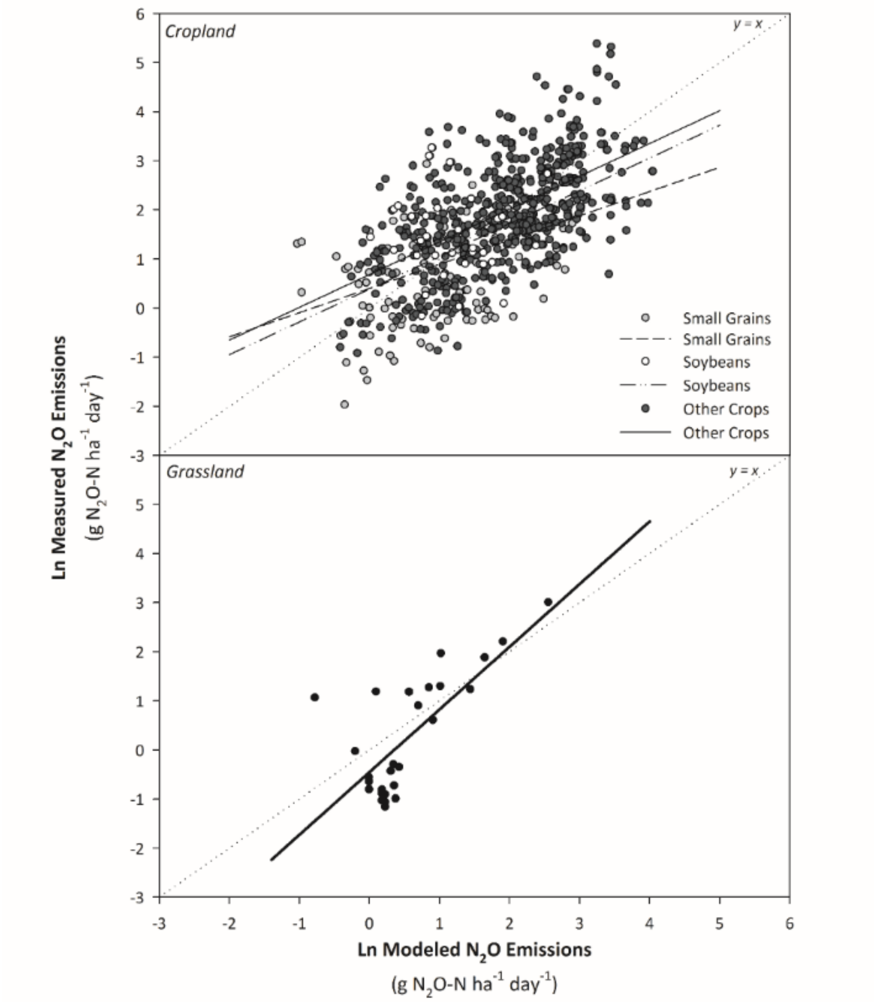
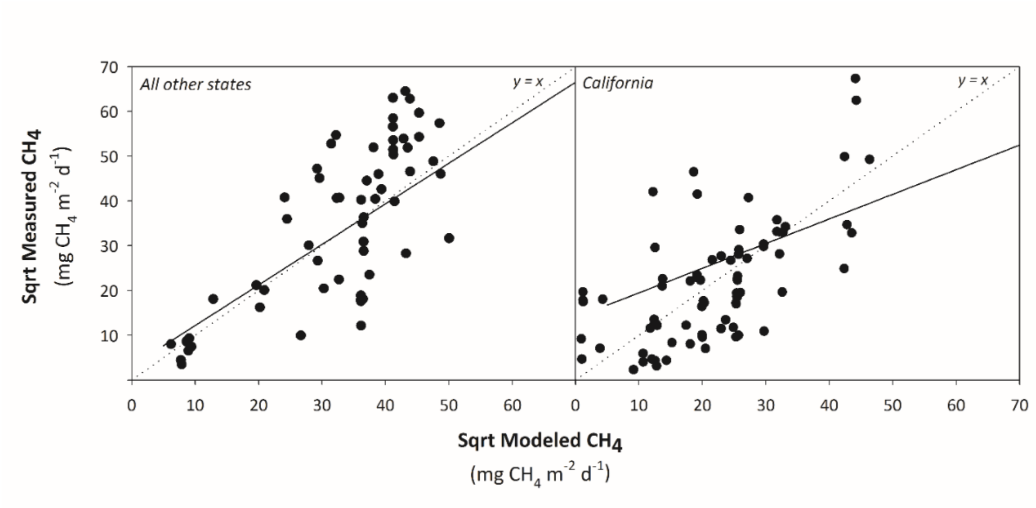


Figure A-14: Comparisons of Results from DAYCENT Model and Measurements of Soil Methane Emissions



Inventory Compilation Steps

There are five steps involved in estimating soil organic C stock changes for *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland* and *Land Converted to Grassland;* direct N_2O emissions from cropland and grassland soils; indirect N_2O emissions from volatilization, leaching, and runoff from croplands and grasslands; and CH_4 emissions from rice cultivation. First, the activity data are derived from a combination of land-use, livestock, crop, and grassland management surveys, as well as expert knowledge. In the second, third, and fourth steps, soil organic C stock changes, direct and indirect N_2O emissions are estimated using DAYCENT and/or the Tier 1 and 2 methods. In the fifth step, total emissions are computed by summing all components separately for soil organic C stock changes and N_2O emissions. The remainder of this annex describes the methods underlying each step.

Step 1: Derive Activity Data

The following describes how the activity data are derived to estimate soil organic C stock changes and direct and indirect N_2O emissions. The activity data requirements include: (1) land base and history data, (2) crop-specific mineral N fertilizer rates,[86] (3) crop-specific manure amendment N rates and timing, (4) other N inputs, (5) tillage practices, (6) irrigation data, (7) Enhanced Vegetation Index (EVI), (8) daily weather data, and (9) edaphic characteristics.[87]

Step 1a: Activity Data for the Agricultural Land Base and Histories

The U.S. Department of Agriculture's 2010 National Resources Inventory (NRI) (USDA-NRCS 2013) provides the basis for identifying the U.S. agricultural land base on non-federal lands, and classifying parcels into *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. In 1998, the NRI program began collecting annual data, and data are currently available through 2012 (USDA-NRCS, 2015) although this Inventory only uses NRI data through 2010 because newer data were not made available in time to incorporate the additional years into this Inventory. Note that the Inventory does not include estimates of N_2O emissions for federal grasslands (with the exception of soil N_2O from PRP manure N, i.e., manure deposited directly onto pasture, range or paddock by grazing livestock) and a minor amount of croplands on federal lands.

The NRI has a stratified multi-stage sampling design, where primary sample units are stratified on the basis of county and township boundaries defined by the U.S. Public Land Survey (Nusser and Goebel 1997). Within a primary sample unit, typically a 160-acre (64.75 ha) square quarter-section, three sample points are selected according to a restricted randomization procedure. Each point in the survey is assigned an area weight (expansion factor) based on other known areas and land-use information (Nusser and Goebel 1997). In principle, the expansion factors represent the amount of area with the land use and land use change history that is the same as the point location. It is important to note that the NRI uses a sampling approach, and therefore there is some uncertainty associated with scaling the point data to a region or the country using the expansion factors. In general, those uncertainties decline at larger scales, such as states compared to smaller county units, because of a larger sample size. An extensive amount of soils, land-use, and land management data have been collected through the survey (Nusser et al. 1998).[88] Primary sources for data include aerial photography and remote sensing imagery as well as field visits and county office records.

The annual NRI data product provides crop data for most years between 1979 and 2010, with the exception of 1983, 1988, and 1993. These years are gap-filled using an automated set of rules so that cropping sequences are filled with the most likely crop type given the historical cropping pattern at each NRI point location. Grassland data are reported on 5-year increments prior to 1998, but it is assumed that the land use is also grassland between the years of data collection (see Easter et al. 2008 for more information).

NRI points are included in the land base for the agricultural soil C and N_2O emissions inventories if they are identified as cropland or grassland[89] between 1990 and 2010 (Table A-217).[90] NRI does not provide land use data on federal

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[86] No data are currently available at the national scale to distinguish the type of fertilizer applied or timing of applications rates. It is a planned improvement to address variation in these practices in future inventories.

[87] Edaphic characteristics include such factors as water content, acidity, aeration, and the availability of nutrients.

[88] In the current Inventory, NRI data only provide land-use and management statistics through 2010. More recent data will be incorporated in the future to extend the time series of land use and management data.

[89] Includes only non-federal lands because federal lands are not classified into land uses as part of the NRI survey (i.e., they are only designated as federal lands).

[90] Land use for 2011 to 2014 is assumed to be the same as 2010, but will be updated with newer NRI (i.e. USDA-NRCS 2015).

lands, therefore land use on federal lands are derived from the National Land Cover Database (NLCD) (Fry et al. 2011; Homer et al. 2007; Homer et al. 2015). Federal NRI points classified as cropland or grassland according to the NLCD are included in the agricultural land base. The NRI data are reconciled with the Forest Inventory and Analysis Dataset, and in this process, the time series for *Grassland Remaining Grassland* and *Land Converted to Grassland* is modified to account for differences in forest land area between the two national surveys (See Section 6.1 for more information on the U.S. land representation). Overall, 674,613 NRI survey points are included in the inventory (USDA-NRCS 2013).

For each year, land parcels are subdivided into *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. Land parcels under cropping management in a specific year are classified as *Cropland Remaining Cropland* if the parcel has been used as cropland for at least 20 years[91]. Similarly land parcels under grassland management in a specific year of the inventory are classified as *Grassland Remaining Grassland* if they have been designated as grassland for at least 20 years. Otherwise, land parcels are classified as *Land Converted to Cropland* or *Land Converted to Grassland* based on the most recent use in the inventory time period. Lands are retained in the land-use change categories (i.e., *Land Converted to Cropland* and *Land Converted to Grassland*) for 20 years as recommended by the *2006 IPCC Guidelines*. Lands converted into Cropland and Grassland are further subdivided into the specific land use conversions (e.g., *Forest Land Converted to Cropland)*.

Table A-217: Total Land Areas for the Agricultural Soil C and N_2O Inventory, Subdivided by Land Use Categories (Million Hectares)

	Land Areas (million ha)											
Category	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Mineral Soils	**447.61**	**446.84**	**446.07**	**445.35**	**444.64**	**443.71**	**442.77**	**441.91**	**441.02**	**439.68**	**439.60**	**438.95**
Croplands	**173.95**	**173.85**	**173.64**	**173.11**	**172.79**	**172.32**	**172.05**	**171.70**	**169.18**	**168.33**	**168.39**	**168.11**
Cropland Remaining Cropland	161.24	160.80	160.28	158.53	156.83	156.20	155.60	155.03	151.39	150.27	150.76	150.86
Grassland Converted to Cropland	12.07	12.40	12.71	13.88	15.20	15.36	15.70	15.92	16.99	17.26	16.84	16.48
Forest Converted to Cropland	0.24	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.17	0.15	0.14
Other Lands Converted to Cropland	0.19	0.20	0.21	0.23	0.26	0.26	0.27	0.27	0.28	0.30	0.32	0.31
Settlements Converted to Croplands	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.12	0.13	0.13	0.13
Wetlands Converted to Croplands	0.13	0.13	0.13	0.16	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20
Grasslands	**273.65**	**272.99**	**272.43**	**272.24**	**271.86**	**271.39**	**270.71**	**270.20**	**271.84**	**271.35**	**271.21**	**270.83**
Grasslands Remaining Grasslands	263.76	262.86	262.03	260.35	258.59	257.79	256.97	256.24	253.84	252.77	252.34	251.64
Croplands Converted to Grasslands	8.76	8.87	9.06	10.42	11.67	11.94	12.08	12.26	15.07	15.60	15.89	16.16
Forest Converted to Grasslands	0.33	0.33	0.33	0.33	0.33	0.36	0.35	0.34	1.34	1.34	1.32	1.31
Other Lands Converted to Grasslands	0.43	0.45	0.50	0.59	0.70	0.74	0.74	0.78	0.93	0.95	0.99	1.05
Settlements Converted to Grasslands	0.06	0.07	0.07	0.08	0.09	0.09	0.10	0.10	0.12	0.13	0.13	0.14
Wetlands Converted to Grasslands	0.32	0.41	0.45	0.46	0.48	0.47	0.48	0.48	0.54	0.55	0.55	0.55
Organic Soils	**1.35**	**1.33**	**1.32**	**1.32**	**1.33**	**1.32**	**1.31**	**1.29**	**1.30**	**1.28**	**1.28**	**1.27**
Croplands	**0.75**	**0.75**	**0.74**	**0.73**	**0.74**	**0.74**	**0.74**	**0.73**	**0.73**	**0.74**	**0.74**	**0.75**
Cropland Remaining Cropland	0.66	0.66	0.65	0.64	0.63	0.63	0.63	0.63	0.61	0.61	0.62	0.61
Grassland Converted to Cropland	0.07	0.07	0.07	0.07	0.08	0.09	0.09	0.08	0.10	0.10	0.10	0.12
Forest Converted to Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Lands Converted to Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Settlements Converted to Croplands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wetlands Converted to Croplands	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Grasslands	**0.59**	**0.58**	**0.58**	**0.59**	**0.59**	**0.58**	**0.57**	**0.56**	**0.56**	**0.55**	**0.55**	**0.52**
Grasslands Remaining Grasslands	0.53	0.53	0.52	0.51	0.50	0.49	0.49	0.48	0.47	0.46	0.45	0.41
Croplands Converted to Grasslands	0.05	0.05	0.05	0.06	0.07	0.07	0.07	0.06	0.08	0.07	0.07	0.08
Forest Converted to Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Lands Converted to Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Settlements Converted to Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wetlands Converted to Grasslands	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	**448.95**	**448.17**	**447.39**	**446.67**	**445.97**	**445.03**	**444.08**	**443.20**	**442.31**	**440.96**	**440.89**	**440.22**

Category	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Mineral Soils	**438.34**	**437.49**	**436.72**	**435.66**	**434.83**	**434.06**	**433.27**	**432.59**	**431.88**	**431.60**	**431.31**	**431.31**	**431.31**
Croplands	**167.84**	**167.22**	**165.74**	**165.28**	**164.79**	**164.47**	**164.03**	**163.58**	**162.98**	**162.98**	**162.98**	**162.98**	**162.98**
Cropland Remaining Cropland	150.89	151.50	151.29	151.10	150.82	151.23	151.48	151.79	151.38	151.38	151.39	151.39	151.39

[91] NRI points are classified according to land-use history records starting in 1982 when the NRI survey began, and consequently the classifications are based on less than 20 years from 1990 to 1998.

Grassland Converted to Cropland	16.21	15.02	13.81	13.59	13.39	12.71	12.05	11.33	11.16	11.16	11.16	11.16	11.16
Forest Converted to Cropland	0.13	0.12	0.11	0.09	0.09	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Other Lands Converted to Cropland	0.30	0.28	0.26	0.24	0.25	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.21
Settlements Converted to Croplands	0.13	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Wetlands Converted to Croplands	0.19	0.18	0.16	0.15	0.15	0.14	0.12	0.10	0.10	0.10	0.10	0.10	0.10
Grasslands	**270.49**	**270.27**	**270.99**	**270.38**	**270.04**	**269.59**	**269.24**	**269.00**	**268.90**	**268.62**	**268.33**	**268.33**	**268.33**
Grasslands Remaining Grasslands	251.09	251.24	251.18	250.46	250.10	250.07	250.31	250.33	250.18	249.90	249.62	249.62	249.62
Croplands Converted to Grasslands	16.36	16.06	16.85	16.55	16.58	16.22	15.79	15.61	15.79	15.79	15.79	15.79	15.79
Forest Converted to Grasslands	1.30	1.25	1.25	1.82	1.82	1.77	1.75	1.75	1.73	1.73	1.73	1.73	1.73
Other Lands Converted to Grasslands	1.06	1.04	1.03	0.93	0.92	0.91	0.89	0.87	0.82	0.82	0.82	0.82	0.82
Settlements Converted to Grasslands	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12
Wetlands Converted to Grasslands	0.54	0.54	0.54	0.49	0.49	0.48	0.39	0.31	0.26	0.26	0.26	0.26	0.26
Organic Soils	**1.26**	**1.25**	**1.24**	**1.24**	**1.24**	**1.23**	**1.23**	**1.22**	**1.22**	**1.22**	**1.21**	**1.21**	**1.21**
Croplands	**0.75**	**0.74**	**0.74**	**0.74**	**0.73**	**0.73**	**0.72**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**
Cropland Remaining Cropland	0.61	0.61	0.64	0.64	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.62
Grassland Converted to Cropland	0.12	0.11	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07
Forest Converted to Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Lands Converted to Cropland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Settlements Converted to Croplands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wetlands Converted to Croplands	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Grasslands	**0.51**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.52**	**0.51**	**0.51**	**0.51**	**0.51**
Grasslands Remaining Grasslands	0.41	0.40	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.38	0.38
Croplands Converted to Grasslands	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
Forest Converted to Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Lands Converted to Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Settlements Converted to Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wetlands Converted to Grasslands	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03
Total	**439.60**	**438.73**	**437.96**	**436.90**	**436.07**	**435.29**	**434.50**	**433.81**	**433.10**	**432.81**	**432.53**	**432.53**	**432.53**

Note: The area estimates are not consistent with the land area values shown in the Representation of the U.S. Land Base chapter because the current Inventory does not estimate emissions and removals for all managed lands. Specifically, grassland and cropland in Alaska are not included in the current Inventory.

The Tier 3 method using the DAYCENT model is applied to estimate soil C stock changes and N_2O emissions for most of the NRI points that occur on mineral soils. For the Tier 3 inventory, the actual crop and grassland histories are simulated with the DAYCENT model. Parcels of land that are not simulated with DAYCENT are allocated to the Tier 2 approach for estimating soil organic C stock change, and a Tier 1 method (IPCC 2006) to estimate soil N_2O emissions (Table A-218) (Note: the Tier 1 method for soil N_2O does not require land area data with the exception of emissions from drainage and cultivation of organic soils, so in practice it is only the amount of N input to mineral soils that is addressed by the Tier 1 method and not the actual land area).

The land base for the Tier 1 and 2 methods includes (1) land parcels occurring on organic soils; (2) land parcels that include non-agricultural uses such as forest and federal lands in one or more years of the inventory; (3) land parcels on mineral soils that are very gravelly, cobbly, or shaley (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles, or shale); or (4) land parcels that are used to produce some of the vegetable crops, perennial/horticultural crops, and tobacco, which are either grown continuously or in rotation with other crops. DAYCENT has not been fully tested or developed to simulate biogeochemical processes in soils used to produce some annual (e.g., tobacco), horticultural (e.g., flowers), or perennial (e.g., vineyards, orchards) crops and agricultural use of organic soils. In addition, DAYCENT has not been adequately tested for soils with a high gravel, cobble, or shale content.

Table A-218: Total Land Area Estimated with Tier 2 and 3 Inventory Approaches (Million Hectares)

	Land Areas (million ha)				
	Mineral			Organic	
Year	Tier 1/2	Tier 3	Total	Tier 1/2	Total
1990	115.64	331.96	447.61	1.35	**448.95**
1991	114.57	332.26	446.84	1.33	**448.17**
1992	113.52	332.55	446.07	1.32	**447.39**
1993	112.33	333.01	445.35	1.32	**446.67**
1994	111.16	333.48	444.64	1.33	**445.97**
1995	109.77	333.94	443.71	1.32	**445.03**
1996	108.31	334.46	442.77	1.31	**444.08**
1997	106.92	334.98	441.91	1.29	**443.20**
1998	105.47	335.55	441.02	1.30	**442.31**
1999	103.25	336.43	439.68	1.28	**440.96**
2000	103.32	336.28	439.60	1.28	**440.89**

2001	102.46	336.48	438.95	1.27	**440.22**
2002	101.66	336.68	438.34	1.26	**439.60**
2003	100.86	336.63	437.49	1.25	**438.73**
2004	100.29	336.44	436.72	1.24	**437.96**
2005	99.44	336.22	435.66	1.24	**436.90**
2006	98.76	336.07	434.83	1.24	**436.07**
2007	98.17	335.89	434.06	1.23	**435.29**
2008	97.69	335.58	433.27	1.23	**434.50**
2009	97.20	335.39	432.59	1.22	**433.81**
2010	96.78	335.10	431.88	1.22	**433.10**
2011	96.61	334.99	431.60	1.22	**432.81**
2012	96.44	334.87	431.31	1.21	**432.53**
2013	96.44	334.87	431.31	1.21	**432.53**
2014	96.44	334.87	431.31	1.21	**432.53**

NRI points on mineral soils are classified into specific crop categories, continuous pasture/rangeland, and other non-agricultural uses for the Tier 2 inventory analysis (Table A-219). NRI points are assigned to IPCC input categories (low, medium, high, and high with organic amendments) according to the classification provided in IPCC (2006). For croplands on federal lands, information on specific cropping systems is not available, so all croplands are assumed to be medium input. In addition, NRI differentiates between improved and unimproved grassland, where improvements include irrigation and interseeding of legumes. Grasslands on federal lands (as identified with the NLCD) are classified according to rangeland condition (nominal, moderately degraded and severely degraded) in areas where information is available. For lands managed for livestock grazing by the Bureau of Land Management (BLM), IPCC rangeland condition classes are interpreted at the state-level from the Rangeland Inventory, Monitoring and Evaluation Report (BLM 2014). In order to estimate uncertainties, probability distribution functions (PDFs) for the NRI land-use data are constructed as multivariate normal based on the total area estimates for each land-use/management category and associated covariance matrix. Through this approach, dependencies in land use are taken into account resulting from the likelihood that current use is correlated with past use. These dependencies occur because as some land use/management categories increase in area, the area of other land use/management categories will decline. The covariance matrix addresses these relationships.

Table A-219: Total Land Areas by Land-Use and Management System for the Tier 2 Mineral Soil Organic C Approach (Million Hectares)

	Land Areas (million hectares)											
Land-Use/Management System	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Cropland Systems	**21.65**	**21.35**	**21.02**	**20.55**	**20.10**	**19.68**	**19.27**	**18.88**	**17.65**	**16.91**	**17.03**	**16.82**
Conservation Reserve Program	1.79	2.02	2.06	1.90	1.77	1.68	1.55	1.51	1.13	0.96	1.02	1.01
High Input Cropping Systems	2.25	2.12	1.95	1.89	1.91	1.92	1.98	1.85	1.72	1.67	1.64	1.54
Medium Input Cropping Systems	10.85	10.54	10.24	10.05	9.84	9.55	9.41	9.23	8.44	8.21	8.25	8.21
Low Input Cropping Systems	2.35	2.32	2.42	2.39	2.32	2.45	2.43	2.42	2.32	2.23	2.19	2.13
Hay with Legumes or Irrigation	1.08	1.05	1.05	1.00	1.02	0.95	0.83	0.79	0.70	0.63	0.62	0.60
Hay, Unimproved	0.80	0.80	0.80	0.80	0.71	0.64	0.60	0.63	0.69	0.54	0.54	0.51
Perennial Croplands	2.43	2.40	2.40	2.43	2.44	2.41	2.39	2.37	2.55	2.59	2.65	2.70
Rice	0.11	0.10	0.11	0.09	0.10	0.08	0.09	0.08	0.10	0.08	0.12	0.11
Grassland Systems	**94.00**	**93.22**	**92.50**	**91.79**	**91.06**	**90.09**	**89.03**	**88.04**	**87.82**	**86.34**	**86.29**	**85.65**
Pasture with Legumes or Irrigation	4.14	3.87	3.49	3.65	3.61	3.47	3.07	2.48	2.13	2.00	2.06	1.93
Rangelands and Unimproved Pasture	89.86	89.36	89.01	88.14	87.45	86.62	85.97	85.56	85.70	84.34	84.24	83.71
Total	**115.64**	**114.57**	**113.52**	**112.33**	**111.16**	**109.77**	**108.31**	**106.92**	**105.47**	**103.25**	**103.32**	**102.46**

	Land Areas (million hectares)												
Land-Use/Management System	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Cropland Systems	**16.59**	**16.36**	**15.96**	**15.74**	**15.54**	**15.38**	**15.24**	**15.08**	**14.94**	**14.94**	**14.94**	**14.94**	**14.94**
Conservation Reserve Program	0.94	0.81	0.52	0.58	0.56	0.58	0.60	0.49	0.46	0.46	0.46	0.46	0.46
High Input Cropping Systems	1.44	1.40	1.38	1.36	1.32	1.26	1.25	1.28	1.24	1.24	1.24	1.24	1.24
Medium Input Cropping Systems	8.16	8.11	8.10	8.01	7.96	7.95	7.95	7.94	7.91	7.91	7.91	7.91	7.91
Low Input Cropping Systems	2.01	2.03	1.98	1.86	1.80	1.74	1.67	1.58	1.58	1.58	1.58	1.58	1.58
Hay with Legumes or Irrigation	0.66	0.67	0.66	0.65	0.61	0.61	0.61	0.58	0.59	0.59	0.59	0.59	0.59
Hay, Unimproved	0.54	0.55	0.53	0.54	0.53	0.53	0.53	0.53	0.52	0.52	0.52	0.52	0.52
Perennial Croplands	2.70	2.68	2.68	2.65	2.66	2.62	2.54	2.57	2.54	2.54	2.54	2.54	2.54
Rice	0.12	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.10	0.10	0.10
Grassland Systems	**85.06**	**84.50**	**84.33**	**83.69**	**83.22**	**82.78**	**82.46**	**82.12**	**81.84**	**81.67**	**81.50**	**81.50**	**81.50**

Pasture with Legumes or Irrigation	1.83	1.80	1.79	1.73	1.64	1.58	1.53	1.49	1.42	1.42	1.42	1.42	1.42
Rangelands and Unimproved Pasture	83.23	82.70	82.54	81.96	81.58	81.21	80.92	80.63	80.41	80.25	80.08	80.08	80.08
Total	**101.66**	**100.86**	**100.29**	**99.44**	**98.77**	**98.17**	**97.69**	**97.20**	**96.78**	**96.61**	**96.44**	**96.44**	**96.44**

Organic soils are categorized into land-use systems based on drainage (IPCC 2006). Undrained soils are treated as having no loss of organic C or soil N_2O emissions. Drained soils are subdivided into those used for cultivated cropland, which are assumed to have high drainage and relatively large losses of C, and those used for managed pasture, which are assumed to have less drainage with smaller losses of C. N_2O emissions are assumed to be similar for both drained croplands and grasslands. Overall, the area of organic soils drained for cropland and grassland has remained relatively stable since 1990 (see Table A-220).

Table A-220: Total Land Areas for Drained Organic Soils By Land Management Category and Climate Region (Million Hectares)

IPCC Land-Use Category	Land Areas (million ha)													
for Organic Soils	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cold Temperate														
Cultivated Cropland (high drainage)	0.41	0.40	0.41	0.40	0.40	0.40	0.40	0.41	0.41	0.41	0.40	0.39	0.39	0.39
Managed Pasture (low drainage)	0.37	0.37	0.36	0.37	0.37	0.36	0.36	0.34	0.35	0.34	0.34	0.33	0.33	0.33
Undrained	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.02	0.03	0.04	0.03	0.02	0.02
Total	**0.82**	**0.82**	**0.81**	**0.81**	**0.81**	**0.80**	**0.80**	**0.78**	**0.78**	**0.77**	**0.77**	**0.75**	**0.74**	**0.73**
Warm Temperate														
Cultivated Cropland (high drainage)	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09
Managed Pasture (low drainage)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Undrained	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.18**	**0.17**	**0.16**	**0.17**	**0.17**	**0.17**	**0.17**	**0.16**	**0.16**	**0.16**	**0.17**	**0.16**	**0.17**	**0.17**
Sub-Tropical														
Cultivated Cropland (high drainage)	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.25	0.24	0.24
Managed Pasture (low drainage)	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.13	0.10	0.10	0.09
Undrained	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.01	0.00
Total	**0.34**	**0.35**	**0.34**	**0.34**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**0.34**

IPCC Land-Use Category	Land Areas (million ha)										
for Organic Soils	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cold Temperate											
Cultivated Cropland (high drainage)	0.39	0.39	0.39	0.39	0.38	0.38	0.39	0.39	0.39	0.39	0.39
Managed Pasture (low drainage)	0.32	0.32	0.32	0.32	0.33	0.33	0.32	0.32	0.32	0.32	0.32
Undrained	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Total	**0.73**	**0.73**	**0.73**	**0.73**	**0.73**	**0.73**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**
Warm Temperate											
Cultivated Cropland (high drainage)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Managed Pasture (low drainage)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Undrained	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**	**0.17**
Sub-Tropical											
Cultivated Cropland (high drainage)	0.23	0.23	0.23	0.21	0.20	0.21	0.21	0.21	0.21	0.21	0.21
Managed Pasture (low drainage)	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11

Undrained	0.00	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.34**	**0.34**	**0.33**	**0.33**	**0.33**	**0.32**	**0.32**	**0.32**	**0.32**	**0.32**	**0.32**

The harvested rice cultivation area is estimated based on the NRI points classified as flooded rice (Table A-221). Ratoon crops occurs in the Southeast with a second season of rice during the year. Ratoon cropping occurs in Louisiana (LSU 2015 for years 2000 through 2013, 2015) and Texas (TAMU 2015 for years 1993 through 2014), averaging 32 percent and 48 percent of rice acres planted, respectively. Florida also has a large fraction of area with a ratoon crop (45 percent), and ratoon cropping occurs in Arkansas on relatively small fraction of fields estimated at about 1 percent. No data are available about ratoon crops in Missouri or Mississippi, and so amount of ratooning is assumed to be similar to Arkansas. Ratoon rice crops are not grown in California.

Table A-221: Total Rice Harvested Area Estimated with Tier 1 and 3 Inventory Approaches (Million Hectares)

	Land Areas (Million Hectares)		
Year	Tier 1	Tier 3	Total
1990	0.11	1.53	1.64
1991	0.11	1.61	1.72
1992	0.11	1.66	1.78
1993	0.10	1.64	1.74
1994	0.11	1.52	1.63
1995	0.07	1.59	1.66
1996	0.10	1.55	1.65
1997	0.08	1.50	1.58
1998	0.11	1.49	1.60
1999	0.12	1.51	1.63
2000	0.16	1.55	1.71
2001	0.11	1.56	1.66
2002	0.12	1.72	1.83
2003	0.11	1.49	1.59
2004	0.12	1.52	1.64
2005	0.10	1.75	1.85
2006	0.09	1.35	1.45
2007	0.09	1.35	1.44
2008	0.10	1.30	1.40
2009	0.10	1.54	1.63
2010	0.10	1.52	1.62
2011	0.10	1.52	1.62
2012	0.10	1.52	1.62
2013	0.10	1.52	1.62
2014	0.10	1.52	1.62

Note: Land use data for 2011 through 2014 are based on the 2010 NRI data product.

Step 1b: Obtain Management Activity Data for the Tier 3 Method to estimate Soil C Stock Changes, CH_4 and N_2O Emissions from Mineral Soils

Synthetic N Fertilizer Application: Data on N fertilizer rates are based primarily on the USDA–Economic Research Service Cropping Practices Survey through 1995 (USDA-ERS 1997), which became the Agricultural Resource Management Surveys (ARMS) in 1996 (USDA-ERS 2015)[92]. In these surveys, data on inorganic N fertilization rates are collected for crops simulated by DAYCENT (barley, corn, cotton, dry beans, hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat) in the high production states and for a subset of low production states. These data are used to build a time series of fertilizer application rates for specific crops and states for the 1990 through 1999 time period and 2000 through 2014 time period. If only a single survey is available for a crop, as is the case with sorghum, the rates for the one survey are used for both time periods.

[92] Available online at <http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/arms-data.aspx>

Mean fertilizer rates and standard deviations for irrigated and rainfed crops are produced for each state. If a state is not surveyed for a particular crop or if there are not enough data to produce a state-level estimate, then data are aggregated to USDA Farm Production Regions in order to estimate a mean and standard deviation for fertilization rates (Farm Production Regions are groups of states in the United States with similar agricultural commodities). If Farm Production Region data are not available, crop data are aggregated to the entire United States (all major states surveyed) to estimate a mean and standard deviation. Standard deviations for fertilizer rates are used to construct PDFs with log-normal densities in order to address uncertainties in application rates (see Step 2a for discussion of uncertainty methods). The survey summaries also present estimates for fraction of crop acres receiving fertilizer, and these fractions are used to determine if a crop is receiving fertilizer. Alfalfa hay and grass-clover hay are assumed to not be fertilized, but grass hay is fertilized according to rates from published farm enterprise budgets (NRIAI 2003). Total fertilizer application data are found in Table A-222.

Simulations are conducted for the period prior to 1990 in order to initialize the DAYCENT model (see Step 2a), and crop-specific regional fertilizer rates prior to 1990 are based largely on extrapolation/interpolation of fertilizer rates from the years with available data. For crops in some states, little or no data are available, and, therefore, a geographic regional mean is used to simulate N fertilization rates (e.g., no data are available for the State of Alabama during the 1970s and 1980s for corn fertilization rates; therefore, mean values from the southeastern United States are used to simulate fertilization to corn fields in this state).

Managed Livestock Manure Amendments:[93] County-level manure addition estimates have been derived from manure N addition rates developed by the USDA Natural Resources Conservation Service (NRCS) (Edmonds et al. 2003). Working with the farm-level crop and animal data from the 1997 Census of Agriculture, USDA-NRCS has coupled estimates of manure N produced with estimates of manure N recoverability by animal waste management system to produce county-level rates of manure N application to cropland and pasture. Edmonds et al. (2003) defined a hierarchy that included 24 crops, permanent pasture, and cropland used as pasture. They estimated the area amended with manure and application rates in 1997 for both manure-producing farms and manure-receiving farms within a county and for two scenarios—before implementation of Comprehensive Nutrient Management Plans (baseline) and after implementation (Edmonds et al. 2003). The goal of nutrient management plans is to apply manure nutrients at a rate meeting plant demand, thus limiting leaching losses of nutrients to groundwater and waterways.

For DAYCENT simulations, the rates for manure-producing farms and manure-receiving farms have been area-weighted and combined to produce a single county-level estimate for the amount of land amended with manure and the manure N application rate for each crop in each county. The estimates were based on the assumption that Comprehensive Nutrient Management Plans have not been fully implemented. This is a conservative assumption because it allows for higher leaching rates due to some over-application of manure to soils. In order to address uncertainty in these data, uniform probability distributions are constructed based on the proportion of land receiving manure versus the amount not receiving manure for each crop type and pasture. For example, if 20 percent of land producing corn in a county is amended with manure, randomly drawing a value equal to or greater than 0 and less than 20 would lead to a simulation with a manure amendment, while drawing a value greater than or equal to 20 and less than 100 would lead to no amendment in the simulation (see Step 2a for further discussion of uncertainty methods).

Edmonds et al. (2003) only provides manure application rate data for 1997, but the amount of managed manure available for soil application changes annually, so the area amended with manure is adjusted relative to 1997 to account for all the manure available for application in other years. Specifically, the manure N available for application in other years is divided by the manure N available in 1997. If the ratio is greater than 1, there is more manure N available in that county relative to the amount in 1997, and so it is assumed a larger area is amended with manure. In contrast, ratios less than one imply less area is amended with manure because there is a lower amount available in the year compared to 1997. The amendment area in each county for 1997 is multiplied by the ratio to reflect the impact of manure N availability on the area amended. The amount of managed manure N available for application to soils is calculated by determining the populations of livestock on feedlots or otherwise housed, requiring collection and management of the manure. The methods are described in the Manure Management section (Section 5.2) and annex (Annex 3.11). The total managed manure N applied to soils is found in Table A-223.

To estimate C inputs (associated with manure N application rates derived from Edmonds et al. (2003), carbon-nitrogen (C:N) ratios for livestock-specific manure types are adapted from the Agricultural Waste Management Field

[93] For purposes of the Inventory, total livestock manure is divided into two general categories: (1) managed manure, and (2) unmanaged manure. Managed manure includes manure that is stored in manure management systems such as drylots, pits and lagoons, as well as manure applied to soils through daily spread manure operations. Unmanaged manure encompasses all manure deposited on soils by animals on PRP.

Handbook (USDA 1996), On-Farm Composting Handbook (NRAES 1992), and recoverability factors provided by Edmonds et al (2003). The C:N ratios are applied to county-level estimates of manure N excreted by animal type and management system to produce a weighted county average C:N ratio for manure amendments. The average C:N ratio is used to determine the associated C input for crop amendments derived from Edmonds et al. (2003).

To account for the common practice of reducing inorganic N fertilizer inputs when manure is added to a cropland soil, crop-specific reduction factors are derived from mineral fertilization data for land amended with manure versus land not amended with manure in the ERS 1995 Cropping Practices Survey (USDA-ERS 1997). Mineral N fertilization rates are reduced for crops receiving manure N based on a fraction of the amount of manure N applied, depending on the crop and whether it is irrigated or rainfed. The reduction factors are randomly selected from PDFs with normal densities in order to address uncertainties in the dependence between manure amendments and mineral fertilizer application.

PRP Manure N: Another key source of N for grasslands is PRP manure N deposition (i.e., manure deposited by grazing livestock). The total amount of PRP manure N is estimated using methods described in the Manure Management section (Section 5.2) and annex (Annex 3.11). Nitrogen from PRP animal waste deposited on non-federal grasslands in a county is generated by multiplying the total PRP N (based on animal type and population data in a county) by the fraction of non-federal grassland area in the county. PRP manure N input rates for the Tier 3 DAYCENT simulations are estimated by dividing the total PRP manure N amount by the land area associated with non-federal grasslands in the county from the NRI survey data. The total PRP manure N added to soils is found in Table A-223.

Residue N Inputs: Crop residue N, fixation by legumes, and N residue inputs from senesced grass litter are included as sources of N to the soil, and are estimated in the DAYCENT simulations as a function of vegetation type, weather, and soil properties. That is, while the model accounts for the contribution of N from crop residues to the soil profile and subsequent N_2O emissions, this source of mineral soil N is not "activity data" as it is not a model input. The simulated total N inputs of above- and below-ground residue N and fixed N that is not harvested and not burned (the DAYCENT simulations assumed that 3 percent of non-harvested above ground residues for crops are burned[94]) are provided in Table A-224.

Other N Inputs: Other N inputs are estimated within the DAYCENT simulation, and thus input data are not required, including mineralization from decomposition of soil organic matter and asymbiotic fixation of N from the atmosphere. Mineralization of soil organic matter will also include the effect of land use change on this process as recommended by the IPCC (2006). The influence of additional inputs of N are estimated in the simulations so that there is full accounting of all emissions from managed lands, as recommended by the IPCC (2006). The simulated N input from residues, soil organic matter mineralization and asymbiotic N fixation are provided in Table A-224.

Tillage Practices: Tillage practices are estimated for each cropping system based on data from the Conservation Technology Information Center[95] (CTIC 2004). CTIC compiles data on cropland area under five tillage classes by major crop species and year for each county. Because the surveys involve county-level aggregate area, they do not fully characterize tillage practices as they are applied within a management sequence (e.g., crop rotation). This is particularly true for area estimates of cropland under no-till, which include a relatively high proportion of "intermittent" no-till, where no-till in one year may be followed by tillage in a subsequent year. For example, a common practice in maize-soybean rotations is to use tillage in the maize crop while no-till is used for soybean, such that no-till practices are not continuous in time. Estimates of the area under continuous no-till are provided by experts at CTIC to account for intermittent tillage activity and its impact on soil C (Towery 2001).

Tillage practices are grouped into 3 categories: full, reduced, and no-tillage. Full tillage is defined as multiple tillage operations every year, including significant soil inversion (e.g., plowing, deep disking) and low surface residue coverage. This definition corresponds to the intensive tillage and "reduced" tillage systems as defined by CTIC (2004). No-till is defined as not disturbing the soil except through the use of fertilizer and seed drills and where no-till is applied to all crops in the rotation. Reduced tillage made up the remainder of the cultivated area, including mulch tillage and ridge tillage as defined by CTIC and intermittent no-till. The specific tillage implements and applications used for different crops, rotations, and regions to represent the three tillage classes are derived from the 1995 Cropping Practices Survey by the Economic Research Service (USDA-ERS 1997).

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[94] Another improvement is to reconcile the amount of crop residues burned with the *Field Burning of Agricultural Residues* source category (Section 5.5).

[95] National scale tillage data are no longer collected by CTIC, and a new data source will be needed, which is a planned improvement.

Tillage data are further processed to construct PDFs. Transitions between tillage systems are based on observed county-level changes in the frequency distribution of the area under full, reduced, and no-till from the 1980s through 2004. Generally, the fraction of full tillage decreased during this time span, with concomitant increases in reduced till and no-till management. Transitions that are modeled and applied to NRI points occurring within a county are full tillage to reduced and no-till, and reduced tillage to no-till. The remaining amount of cropland is assumed to have no change in tillage (e.g., full tillage remained in full tillage). Transition matrices are constructed from CTIC data to represent tillage changes for three time periods, 1980 through 1989, 1990 through 1999, 2000 through 2007. Areas in each of the three tillage classes—full till (FT), reduced till (RT), no-till (NT)—in 1989 (the first year the CTIC data are available) are used for the first time period, data from 1997 are used for the second time period, and data from 2004 are used for the last time period. Percentage areas of cropland in each county are calculated for each possible transition (e.g., FT→FT, FT→RT, FT→NT, RT→RT, RT→NT) to obtain a probability for each tillage transition at an NRI point. It is assumed that there are no transitions for NT→FT or NT→NT after accounting for NT systems that have intermittent tillage. Uniform probability distributions are established for each tillage scenario in the county. For example, a particular crop rotation had 80 percent chance of remaining in full tillage over the two decades, a 15 percent chance of a transition from full to reduced tillage and a 5 percent chance of a transition from full to no-till. The uniform distribution is subdivided into three segments with random draws in the Monte Carlo simulation (discussed in Step 2b) leading to full tillage over the entire time period if the value is greater than or equal to 0 and less than 80, a transition from full to reduced till if the random draw is equal to or greater than 80 and less than 95, or a transition from full to no-till if the draw is greater than or equal to 95. See step 2b for additional discussion of the uncertainty analysis.

Irrigation: NRI (USDA-NRCS 2013) differentiates between irrigated and non-irrigated land, but does not provide more detailed information on the type and intensity of irrigation. Hence, irrigation is modeled by assuming that applied water to field capacity with intervals between irrigation events where the soils drain to about 60 percent of field capacity.

Daily Weather Data: Daily maximum/minimum temperature and precipitation data are based on gridded weather data from the PRISM Climate Group (2015). It is necessary to use computer-generated weather data because weather station data do not exist near all NRI points, and moreover weather station data are for a point in space. The PRISM product uses this information with interpolation algorithms to derive weather patterns for areas between these stations (Daly et al. 1998). PRISM weather data are available for the U.S. from 1981 through 2010 at a 4 km resolution. Each NRI point is assigned the PRISM weather data for the grid cell containing the point.

Enhanced Vegetation Index: The Enhanced Vegetation Index (EVI) from the MODIS vegetation products, (MOD13Q1 and MYD13Q1) is an input to DAYCENT for estimating net primary production using the NASA-CASA production algorithm (Potter et al. 1993, 2007). MODIS imagery is collected on a nominal 8 day-time frequency when combining the two products. A best approximation of the daily time series of EVI data is derived using a smoothing process based on the Savitzky-Golay Filter (Savitzky and Golay 1964) after pre-screening for outliers and for cloud-free, high quality data as identified in the MODIS data product quality layer. The NASA-CASA production algorithm is only used for the following crops: corn, soybeans, sorghum, cotton, wheat and other close-grown crops such as barley and oats.[96]

The MODIS EVI products have a 250 m spatial resolution, and some pixels in images have mixed land uses and crop types at this resolution, which is problematic for estimating NPP associated with a specific crop at a NRI point. Therefore, a threshold of 90 percent purity in an individual pixel is the cutoff for estimating NPP using the EVI data derived from the imagery (i.e., pixels with less than 90 percent purity for a crop are assumed to generate bias in the resulting NPP estimates). The USDA-NASS Crop Data Layer (CDL) (Johnson and Mueller 2010) is used to determine the purity levels of the EVI data. CDL data have a 30 to 58 m spatial resolution, depending on the year. The level of purity for individual pixels in the MODIS EVI products is determined by aggregating the crop cover data in CDL to the 250m resolution of the EVI data. In this step, the percent cover of individual crops is determined for the 250m EVI pixels. Pixels that did not meet a 90 percent purity level for any crop are eliminated from the dataset. CDL did not provide full coverage of crop maps for the conterminous United States until 2009 so it is not possible to evaluate purity for the entire cropland area prior to 2009. The nearest pixel with at least 90 percent purity for a crop is assigned to the NRI point based on a 10 km buffer surrounding the survey location. EVI data are not assigned to a point if there are no pixels with at least 90 percent purity within the 10 km buffer. In these cases, production is simulated with a single value for the maximum daily NPP, which is reduced if there is water, temperature or nutrient stress affecting the plants growth.

Water Management for Rice Cultivation: While rice crop production in the U.S. includes a minor amount of land with mid-season drainage or alternate wet-dry periods, the majority of rice growers use continuously flooded water management systems (Hardke 2015; UCCE 2015; Hollier 1999; Way et al. 2014). Therefore, continuous flooding is applied

[96] Additional crops and grassland will be used with the NASA-CASA method in the future, as a planned improvement.

to all rice cultivation areas in the inventory. Winter flooding is another key practice associated with water management in rice fields. Winter flooding occurs on 34 percent of rice fields in California (Miller et al. 2010; Fleskes et al. 2005), and approximately 21 percent of the fields in Arkansas (Wilson and Branson 2005 and 2006; Wilson and Runsick 2007 and 2008; Wilson et al. 2009 and 2010; Hardke and Wilson 2013 and 2014; Hardke 2015). No data are available on winter flooding for Texas, Louisiana, Florida, Missouri, or Mississippi. For these states, the average amount of flooding is assumed to be similar to Arkansas. In addition, the amount of winter flooding is assumed to be relatively constant over the Inventory time period.

Organic Amendments for Rice Cultivation: Rice straw is not typically harvested from fields in the U.S. The C input from rice straw is simulated directly within the DAYCENT model for the Tier 3 method. For the Tier 1 method, residue inputs are assumed to be left on the field for more than 30 days prior to cultivation and flooding for the next crop, with the exception of ratoon crops, which are assumed to have residues on the field for less than 30 days prior to the next crop. To estimate the amount of rice straw, crop yield data (except rice in Florida) are compiled from USDA NASS QuickStats (USDA 2015). Rice yield data for Florida are estimated separately because yield data are not collected by USDA. Total rice production for Florida is determined using NRI crop areas, and total yields are based on average primary and ratoon rice yields from Deren (2002). Relative proportions of ratoon crops are derived from information in several publications (Schueneman 1997, 1999, 2000, 2001; Deren 2002; Kirstein 2003, 2004, 2006; Cantens 2004, 2005; Gonzalez 2007 through 2014). The yields are multiplied by residue:crop product ratios from Strehler and Stützle (1987), to estimate rice straw input amounts for the Tier 1 method.

Soil Properties: Soil texture and natural drainage capacity (i.e., hydric vs. non-hydric soil characterization) are the main soil variables used as input to the DAYCENT model. Texture is one of the main controls on soil C turnover and stabilization in the DAYCENT model, which uses particle size fractions of sand (50-2,000 μm), silt (2-50 μm), and clay (<2 μm) as inputs. Hydric condition are poorly-drained, and hence prone to have a high water table for part of the year in their native (pre-cultivation) condition , Non-hydric soils are moderately to well-drained .[97] Poorly drained soils can be subject to anaerobic (lack of oxygen) conditions if water inputs (precipitation and irrigation) exceed water losses from drainage and evapotranspiration. Depending on moisture conditions, hydric soils can range from being fully aerobic to completely anaerobic, varying over the year. Decomposition rates are modified according to a linear function that varies from 0.3 under completely anaerobic conditions to 1.0 under fully aerobic conditions (default parameters in DAYCENT).[98] Other soil characteristics needed in the simulation, such as field capacity and wilting-point water contents, are estimated from soil texture data using a standardized hydraulic properties calculator (Saxton et al. 1986). Soil input data are derived from Soil Survey Geographic Database (SSURGO) (Soil Survey Staff 2015). The data are based on field measurements collected as part of soil survey and mapping. Each NRI point is assigned the dominant soil component in the polygon containing the point from the SSURGO data product.

Step 1c: Obtain Additional Management Activity Data for the Tier 1 Method to estimate Soil N_2O Emissions from Mineral Soils

Synthetic N Fertilizer: A process-of-elimination approach is used to estimate synthetic N fertilizer additions to crops in the Tier 1 method. The total amount of fertilizer used on-farms has been estimated by the USGS from 1990 through 2001 on a county scale from fertilizer sales data (Ruddy et al. 2006). For 2002 through 2014, county-level fertilizer used on-farms is adjusted based on annual fluctuations in total U.S. fertilizer sales (AAPFCO 1995 through 2014). Fertilizer application data are available for crops and grasslands simulated by DAYCENT (discussed in Step 1a section for Tier 3). Thus, the amount of N applied to crops in the Tier 1 method (i.e., not simulated by DAYCENT) is assumed to be the remainder of the fertilizer used on farms after subtracting the amount applied to crops and non-federal grasslands simulated by DAYCENT. The differences are aggregated to the state level, and PDFs are derived based on uncertainties in the amount of N applied to crops and non-federal grasslands for the Tier 3 method. Total fertilizer application to crops in the Tier 1 method is found in Table A-225.

Managed Livestock Manure and Other Organic Amendments: Manure N that is not applied to crops and grassland simulated by DAYCENT is assumed to be applied to other crops that are included in the Tier 1 method. Estimates of total national annual N additions from other commercial organic fertilizers are derived from organic fertilizer statistics (TVA 1991 through 1994; AAPFCO 1995 through 2014). Commercial organic fertilizers include dried blood, tankage, compost,

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97 Artificial drainage (e.g., ditch- or tile-drainage) is simulated as a management variable.

98 Hydric soils are primarily subject to anaerobic conditions outside the plant growing season (i.e., in the absence of active plant water uptake). Soils that are water-logged during much of the year are typically classified as organic soils (e.g., peat), which are not simulated with the DAYCENT model.

and other; dried manure and sewage sludge that are used as commercial fertilizer are subtracted from totals to avoid double counting. The dried manure N is counted with the non-commercial manure applications, and sewage sludge is assumed to be applied only to grasslands. The organic fertilizer data, which are recorded in mass units of fertilizer, had to be converted to mass units of N by multiplying the consumption values by the average organic fertilizer N content of 0.5 percent (AAPFCO 2000). The fertilizer consumption data are recorded in "fertilizer year" totals, (i.e., July to June), but are converted to calendar year totals. This is done by assuming that approximately 35 percent of fertilizer usage occurred from July to December and 65 percent from January to June (TVA 1992b). Values for July to December are not available for calendar year 2013 so a "least squares line" statistical extrapolation using the previous 5 years of data is used to arrive at an approximate value. PDFs are derived for the organic fertilizer applications assuming a default ±50 percent uncertainty. Annual consumption of other organic fertilizers is presented in Table A-226. The fate of manure N is summarized in Table A-223.

PRP Manure N: Soil N_2O emissions from PRP manure N deposited on federal grasslands are estimated with a Tier 1 method. PRP manure N data are derived using methods described in the Manure Management section (Section 5.2) and Annex 3.11. PRP N deposited on federal grasslands is calculated using a process of elimination approach. The amount of PRP N generated by DAYCENT model simulations of non-federal grasslands was subtracted from total PRP N and this difference was assumed to be applied to federal grasslands. The total PRP manure N added to soils is found in Table A-223.

Sewage Sludge Amendments: Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment works and is typically used as a soil amendment, or is sent to waste disposal facilities, such as landfills. In this Inventory, all sewage sludge that is amended to agricultural soils is assumed to be applied to grasslands. Estimates of the amounts of sewage sludge N applied to agricultural lands are derived from national data on sewage sludge generation, disposition, and N content. Total sewage sludge generation data for 1990 through 2012, in dry mass units, are obtained from AAPFCO (1995 through 2014). Values for 2013 and 2014 were not available so a "least squares line" statistical extrapolation using the previous 5 years of data was used to arrive at an approximate value. The total sludge generation estimates are then converted to units of N by applying an average N content of 69 percent (AAPFCO 2000), and disaggregated into use and disposal practices using historical data in EPA (1993) and NEBRA (2007). The use and disposal practices are agricultural land application, other land application, surface disposal, incineration, landfilling, ocean dumping (ended in 1992), and other disposal methods. The resulting estimates of sewage sludge N applied to agricultural land are used to estimate N_2O emissions from agricultural soil management; the estimates of sewage sludge N applied to other land and surface-disposed are used in estimating N_2O fluxes from soils in Settlements Remaining Settlements (see section 6.9 of the Land Use, Land-Use Change, and Forestry chapter). Sewage sludge disposal data are provided in Table A-227.

Residue N Inputs: Soil N_2O emissions for residue N inputs from croplands that are not simulated by DAYCENT are estimated with a Tier 1 method. Annual crop production statistics for all major commodity and specialty crops are taken from U.S. Department of Agriculture crop production reports (USDA-NASS 2015). Total production for each crop is converted to tons of dry matter product using the residue dry matter fractions shown in Table A-228. Dry matter yield is then converted to tons of above- and below-ground biomass N. Above-ground biomass is calculated by using linear equations to estimate above-ground biomass given dry matter crop yields, and below-ground biomass is calculated by multiplying above-ground biomass by the below-to-above-ground biomass ratio. N inputs are estimated by multiplying above- and below-ground biomass by respective N concentrations and by the portion of cropland that was not simulated by DAYCENT. All ratios and equations used to calculate residue N inputs are from IPCC (2006) and Williams (2006). PDFs are derived assuming a ±50 percent uncertainty in the yield estimates (USDA-NASS does not provide uncertainty), along with uncertainties provided by the IPCC (2006) for dry matter fractions, above-ground residue, ratio of below-ground to above-ground biomass, and residue N fractions. The resulting annual residue N inputs are presented in Table A-229.

Step 1d: Obtain Additional Management Activity Data for the Tier 2 Method to estimate Soil C Stock Changes in Mineral Soils

Tillage Practices: For the Tier 2 method that is used to estimate soil organic C stock changes, PDFs are constructed for the CTIC tillage data (CTIC 2004) as bivariate normal on a log-ratio scale to reflect negative dependence among tillage classes. This structure ensured that simulated tillage percentages are non-negative and summed to 100 percent. CTIC data do not differentiate between continuous and intermittent use of no-tillage, which is important for estimating SOC storage. Thus, regionally based estimates for continuous no-tillage (defined as 5 or more years of continuous use) are modified based on consultation with CTIC experts, as discussed in Step 1a (downward adjustment of total no-tillage area based on the amount of no-tillage that is rotated with more intensive tillage practices) (Towery 2001).

Managed Livestock Manure Amendments: USDA provides information on the amount of land amended with manure for 1997 based on manure production data and field-scale surveys detailing application rates that had been collected in the *Census of Agriculture* (Edmonds et al. 2003). Similar to the DAYCENT model discussion in Step1b, the amount of land receiving manure is based on the estimates provided by Edmonds et al. (2003), as a proportion of crop and grassland amended with manure within individual climate regions. The resulting proportions are used to re-classify a portion of crop and grassland into a new management category. Specifically, a portion of medium input cropping systems is re-classified as high input, and a portion of the high input systems is re-classified as high input with amendment. In grassland systems, the estimated proportions for land amended with manure are used to re-classify a portion of nominally-managed grassland as improved, and a portion of improved grassland as improved with high input. These classification approaches are consistent with the IPCC inventory methodology (IPCC 2006). Uncertainties in the amount of land amended with manure are based on the sample variance at the climate region scale, assuming normal density PDFs (i.e., variance of the climate region estimates, which are derived from county-scale proportions).

Sewage Sludge Amendments: Sewage sludge is generated from the treatment of raw sewage in public or private wastewater treatment facilities and is typically used as a soil amendment or is sent for waste disposal to landfills. In this Inventory, all sewage sludge that is amended to agricultural soils is assumed to be applied to grasslands. See section on sewage sludge in Step 1c for more information about the methods used to derive sewage sludge N estimates. The total amount of sewage sludge N is given in Table A-227. Sewage sludge N is assumed to be applied at the assimilative capacity provided in Kellogg et al. (2000), which is the amount of nutrients taken up by a crop and removed at harvest, representing the recommended application rate for manure amendments. This capacity varies from year to year, because it is based on specific crop yields during the respective year (Kellogg et al. 2000). Total sewage sludge N available for application is divided by the assimilative capacity to estimate the total land area over which sewage sludge had been applied. The resulting estimates are used for the estimation of soil C stock change.

CRP Enrollment after 2010: The change in enrollment for the Conservation Reserve Program after 2010 is based on the amount of land under active contracts from 2011 through 2014 relative to 2010 (USDA-FSA 2014).

Wetland Reserve: Wetlands enrolled in the Conservation Reserve Program have been restored in the Northern Prairie Pothole Region through the Partners for Wildlife Program funded by the U.S. Fish and Wildlife Service (USFWS 2010). The area of restored wetlands is estimated from contract agreements (Euliss and Gleason 2002). While the contracts provide reasonable estimates of the amount of land restored in the region, they do not provide the information necessary to estimate uncertainty. Consequently, a ±50 percent range is used to construct the PDFs for the uncertainty analysis.

Table A-222: Synthetic Fertilizer N Added to Tier 3 Crops (kt N)

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fertilizer N	9,809	9,529	10,063	9,877	9,996	9,918	10,113	10,168	9,863	10,613	10,085	10,117	9,598	9,598	9,599	9,599	9,599

Table A-223: Fate of Livestock Manure Nitrogen (kt N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Managed Manure N Applied to Tier 3 Cropland and Non-federal Grasslands[a,b]	957	887	1,123	1,083	1,089	1,071	1,070	1,075	1,055	1,152	1,108	1,187	1,211	1,211	1,211	1,211	1,211
Managed Manure N Applied to Tier 1 Cropland[c]	1,453	1,645	1,487	1,521	1,553	1,585	1,511	1,545	1,647	1,576	1,599	1,499	1,469	1,498	1,526	1,519	1,519
Managed Manure N Applied to Grasslands	53	55	72	72	71	72	68	68	68	67	68	71	72	72	72	72	72
Pasture, Range, & Paddock Manure N	4,266	4,533	4,149	4,143	4,146	4,155	4,106	4,133	4,174	4,061	4,009	3,978	3,931	3,843	3,743	3,672	3,672
Total	**6,729**	**7,121**	**6,831**	**6,818**	**6,860**	**6,883**	**6,755**	**6,822**	**6,944**	**6,856**	**6,782**	**6,735**	**6,683**	**6,625**	**6,552**	**6,475**	**6,475**

[a] Accounts for N volatilized and leached/runoff during treatment, storage and transport before soil application.
[b] Includes managed manure and daily spread manure amendments
[c] Totals may not sum exactly due to rounding.

Table A-224: Crop Residue N and Other N Inputs to Tier 3 Crops as Simulated by DAYCENT (kt N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Residue N[a]	4,345	4,785	4,728	4,624	4,693	4,834	4,286	4,648	4,446	4,565	4,455	4,487	4,875	4,875	4,875	4,875	4,875
Mineralization & Asymbiotic Fixation	13,323	13,089	12,766	13,177	12,887	13,319	14,414	13,236	12,957	13,508	13,362	14,016	15,254	15,254	15,255	15,255	15,255

[a] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Table A-225: Synthetic Fertilizer N Added to Tier 1 Crops (kt N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fertilizer N	1,263	1,389	1,309	1,213	1,344	1,569	1,541	1,438	1,579	1,573	1,424	1,289	1,574	2,003	2,153	1,710	1,663

Table A-226: Other Organic Commercial Fertilizer Consumption on Agricultural Lands (kt N)

Activity	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other Commercial Organic Fertilizer N[a]	4	10	9	7	8	8	9	10	12	15	12	10	10	11	11	10	10

[a] Includes dried blood, tankage, compost, other. Excludes dried manure and sewage sludge used as commercial fertilizer to avoid double counting.

Table A-227: Sewage Sludge Nitrogen by Disposal Practice (kt N)

Disposal Practice	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Applied to Agricultural Soils	52	68	84	86	89	91	94	98	101	104	107	110	113	116	119	122	122
Other Land Application	25	28	30	30	30	30	30	31	31	32	32	32	32	33	33	33	33
Surface Disposal	20	16	10	9	8	6	5	5	4	4	3	3	3	2	2	2	2
Total	**97**	**111**	**124**	**125**	**127**	**128**	**130**	**134**	**137**	**140**	**142**	**145**	**148**	**151**	**153**	**156**	**156**

Note: Totals may not sum due to independent rounding.

Table A-228: Key Assumptions for Crop Production in the Tier 1 Method

Crop	Dry Matter Fraction of Harvested Product	Above-ground Residue		Ratio of Below-ground Residue to Above-ground Biomass	Residue N Fraction	
		Slope	Intercept		Above-ground	Below-ground
Alfalfa	0.9	0.29	0	0.4	0.027	0.019
Artichokes	0.16	0.3	0	0.2	0.006	0.009
Asparagus	0.07	0.5	0	0.2	0.006	0.009
Barley	0.89	0.98	0.59	0.22	0.007	0.014
Beans	0.91	1.13	0.85	0.19	0.008	0.008
Beets	0.22	0.1	1.06	0.2	0.019	0.014
Broccoli	0.09	0.1	0	0.11	0.006	0.009
Brussels sprouts	0.14	0.1	0	0.11	0.0093	0.0093
Cabbage	0.08	0.1	0	0.11	0.006	0.009
Cantaloup	0.06	1.77	0	0.04	0.006	0.009
Carrots	0.13	0.46	0.02	0.15	0.019	0.014
Cauliflower	0.08	0.1	0	0.11	0.006	0.009
Celery	0.05	0.23	0	0.11	0.006	0.009
Collard greens	0.08	0.1	0	0.11	0.006	0.009
Corn	0.87	1.03	0.61	0.22	0.006	0.007
Corn silage	0.3	0.3	0	0.22	0.006	0.007
Cotton	0.93	1.49	4.41	0.13	0.012	0.007
Cucumbers	0.04	1.77	0	0.03	0.006	0.009
Dry beans	0.9	0.36	0.68	0.19	0.01	0.01
Eggplant	0.08	1.77	0	0.04	0.006	0.009
Escarole	0.94	1.07	1.54	0.2	0.016	0.014
Flaxseed	0.88	1.09	0.88	0.22	0.006	0.009
Garlic	0.11	0.23	0	0.15	0.019	0.014
Hay	0.9	0.2075	0	0.505	0.018	0.01375
Honeydew	0.06	1.77	0	0.04	0.006	0.009
Kale greens	0.08	0.1	0	0.11	0.006	0.009
Lentils	0.91	1.13	0.85	0.2	0.019	0.014
Lettuce	0.04	0.1	0	0.11	0.006	0.009
Millet	0.88	1.09	0.88	0.22	0.006	0.009
Mustard greens	0.08	0.1	0	0.11	0.006	0.009
Oats	0.89	0.91	0.89	0.25	0.007	0.008
Okra	0.1	1.4	0	0.14	0.006	0.009
Onions	0.12	0.23	0	0.14	0.019	0.014
Peanuts	0.94	1.07	1.54	0.2	0.016	0.014
Peas	0.91	1.13	0.85	0.05	0.011	0.008

Peppermint Oil	0.09	1	0	1.48	0.008	0.008
Peppers	0.08	1.4	0	0.14	0.006	0.009
Potatoes	0.22	0.1	1.06	0.2	0.019	0.014
Pumpkins	0.1	1.77	0	0.04	0.006	0.009
Radishes	0.05	1.21	0.46	0.15	0.019	0.014
Rapeseed	0.88	1.09	0.88	0.22	0.006	0.009
Rice	0.89	0.95	2.46	0.16	0.007	0.009
Rye	0.88	1.09	0.88	0.22	0.006	0.009
Safflower	0.88	1.09	0.88	0.22	0.006	0.009
Sorghum	0.89	0.88	1.33	0.22	0.007	0.006
Sorghum silage	0.3	0.3	0	0.22	0.007	0.006
Soybeans	0.91	0.93	1.35	0.19	0.008	0.008
Spearmint Oil	0.09	1	0	1.48	0.008	0.008
Spinach	0.08	0.9	0	0.11	0.006	0.009
Squash	0.05	1.57	0	0.04	0.006	0.009
Sugarcane	0.25	0.41	0	0.16	0.007	0.005
Sunflower	0.88	1.09	0.88	0.22	0.006	0.009
Sweet potatoes	0.35	0.27	1.74	0.15	0.019	0.014
Tobacco	0.87	0.3	0	0.4	0.008	0.018
Tomatoes	0.05	0.59	0.57	0.19	0.006	0.009
Turnip greens	0.08	0.1	0	0.11	0.006	0.009
Watermelon	0.085	1.77	0	0.04	0.006	0.009
Wheat	0.89	1.51	0.52	0.24	0.006	0.009

Table A-229: Nitrogen in Crop Residues Retained on Soils Producing Crops not Simulated by DAYCENT (kt N)

Crop Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007
Alfalfa	68,294	61,587	41,929	34,943	34,573	34,231	35,115	34,279	30,769	30,213
Artichokes	4	4	4	4	4	4	3	2	3	3
Asparagus	5	5	5	5	4	4	5	2	2	2
Barley	5,900	4,574	3,165	2,228	2,487	2,517	1,454	1,969	1,405	1,822
Beans	1,888	1,881	1,836	1,697	1,706	1,623	1,832	1,020	1,233	1,170
Beets	1,795	2,282	1,548	1,192	746	1,033	999	893	1,928	505
Broccoli	18	18	18	17	16	17	18	10	12	12
Brussels sprouts	1	1	1	1	0	0	0	0	0	0
Cabbage	22	22	21	21	19	17	20	11	13	13
Cantaloup	103	102	91	95	89	90	92	50	57	58
Carrots	403	401	345	345	298	324	335	195	208	200
Cauliflower	6	6	6	5	5	5	5	3	4	4
Celery	16	16	14	15	14	15	16	9	10	10
Collard greens	0	0	1	1	0	0	0	0	0	0
Corn	157,096	111,997	109,000	99,081	96,451	101,376	120,332	107,939	106,560	118,834
Corn silage	9,419	8,109	6,779	6,513	4,855	6,431	6,867	5,223	5,754	5,751
Cotton	40,634	52,686	52,456	57,126	51,494	50,597	48,554	55,583	52,681	38,979
Cucumbers	72	72	63	61	60	59	62	32	36	38
Dry beans	2,264	2,099	1,576	1,205	1,671	1,300	1,155	913	1,019	1,006
Eggplant	5	5	9	10	0	0	0	0	0	0
Escarole	91	90	128	129	0	0	0	0	0	0
Flaxseed	1,234	732	2,064	2,055	1,925	1,079	694	819	846	481
Garlic	29	29	25	27	25	28	25	13	14	13
Hay	124,991	115,116	88,222	85,416	76,725	80,977	81,141	76,822	68,257	70,885
Honeydew	24	24	21	20	20	21	21	10	12	12
Kale greens	0	0	1	1	0	0	0	0	0	0
Lentils	267	563	661	634	566	585	985	720	617	564
Lettuce	40	40	39	39	38	41	44	23	29	26
Millet	3,898	3,992	1,278	2,609	597	1,040	829	463	596	978
Mustard greens	0	0	1	1	0	0	0	0	0	0
Oats	3,848	2,151	1,287	847	1,203	1,579	1,528	1,487	1,745	1,303
Okra	0	0	1	1	0	0	0	0	0	0
Onions	378	376	354	344	323	349	423	210	247	261

Peanuts	13,885	11,663	9,748	10,315	8,565	11,914	14,400	13,586	13,023	13,702
Peas	308	526	348	387	484	554	1,163	854	1,003	1,087
Peppermint Oil	1	2	1	1	1	1	1	1	1	1
Peppers	113	113	112	109	99	110	122	68	78	74
Potatoes	4,344	3,843	2,931	2,577	2,886	3,216	4,156	3,555	3,945	5,490
Pumpkins	71	70	64	59	56	55	73	44	51	54
Radishes	0	0	17	19	0	0	0	0	0	0
Rapeseed	79	15	17	12	10	2	12	2	1	2
Rice	6,719	4,601	9,910	7,407	8,515	7,120	8,577	7,541	7,033	6,454
Rye	2,541	2,603	1,390	1,060	878	735	477	274	422	427
Safflower	984	892	695	623	674	736	713	788	794	694
Sorghum	7,944	5,731	4,118	4,517	3,458	4,036	3,253	1,867	1,505	2,000
Sorghum silage	873	504	387	185	162	117	104	217	14	38
Soybeans	72,959	54,617	51,834	55,888	52,456	48,123	59,561	60,651	57,665	53,229
Spearmint Oil	1	0	0	0	0	0	0	0	0	0
Spinach	21	21	24	21	22	25	30	19	18	17
Squash	29	29	27	24	26	22	23	14	17	13
Sugarcane	19,061	12,147	15,376	15,019	15,472	15,441	17,283	16,033	18,923	16,296
Sunflower	415	504	251	431	433	379	247	152	247	209
Sweet potatoes	437	424	409	424	352	431	462	254	305	328
Tobacco	12,508	11,597	8,865	8,073	7,305	5,978	5,911	3,458	5,808	5,644
Tomatoes	587	584	575	517	584	518	654	324	392	429
Turnip greens	0	0	1	1	0	0	0	0	0	0
Watermelon	251	250	221	242	222	221	226	129	164	149
Wheat	40,306	30,994	26,666	22,252	21,399	26,664	22,829	23,199	17,851	21,863
Total	**607,182**	**510,710**	**446,941**	**426,852**	**399,973**	**411,740**	**442,832**	**421,735**	**403,316**	**401,341**

Crop Type	2008	2009	2010	2011	2012	2013	2014
Alfalfa	30,605	29,463	29,711	29,711	26,300	28,309	29,095
Artichokes	3	4	3	4	3	3	3
Asparagus	2	2	1	2	2	2	1
Barley	1,781	2,443	2,622	2,495	2,426	2,565	2,610
Beans	1,239	1,440	1,257	1,419	1,289	1,256	1,166
Beets	1,238	1,030	1,339	1,198	1,397	1,364	1,328
Broccoli	13	15	13	16	15	17	16
Brussels sprouts	0	0	0	0	0	0	0
Cabbage	14	15	14	16	13	16	15
Cantaloup	57	68	59	77	58	67	52
Carrots	214	232	208	264	232	258	244
Cauliflower	4	5	4	5	4	5	5
Celery	11	13	12	15	13	12	12
Collard greens	0	0	0	0	0	0	0
Corn	111,272	117,718	104,642	101,834	86,596	108,517	116,268
Corn silage	5,893	5,795	5,790	5,520	4,710	5,640	6,030
Cotton	38,123	29,267	39,439	39,193	40,317	39,522	39,712
Cucumbers	39	47	40	45	40	41	37
Dry beans	1,047	1,261	1,409	1,152	1,485	1,234	1,406
Eggplant	0	0	0	0	0	0	0
Escarole	0	0	0	0	0	0	0
Flaxseed	475	545	577	278	533	214	434
Garlic	14	15	13	19	16	16	15
Hay	70,656	69,663	66,882	64,680	58,899	64,128	67,431
Honeydew	11	13	12	15	11	13	13
Kale greens	0	0	0	0	0	0	0
Lentils	437	1,087	1,458	1,099	1,024	972	631
Lettuce	25	29	28	36	31	30	28

Millet	875	517	574	672	270	913	716
Mustard greens	0	0	0	0	0	0	0
Oats	1,234	1,338	1,553	1,426	1,493	1,544	1,610
Okra	0	0	0	0	0	0	0
Onions	259	314	272	356	288	302	295
Peanuts	13,798	15,525	11,364	11,550	13,620	13,092	12,895
Peas	949	1,444	1,081	596	941	1,393	1,439
Peppermint Oil	1	1	1	1	1	1	1
Peppers	78	100	82	109	91	91	91
Potatoes	4,295	2,984	5,073	5,056	5,130	5,181	5,242
Pumpkins	53	55	57	73	69	69	76
Radishes	0	0	0	0	0	0	0
Rapeseed	0	2	4	4	6	2	3
Rice	6,910	6,964	6,813	7,074	7,414	7,592	7,498
Rye	547	457	420	489	496	415	428
Safflower	842	633	567	453	469	432	549
Sorghum	1,602	1,225	1,132	919	866	985	1,081
Sorghum silage	102	207	38	31	36	43	39
Soybeans	53,300	58,487	57,209	55,863	54,070	57,660	60,801
Spearmint Oil	0	0	0	0	0	0	0
Spinach	19	26	19	26	20	23	22
Squash	15	19	15	21	19	17	15
Sugarcane	13,743	13,828	11,800	12,669	13,471	12,754	13,207
Sunflower	186	268	131	128	133	126	132
Sweet potatoes	350	433	470	686	563	557	622
Tobacco	5,380	4,430	5,023	4,346	5,349	4,797	5,462
Tomatoes	435	586	473	599	526	543	577
Turnip greens	0	0	0	0	0	0	0
Watermelon	168	196	187	210	177	190	157
Wheat	26,921	27,396	25,467	24,219	25,510	25,960	24,262
Total	**395,233**	**397,604**	**385,359**	**376,667**	**356,441**	**388,884**	**403,771**

Step 1e: Additional Activity Data for Indirect N_2O Emissions

A portion of the N that is applied as synthetic fertilizer, livestock manure, sewage sludge, and other organic amendments volatilizes as NH_3 and NO_x. In turn, this N is returned to soils through atmospheric deposition, thereby increasing mineral N availability and enhancing N_2O production. Additional N is lost from soils through leaching as water percolates through a soil profile and through runoff with overland water flow. N losses from leaching and runoff enter groundwater and waterways, from which a portion is emitted as N_2O. However, N leaching is assumed to be an insignificant source of indirect N_2O in cropland and grassland systems where the amount of precipitation plus irrigation does not exceed 80 percent of the potential evapotranspiration. These areas are typically semi-arid to arid, and nitrate leaching to groundwater is a relatively uncommon event; moreover IPCC (2006) recommends limiting the amount of nitrate leaching assumed to be a source of indirect N_2O emissions based on precipitation, irrigation and potential evapotranspiration.

The activity data for synthetic fertilizer, livestock manure, other organic amendments, residue N inputs, sewage sludge N, and other N inputs are the same as those used in the calculation of direct emissions from agricultural mineral soils, and may be found in Table A-222 through Table A-227, and Table A-229.

Using the DAYCENT model, volatilization and leaching/surface run-off of N from soils is computed internally for crops and non-federal grasslands in the Tier 3 method. DAYCENT simulates the processes leading to these losses of N based on environmental conditions (i.e., weather patterns and soil characteristics), management impacts (e.g., plowing, irrigation, harvest), and soil N availability. Note that the DAYCENT model accounts for losses of N from all anthropogenic activity, not just the inputs of N from mineral fertilization and organic amendments, which are addressed in the Tier 1 methodology. Similarly, the N available for producing indirect emissions resulting from grassland management as well as deposited PRP manure is also estimated by DAYCENT. Estimated leaching losses of N from DAYCENT are not used in the indirect N_2O calculation if the amount of precipitation plus irrigation did not exceed 80 percent of the potential evapotranspiration. Volatilized losses of N are summed for each day in the annual cycle to provide an estimate of the amount of N subject to indirect N_2O emissions. In addition, the daily losses of N through leaching and runoff in overland flow are summed for the annual cycle. Uncertainty in the estimates is derived from uncertainties in the activity data for the N inputs (i.e., fertilizer and organic amendments; see Step 1a for further information).

The Tier 1 method is used to estimate N losses from mineral soils due to volatilization and leaching/runoff for crops, sewage sludge applications, and PRP manure on federal grasslands, which is simulated by DAYCENT. To estimate volatilized losses, synthetic fertilizers, manure, sewage sludge, and other organic N inputs are multiplied by the fraction subject to gaseous losses using the respective default values of 0.1 kg N/kg N added as mineral fertilizers and 0.2 kg N/kg N added as manure (IPCC 2006). Uncertainty in the volatilized N ranges from 0.03-0.3 kg NH_3-N+NO_x-N/kg N for synthetic fertilizer and 0.05-0.5 kg NH_3-N+NO_x-N/kg N for organic amendments (IPCC 2006). Leaching/runoff losses of N are estimated by summing the N additions from synthetic and other organic fertilizers, manure, sewage sludge, and above- and below-ground crop residues, and then multiplying by the default fraction subject to leaching/runoff losses of 0.3 kg N/kg N applied, with an uncertainty from 0.1–0.8 kg NO_3-N/kg N (IPCC 2006). However, N leaching is assumed to be an insignificant source of indirect N_2O emissions if the amount of precipitation plus irrigation did not exceed 80 percent of the potential evapotranspiration. PDFs are derived for each of the N inputs in the same manner as direct N_2O emissions, discussed in Steps 1a and 1c.

Volatilized N is summed for losses from croplands and grasslands. Similarly, the annual amounts of N lost from soil profiles through leaching and surface runoff are summed to obtain the total losses for this pathway.

Step 2: Estimate Soil Organic C Stock Changes, Direct N_2O Emissions from Mineral Soils, and CH_4 Emissions from Rice Cultivation

In this step, soil organic C stock changes, N_2O emissions, and CH_4 emissions from rice cultivation are estimated for cropland and non-federal grasslands. Three methods are used to estimate soil organic C stock changes, direct N_2O emissions from mineral soils, and CH_4 emissions from rice cultivation. The DAYCENT process-based model is used for the croplands and non-federal grasslands included in the Tier 3 method. A Tier 2 method is used to estimate soil organic C stock changes for crop histories that included crops that were not simulated by DAYCENT and land use change other than conversions between cropland and grassland. A Tier 1 methodology is used to estimate N_2O emissions from crops that are not simulated by DAYCENT, PRP manure N deposition on federal grasslands, and CH_4 emissions from rice cultivation. Soil organic C stock changes and N_2O emissions are not estimated for federal grasslands (other than the effect of PRP manure N), but are under evaluation as a planned improvement and may be estimated in future inventories.

Step 2a: Estimate Soil Organic C Stock Changes, N_2O Emissions, and CH_4 emissions for Crops and Non-Federal Grassland with the Tier 3 DAYCENT Model

Crops that are simulated with DAYCENT include alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat, which combined represent approximately 87 to 90 percent of total cropland in the U.S. The DAYCENT simulations also included all non-federal grasslands in the U.S.

The methodology description is divided into two sub-steps. First, the model is used to establish the initial conditions and C stocks for 1979, which is the last year before the NRI survey is initiated. In the second sub-step, DAYCENT is used to estimate changes in soil organic C stocks, direct N_2O emissions, and CH_4 emissions from rice cultivation based on the land-use and management histories recorded in the NRI from 1990 through 2010 (USDA-NRCS 2013).

Simulate Initial Conditions (Pre-NRI Conditions): DAYCENT model initialization involves two steps, with the goal of estimating the most accurate stock for the pre-NRI history, and the distribution of organic C among the pools represented in the model (e.g., Structural, Metabolic, Active, Slow, and Passive). Each pool has a different turnover rate (representing the heterogeneous nature of soil organic matter), and the amount of C in each pool at any point in time influences the forward trajectory of the total soil organic C storage. There is currently no national set of soil C measurements that can be used for establishing initial conditions in the model. Sensitivity analysis of the soil organic C algorithms showed that the rate of change of soil organic matter is relatively insensitive to the *amount* of total soil organic C but is highly sensitive to the relative *distribution* of C among different pools (Parton et al. 1987). By simulating the historical land use prior to the inventory period, initial pool distributions are estimated in an unbiased way.

The first step involves running the model to a steady-state condition (e.g., equilibrium) under native vegetation, historical climate data based on the PRISM product (1981 through 2010), and the soil physical attributes for the NRI points.

Native vegetation is represented at the MLRA level for pre-settlement time periods in the United States. The model simulates 5,000 years in the pre-settlement era in order to achieve a steady-state condition.

The second step is to simulate the period of time from European settlement and expansion of agriculture to the beginning of the NRI survey, representing the influence of historic land-use change and management, particularly the conversion of native vegetation to agricultural uses. This encompasses a varying time period from land conversion (depending on historical settlement patterns) to 1979. The information on historical cropping practices used for DAYCENT simulations has been gathered from a variety of sources, ranging from the historical accounts of farming practices reported in the literature (e.g., Miner 1998) to national level databases (e.g., NASS 2004). A detailed description of the data sources and assumptions used in constructing the base history scenarios of agricultural practices can be found in Williams and Paustian (2005).

NRI History Simulations: After model initialization, DAYCENT is used to simulate the NRI land use and management histories from 1979 through 2010.[99] The simulations address the influence of soil management on direct N_2O emissions, soil organic C stock changes and losses of N from the profile through leaching/runoff and volatilization. The NRI histories identify the land use and land use change histories for the NRI survey locations, as well as cropping patterns and irrigation history (see Step 1a for description of the NRI data). The input data for the model simulations also include the PRISM weather dataset and SSURGO soils data, synthetic N fertilizer rates, managed manure amendments to cropland and grassland, manure deposition on grasslands (i.e., PRP), tillage histories and EVI data (See Step 1b for description of the inputs). The total number of DAYCENT simulations is over 18 million with a 100 repeated simulations (i.e., iterations) for each NRI point location in a Monte Carlo Analysis. The simulation system incorporates a dedicated MySQL database server and a 30-node parallel processing computer cluster. Input/output operations are managed by a set of run executive programs written in PERL.

The simulations for the NRI history are integrated with the uncertainty analysis. Evaluating uncertainty is an integral part of the analysis and includes three components: (1) uncertainty in the main activity data inputs affecting soil C and N_2O emissions (input uncertainty); (2) uncertainty in the model formulation and parameterization (structural uncertainty); and (3) uncertainty in the land-use and management system areas (scaling uncertainty) (Ogle et al. 2010; Del Grosso et al. 2010). For component 1, input uncertainty is evaluated for fertilization management, manure applications, and tillage, which are primary management activity data that are supplemental to the NRI observations and have significant influence on soil organic C dynamics, soil N_2O and CH_4 emissions. As described in Step 1b, PDFs are derived from surveys at the county scale for the inputs in most cases. In addition, uncertainty is included for predictions of EVI data that are needed to fill-data gaps and extend the time series (see Enhanced Vegetation Index in Step 1b). To represent uncertainty in all of these inputs, a Monte-Carlo Analysis is used with 100 iterations for each NRI point; random draws are made from PDFs for fertilizer, manure application, tillage, and EVI predictions. As described above, an adjustment factor is also selected from PDFs with normal densities to represent the dependence between manure amendments and N fertilizer application rates.

The second component deals with uncertainty inherent in model formulation and parameterization. This component is the largest source of uncertainty in the Tier 3 model-based inventory analysis, accounting for more than 80 percent of the overall uncertainty in the final estimates (Ogle et al. 2010; Del Grosso et al. 2010). An empirically-based procedure is applied to develop a structural uncertainty estimator from the relationship between modeled results and field measurements from agricultural experiments (Ogle et al. 2007). For soil organic C, the DAYCENT model is evaluated with measurements from 84 long-term field experiments that have over 900 treatment observations, representing a variety of management conditions (e.g., variation in crop rotation, tillage, fertilization rates, and manure amendments). There are 27 experimental sites available with 93 treatment observations to evaluate structural uncertainty in the N_2O emission predictions from DAYCENT (Del Grosso et al. 2010). There are 10 experiments with 126 treatment observations for CH_4 emissions from rice cultivation,. The inputs to the model are essentially known in the simulations for the long-term experiments, and, therefore, the analysis is designed to evaluate uncertainties associated with the model structure (i.e., model algorithms and parameterization). USDA is developing a national soil monitoring network to evaluate the Inventory in the future (Spencer et al. 2011).

The relationship between modeled soil organic C stocks and field measurements are statistically analyzed using linear-mixed effect modeling techniques. Additional fixed effects are included in the mixed effect model if they explained

[99] The estimated soil C stock change in 2010 is currently assumed to represent the changes between 2011 and 2014. More recent data will be incorporated in the future to extend the time series of land use and management data.

significant variation in the relationship between modeled and measured stocks (i.e., if they met an alpha level of 0.05 for significance). Several variables are tested, including land-use class; type of tillage; cropping system; geographic location; climate; soil texture; time since the management change; original land cover (i.e., forest or grassland); grain harvest as predicted by the model compared to the experimental values; and variation in fertilizer and residue management. The final cropland model includes variables for modeled soil organic C inclusion of hay/pasture in cropping rotations, use of no-till, set-aside lands, organic matter amendments, and inclusion of bare fallow in the rotation, which are significant at an alpha level of 0.05. The final grassland model only included the model soil organic C. These fixed effects are used to make an adjustment to modeled values due to biases that are creating significant mismatches between the modeled and measured stocks. For soil N_2O, simulated DAYCENT emissions are a highly significant predictor of the measurements, with a p-value of <0.01. Several other variables are considered in the statistical model to evaluate if DAYCENT exhibits bias under certain conditions related to climate, soil types, and management practices. Random effects are included in the model to capture the dependence in time series and data collected from the same site, which are needed to estimate appropriate standard deviations for parameter coefficients. For rice CH_4 emissions, simulated DAYCENT emissions are a significant predictor of measured emission, similar to the results for soil N_2O emissions. Several other variables are tested including soil characteristics, geographic location (i.e., state), and management practices (e.g., with and without winter flooding). The only other significant variable is geographic location because the model does not predict emissions as accurately for California as other rice-producing states. Random effects are included to capture the dependence in time series and the data collected from the same site.

A Monte Carlo approach is used to apply the uncertainty estimator (Ogle et al. 2010). Parameter values for the statistical equation (i.e., fixed effects) are selected from their joint probability distribution, as well as random error associated with fine-scale estimates at NRI points, and the residual or unexplained error associated with the linear mixed-effect model. The estimate and associated management information is then used as input into the equation, and adjusted values are computed for each C stock, N_2O and CH_4 emissions estimate. The variance of the adjusted estimates is computed from the 100 simulated values from the Monte Carlo analysis.

The third element is the uncertainty associated with scaling the DAYCENT results for each NRI point to the entire land base, using the expansion factors provided with the NRI survey dataset. The expansion factors represent the number of hectares associated with the land-use and management history for a particular point. This uncertainty is determined by computing the variances from a set of replicated weights for the expansion factor. For the land base that is simulated with the DAYCENT model, soil organic C stock changes are provided in Table A-230, soil N_2O emissions are provided in Table A-231, and rice cultivation CH_4 emissions in Table A-232.

Table A-230: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Land Base Simulated with the Tier 3 DAYCENT Model-Based Approach (MMT CO_2 Eq.)

	Cropland Remaining Cropland		Land Converted to Cropland		Grassland Remaining Grassland		Land Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
1990	(56.17)	(85.13) to (27.20)	12.91	3.82 to 21.99	(17.87)	(57.42) to 21.68	(3.81)	(8.28) to 0.67
1991	(57.01)	(88.19) to (25.83)	12.80	3.55 to 22.05	(8.44)	(41.12) to 24.25	(4.72)	(9.42) to (0.01)
1992	(58.33)	(92.79) to (23.88)	13.63	3.30 to 23.96	(9.35)	(42.21) to 23.52	(4.67)	(9.62) to 0.29
1993	(37.09)	(70.77) to (3.40)	11.65	1.84 to 21.46	(8.68)	(46.74) to 29.38	(5.12)	(11.21) to 0.96
1994	(48.47)	(77.48) to (19.47)	6.47	(4.12) to 17.06	(24.18)	(66.44) to 18.08	(5.42)	(11.13) to 0.28
1995	(42.96)	(74.79) to (11.13)	13.62	3.64 to 23.61	(7.36)	(40.08) to 25.37	(5.61)	(11.06) to (0.16)
1996	(50.59)	(83.49) to (17.70)	11.18	0.04 to 22.33	(16.46)	(54.41) to 21.49	(5.96)	(11.88) to (0.04)
1997	(47.13)	(78.45) to (15.81)	13.12	2.94 to 23.30	(9.94)	(53.81) to 33.94	(6.64)	(12.54) to (0.74)
1998	(33.49)	(63.73) to (3.26)	7.63	(2.64) to 17.90	(13.09)	(50.63) to 24.44	(6.83)	(13.57) to (0.10)
1999	(46.54)	(80.91) to (12.17)	8.52	(3.15) to 20.18	(3.76)	(43.22) to 35.69	(6.88)	(14.67) to 0.91
2000	(51.06)	(79.03) to (23.10)	8.41	(2.24) to 19.06	(19.22)	(52.43) to 13.99	(7.14)	(15.49) to 1.21
2001	(50.85)	(83.65) to (18.06)	8.16	(2.66) to 18.99	(8.46)	(51.41) to 34.49	(7.63)	(15.88) to 0.62
2002	(42.21)	(72.67) to (11.75)	8.62	(0.84) to 18.08	(6.80)	(42.05) to 28.46	(8.16)	(16.50) to 0.18
2003	(32.95)	(64.45) to (1.45)	7.68	(2.02) to 17.37	(5.15)	(45.88) to 35.58	(7.31)	(16.01) to 1.39
2004	(38.11)	(69.39) to (6.84)	6.93	(3.16) to 17.03	(7.38)	(45.0) to 30.24	(8.01)	(17.05) to 1.03
2005	(37.19)	(69.31) to (5.07)	7.94	(1.98) to 17.86	(5.26)	(44.04) to 33.52	(7.23)	(16.46) to 2.0
2006	(37.66)	(71.38) to (3.95)	7.94	(2.31) to 18.18	(14.35)	(55.71) to 27.01	(7.98)	(16.23) to 0.27
2007	(37.76)	(69.09) to (6.44)	5.84	(3.94) to 15.62	1.26	(34.83) to 37.35	(7.87)	(16.75) to 1.0
2008	(29.74)	(63.12) to 3.64	6.79	(1.73) to 15.31	(8.44)	(47.35) to 30.48	(8.13)	(17.73) to 1.47
2009	(22.33)	(51.73) to 7.07	5.77	(5.39) to 16.93	(10.79)	(45.11) to 23.53	(7.98)	(16.89) to 0.94
2010	(22.03)	(56.14) to 12.07	6.65	(3.93) to 17.23	(9.05)	(46.92) to 28.82	(7.67)	(16.74) to 1.39
2011	(36.74)	(68.95) to (4.53)	4.54	(5.34) to 14.42	1.06	(35.84) to 37.95	(7.16)	(15.94) to 1.61
2012	(36.75)	(68.95) to (4.54)	4.54	(5.34) to 14.42	1.08	(35.81) to 37.97	(7.16)	(15.94) to 1.61

2013	(36.75)	(68.95) to (4.54)	4.54	(5.34) to 14.42	1.08	(35.81) to 37.97	(7.16)	(15.94) to 1.61
2014	(36.75)	(68.95) to (4.54)	4.54	(5.34) to 14.42	1.08	(35.81) to 37.97	(7.16)	(15.94) to 1.61

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-231: Annual N_2O Emissions (95% Confidence Interval) for the Land Base Simulated with the Tier 3 DAYCENT Model-Based Approach (MMT CO_2 Eq.)

	Tier 3 Cropland		Non-Federal Grasslands	
Year	Estimate	95% CI	Estimate	95% CI
1990	153.1	144.73 to 164.12	65.6	61.13 to 72.06
1991	150.0	142.04 to 160.62	66.2	61.67 to 72.46
1992	151.0	142.84 to 161.88	66.6	62.37 to 72.78
1993	153.1	144.62 to 164.31	66.2	61.92 to 72.23
1994	149.0	141.15 to 159.37	62.5	58.41 to 68.26
1995	149.5	141.58 to 160.1	64.1	59.93 to 69.93
1996	149.9	141.91 to 160.64	66.5	62 to 72.93
1997	149.9	141.91 to 160.56	67.1	62.78 to 73.07
1998	160.0	151.21 to 171.61	72.0	67.3 to 78.85
1999	151.2	143.17 to 161.89	62.1	58.28 to 67.58
2000	155.9	147.86 to 166.29	63.7	59.41 to 70.08
2001	152.9	144.92 to 163.37	64.3	60.03 to 70.38
2002	152.9	144.94 to 163.33	67.1	62.54 to 73.77
2003	155.6	147.63 to 166.14	66.9	62.5 to 73.33
2004	164.9	156.33 to 176.14	77.4	72.13 to 85.08
2005	155.2	147.08 to 165.93	66.4	62.24 to 72.41
2006	155.1	147.08 to 165.62	68.4	63.93 to 74.82
2007	162.1	153.37 to 173.56	70.6	65.83 to 77.54
2008	156.0	147.76 to 166.86	67.8	63.45 to 74.11
2009	156.8	148.59 to 167.66	70.7	66.05 to 77.44
2010	166.5	157.5 to 178.49	70.3	65.83 to 76.87
2011	165.7	156.83 to 177.23	70.5	65.81 to 77.27
2012	165.9	157.07 to 177.48	70.4	65.71 to 77.16
2013	165.2	156.36 to 176.72	70.4	65.71 to 77.16
2014	165.2	156.36 to 176.72	70.4	65.71 to 77.16

Table A-232: Annual CH_4 Emissions (95% Confidence Interval) for Rice Cultivation Simulated with the Tier 3 DAYCENT Model-Based Approach (MMT CO_2 Eq.)

Year	Estimate	95% CI
1990	12.08	10.55 to 13.61
1991	11.93	10.57 to 13.28
1992	11.91	10.18 to 13.64
1993	12.65	11.18 to 14.13
1994	9.32	8.37 to 10.27
1995	12.41	10.78 to 14.04
1996	11.45	10.02 to 12.87
1997	10.47	9.37 to 11.57
1998	12.39	9.94 to 14.85
1999	11.37	8.04 to 14.71
2000	12.83	10.21 to 15.45
2001	10.97	8.87 to 13.06
2002	14.01	9.98 to 18.03
2003	9.87	8.55 to 11.20
2004	9.70	7.78 to 11.63
2005	11.93	10.26 to 13.60
2006	9.25	7.74 to 10.76
2007	8.95	6.93 to 10.98
2008	7.84	6.21 to 9.46
2009	9.88	6.81 to 12.95
2010	10.71	8.78 to 12.64
2011	10.71	8.76 to 12.66
2012	10.72	8.79 to 12.65
2013	10.71	8.78 to 12.64

2014	10.72	8.79 to 12.65

In DAYCENT, the model cannot distinguish among the original sources of N after the mineral N enters the soil pools, and therefore it is not possible to determine which management activity led to specific N_2O emissions. This means, for example, that N_2O emissions from applied synthetic fertilizer cannot be separated from emissions due to other N inputs, such as crop residues. It is desirable, however, to report emissions associated with specific N inputs. Thus, for each NRI point, the N inputs in a simulation are determined for anthropogenic practices discussed in IPCC (2006), including synthetic mineral N fertilization, organic amendments, and crop residue N added to soils (including N-fixing crops). The percentage of N input for anthropogenic practices is divided by the total N input, and this proportion is used to determine the amount of N_2O emissions assigned to each of the practices.[100] For example, if 70 percent of the mineral N made available in the soil is due to mineral fertilization, then 70 percent of the N_2O emissions are assigned to this practice. The remainder of soil N_2O emissions is reported under "other N inputs," which includes mineralization due to decomposition of soil organic matter and litter, as well as asymbiotic N fixation from the atmosphere. Asymbiotic N fixation by soil bacteria is a minor source of N, typically not exceeding 10 percent of total N inputs to agroecosystems. Mineralization of soil organic matter is a more significant source of N, but is still typically less than half of the amount of N made available in the cropland soils compared to application of synthetic fertilizers and manure amendments, along with symbiotic fixation. Mineralization of soil organic matter accounts for the majority of available N in grassland soils. Accounting for the influence of "other N inputs" is necessary in order to meet the recommendation for reporting all emissions from managed lands (IPCC 2006). While this method allows for attribution of N_2O emissions to the individual N inputs to the soils, it is important to realize that sources such as synthetic fertilization may have a larger impact on N_2O emissions than would be suggested by the associated level of N input for this source (Delgado et al. 2009). Further research will be needed to improve upon this attribution method, however. The results associated with subdividing the N_2O emissions based on N inputs are provided in Table A-233 and Table A-234.

[100] This method is a simplification of reality to allow partitioning of N_2O emissions, as it assumes that all N inputs have an identical chance of being converted to N_2O. This is unlikely to be the case, but DAYCENT does not track N_2O emissions by source of mineral N so this approximation is the only approach that can be used currently for partitioning N_2O emissions by source of N input. Moreover, this approach is similar to the IPCC Tier 1 method (IPCC 2006), which uses the same direct emissions factor for most N sources (e.g., PRP). Further research and model development may allow for other approaches in the future.

Table A-233: Direct N_2O Emissions from Cropland Soils (MMT CO_2 Eq.)

N Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total Mineral Soils	**168.6**	**165.5**	**166.2**	**167.2**	**168.0**	**166.2**	**168.4**	**167.2**	**177.7**	**169.0**	**171.1**	**167.7**	**168.4**	**172.4**	**181.3**	**171.2**	**172.2**	**178.8**	**172.1**	**171.8**	**182.6**	**183.9**	**184.9**	**182.2**	**182.0**
Tier 3 Cropland	**153.1**	**150.0**	**151.0**	**153.1**	**149.0**	**149.5**	**149.9**	**149.9**	**160.0**	**151.2**	**155.9**	**152.9**	**152.9**	**155.6**	**164.9**	**155.2**	**155.1**	**162.1**	**156.0**	**156.8**	**166.5**	**165.7**	**165.9**	**165.2**	**165.2**
Synthetic Fertilizer	53.3	53.0	55.2	53.4	54.3	50.8	53.8	53.3	53.5	50.7	55.6	52.9	54.0	53.8	56.6	54.7	54.9	58.2	55.0	53.9	51.9	51.6	51.7	51.5	51.5
Managed Manure	5.0	4.9	5.3	5.1	5.0	4.5	4.9	4.9	5.1	5.8	6.0	5.6	5.7	5.6	5.8	5.6	5.6	6.1	5.8	6.2	6.5	6.4	6.4	6.4	6.4
Residue N[a]	23.1	25.5	23.2	23.9	22.9	25.1	24.3	24.2	23.4	26.8	25.5	24.3	24.9	25.7	23.4	24.6	24.2	24.4	23.7	23.4	26.0	25.8	25.8	25.7	25.7
Mineralization and Asymbiotic Fixation	71.6	66.6	67.3	70.7	66.8	69.1	67.0	67.5	78.0	67.9	68.7	70.1	68.3	70.5	79.1	70.3	70.3	73.3	71.5	73.4	82.2	81.8	82.0	81.6	81.6
Tier 1 Cropland	**15.6**	**15.4**	**15.1**	**14.2**	**19.0**	**16.6**	**18.4**	**17.3**	**17.8**	**17.7**	**15.2**	**14.8**	**15.5**	**16.7**	**16.4**	**16.0**	**17.1**	**16.7**	**16.1**	**15.0**	**16.1**	**18.2**	**19.0**	**17.0**	**16.8**
Synthetic Fertilizer	5.9	5.8	5.6	4.9	9.0	6.5	8.6	7.4	7.9	8.8	6.1	5.7	6.3	7.3	7.2	6.7	7.4	7.4	6.7	6.0	7.4	9.4	10.1	8.0	7.8
Managed Manure and Other Organic Commercial Fertilizer	6.8	7.0	6.9	6.8	7.3	7.8	7.5	7.6	7.6	6.9	7.0	7.2	7.3	7.5	7.1	7.3	7.8	7.5	7.5	7.1	6.9	7.1	7.2	7.2	7.2
Residue N	2.8	2.6	2.7	2.4	2.7	2.4	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.9	2.1	2.0	1.9	1.9	1.9	1.9	1.8	1.8	1.7	1.8	1.9
Organic Soils	**3.2**	**3.2**	**3.2**	**3.1**	**3.1**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.3**	**3.3**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.1**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**
Total*	**171.9**	**168.7**	**169.3**	**170.4**	**171.1**	**169.4**	**171.6**	**170.3**	**180.9**	**172.2**	**174.3**	**171.0**	**171.7**	**175.6**	**184.5**	**174.4**	**175.3**	**182.0**	**175.2**	**174.8**	**185.7**	**186.9**	**187.9**	**185.2**	**185.0**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Table A-234: Direct N_2O Emissions from Grasslands (MMT CO_2 Eq.)

N Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total Mineral Soils	**70.3**	**70.4**	**71.4**	**71.9**	**69.0**	**71.5**	**74.4**	**73.7**	**77.8**	**66.8**	**68.3**	**68.2**	**70.8**	**71.2**	**81.3**	**71.0**	**74.0**	**75.6**	**73.1**	**75.9**	**75.5**	**74.9**	**74.0**	**73.3**	**73.3**
Tier 3	**65.6**	**66.2**	**66.6**	**66.2**	**62.5**	**64.1**	**66.5**	**67.1**	**72.0**	**62.1**	**63.7**	**64.3**	**67.1**	**66.9**	**77.4**	**66.4**	**68.4**	**70.6**	**67.8**	**70.7**	**70.3**	**70.5**	**70.4**	**70.4**	**70.4**
Synthetic Fertilizer	1.1	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.4	1.1	1.2	1.2	1.3	1.3	1.5	1.3	1.4	1.3	1.3	1.4	1.3	1.2	1.2	1.2	1.4
PRP Manure	8.9	8.8	8.8	8.5	8.5	8.2	8.5	8.3	9.3	8.0	8.4	8.5	8.9	8.6	9.6	8.2	8.5	8.4	8.0	8.3	7.9	8.0	8.0	8.0	8.0
Managed Manure	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0.2
Residue N[a]	19.7	20.1	20.3	20.5	18.3	20.3	19.8	20.4	20.2	20.3	19.3	19.8	20.1	20.2	20.9	21.0	20.3	21.5	20.7	20.3	21.8	21.7	21.7	21.7	21.6
Mineralization and Asymbiotic Fixation	35.8	36.1	36.3	35.8	34.4	34.4	36.9	37.1	41.1	32.5	34.7	34.6	36.7	36.6	45.3	35.8	38.0	39.3	37.7	40.5	39.1	39.4	39.4	39.4	39.2
Tier 1	**4.7**	**4.2**	**4.8**	**5.7**	**6.6**	**7.4**	**7.8**	**6.7**	**5.8**	**4.7**	**4.5**	**3.9**	**3.7**	**4.3**	**3.8**	**4.6**	**5.6**	**5.0**	**5.4**	**5.3**	**5.1**	**4.4**	**3.5**	**2.9**	**2.9**
PRP Manure	4.5	4.0	4.5	5.4	6.2	7.1	7.5	6.3	5.4	4.3	4.1	3.5	3.3	3.9	3.4	4.1	5.1	4.5	4.9	4.8	4.6	3.8	3.0	2.3	2.3
Sewage Sludge	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6
Organic Soils	**2.9**	**2.8**	**2.8**	**2.8**	**2.9**	**2.9**	**2.9**	**2.8**	**2.8**	**2.8**	**2.8**	**3.0**	**3.0**	**2.9**	**2.9**	**2.9**	**2.8**	**2.8**	**2.8**	**2.7**	**2.7**	**2.7**	**2.7**	**2.7**	**2.7**
Total	**73.2**	**73.2**	**74.2**	**74.7**	**71.9**	**74.3**	**77.2**	**76.5**	**80.6**	**69.6**	**71.1**	**71.1**	**73.8**	**74.1**	**84.1**	**73.9**	**76.8**	**78.4**	**75.9**	**78.7**	**78.1**	**77.6**	**76.6**	**76.0**	**76.0**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Step 2b: Soil N_2O Emissions from Agricultural Lands on Mineral Soils Approximated with the Tier 1 Approach

To estimate direct N_2O emissions from N additions to crops in the Tier 1 method, the amount of N in applied synthetic fertilizer, manure and other commercial organic fertilizers (i.e., dried blood, tankage, compost, and other) is added to N inputs from crop residues, and the resulting annual totals are multiplied by the IPCC default emission factor of 0.01 kg N_2O-N/kg N (IPCC 2006) (see Table A-233). The uncertainty is determined based on simple error propagation methods (IPCC 2006). The uncertainty in the default emission factor ranges from 0.3–3.0 kg N_2O-N/kg N (IPCC 2006). For flooded rice soils, the IPCC default emission factor is 0.003 kg N_2O-N/kg N and the uncertainty range is 0.000–0.006 kg N_2O-N/kg N (IPCC 2006).[101] Uncertainties in the emission factor and fertilizer additions are combined with uncertainty in the equations used to calculate residue N additions from above- and below-ground biomass dry matter and N concentration to derive overall uncertainty.

The Tier 1 method is also used to estimate emissions from manure N deposited by livestock on federal lands (i.e., PRP manure N), and from sewage sludge application to grasslands. These two sources of N inputs to soils are multiplied by the IPCC (2006) default emission factors (0.01 kg N_2O-N/kg N for sludge and horse, sheep, and goat manure, and 0.02 kg N_2O-N/kg N for cattle, swine, and poultry manure) to estimate N_2O emissions (Table A-234). The uncertainty is determined based on the Tier 1 error propagation methods provided by the IPCC (2006) with uncertainty in the default emission factor ranging from 0.007 to 0.06 kg N_2O-N/kg N (IPCC 2006).

Step 2c: Soil CH_4 Emissions from Agricultural Lands Approximated with the Tier 1 Approach To estimate CH_4 emissions from rice cultivation for the Tier 1 method, an adjusted daily emission factor is calculated using the default baseline emission factor of 1.30 kg CH_4 ha^{-1} d^{-1} (ranging 0.8-2.2 kg CH_4 ha^{-1} d^{-1}) multiplied by a scaling factor for the cultivation water regime, pre-cultivation water regime and a scaling factor for organic amendments (IPCC 2006). The water regime during cultivation is continuously flooded for rice production in the United States and so the scaling factor is always 1 (ranging from 0.79 to 1.26). The pre-season water regime varies based on the proportion of land with winter flooding; land that does not have winter flooding is assigned a value of 0.68 (ranging from 0.58 to 0.80) and areas with winter flooding are assigned a value of 1 (ranging from 0.88 to 1.14). Organic amendments are estimated based on the amount of rice straw and multiplied by 1 (ranging 0.97 to 1.04) for straw incorporated greater than 30 days before cultivation, and by 0.29 (0.2 to 0.4) for straw incorporated greater than 30 days before cultivation. The adjusted daily emission factor is multiplied by the cultivation period and harvested area to estimate the total CH_4 emissions. The uncertainty is propagated through the calculation using an Approach 2 method with a Monte Carlo simulation (IPCC 2006), combining uncertainties associated with the calculation of the adjusted daily emission factor and the harvested areas derived from the USDA NRI survey data.

Step 2d: Soil Organic C Stock Changes in Agricultural Lands on Mineral Soils Approximated with the Tier 2 Approach

Mineral soil organic C stock values are derived for crop rotations that were not simulated by DAYCENT and land converted from non-agricultural land uses to cropland or grassland from 1990-2010, based on the land-use and management activity data in conjunction with appropriate reference C stocks, land-use change, management, input, and wetland restoration factors. Each input to the inventory calculations for the Tier 2 approach has some level of uncertainty that is quantified in PDFs, including the land-use and management activity data, reference C stocks, and management factors. A Monte Carlo Analysis is used to quantify uncertainty in soil organic C stock changes for the inventory period based on uncertainty in the inputs. Input values are randomly selected from PDFs in an iterative process to estimate SOC change for 50,000 times and produce a 95 percent confidence interval for the inventory results.

Derive Mineral Soil Organic C Stock Change Factors: Stock change factors representative of U.S. conditions are estimated from published studies (Ogle et al. 2003; Ogle et al. 2006). The numerical factors quantify the impact of changing land use and management on SOC storage in mineral soils, including tillage practices, cropping rotation or intensification, and land conversions between cultivated and native conditions (including set-asides in the Conservation Reserve Program). Studies from the United States and Canada are used in this analysis under the assumption that they would best represent management impacts for the Inventory.

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[101] Due to lack of data, uncertainties in managed manure N production, PRP manure N production, other commercial organic fertilizer amendments, indirect losses of N in the DAYCENT simulations, and sewage sludge amendments to soils are currently treated as certain; these sources of uncertainty will be included in future Inventories.

The IPCC inventory methodology for agricultural soils divides climate into eight distinct zones based upon average annual temperature, average annual precipitation, and the length of the dry season (IPCC 2006) (Table A-235). Seven of these climate zones occur in the conterminous United States and Hawaii (Eve et al. 2001).

Table A-235: Characteristics of the IPCC Climate Zones that Occur in the United States

Climate Zone	Annual Average Temperature (˚C)	Average Annual Precipitation (mm)	Length of Dry Season (months)
Cold Temperate, Dry	< 10	< Potential Evapotranspiration	NA
Cold Temperate, Moist	< 10	≥ Potential Evapotranspiration	NA
Warm Temperate, Dry	10 – 20	< 600	NA
Warm Temperate, Moist	10 – 20	≥ Potential Evapotranspiration	NA
Sub-Tropical, Dry[a]	> 20	< 1,000	Usually long
Sub-Tropical, Moist (w/short dry season)[a]	> 20	1,000 – 2,000	< 5

[a] The climate characteristics listed in the table for these zones are those that correspond to the tropical dry and tropical moist zones of the IPCC. They have been renamed "sub-tropical" here.

Mean precipitation and temperature (1950-2000) variables from the WorldClim data set (Hijmans et al. 2005)) and potential evapotranspiration data from the Consortium for Spatial Information (CGIAR-CSI) (Zomer et al. 2008; Zomer et al. 2007) are used to classify climate zones (Figure A-15). IPCC climate zones are assigned to NRI point locations.

Soils are classified into one of seven classes based upon texture, morphology, and ability to store organic matter (IPCC 2006). Six of the categories are mineral types and one is organic (i.e., *Histosol)*. Reference C stocks, representing estimates from conventionally managed cropland, are computed for each of the mineral soil types across the various climate zones, based on pedon (i.e., soil) data from the National Soil Survey Characterization Database (NRCS 1997) (Table A-236). These stocks are used in conjunction with management factors to estimate the change in SOC stocks that result from management and land-use activity. PDFs, which represent the variability in the stock estimates, are constructed as normal densities based on the mean and variance from the pedon data. Pedon locations are clumped in various parts of the country, which reduces the statistical independence of individual pedon estimates. To account for this lack of independence, samples from each climate by soil zone are tested for spatial autocorrelation using the Moran's I test, and variance terms are inflated by 10 percent for all zones with significant p-values.

Figure A-15: IPCC Climate Zones

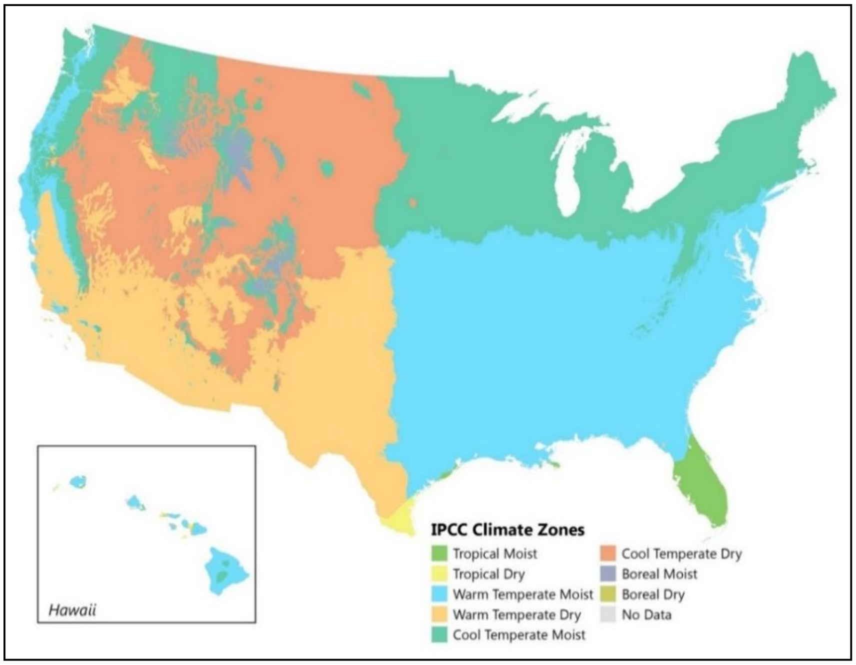


Table A-236: U.S. Soil Groupings Based on the IPCC Categories and Dominant Taxonomic Soil, and Reference Carbon Stocks (Metric Tons C/ha)

		Reference Carbon Stock in Climate Regions					
IPCC Inventory Soil Categories	USDA Taxonomic Soil Orders	Cold Temperate, Dry	Cold Temperate, Moist	Warm Temperate, Dry	Warm Temperate, Moist	Sub-Tropical, Dry	Sub-Tropical, Moist
High Clay Activity Mineral Soils	Vertisols, Mollisols, Inceptisols, Aridisols, and high base status Alfisols	42 (n = 133)	65 (n = 526)	37 (n = 203)	51 (n = 424)	42 (n = 26)	57 (n = 12)
Low Clay Activity Mineral Soils	Ultisols, Oxisols, acidic Alfisols, and many Entisols	45 (n = 37)	52 (n = 113)	25 (n = 86)	40 (n = 300)	39 (n = 13)	47 (n = 7)
Sandy Soils	Any soils with greater than 70 percent sand and less than 8 percent clay (often Entisols)	24 (n = 5)	40 (n = 43)	16 (n = 19)	30 (n = 102)	33 (n = 186)	50 (n = 18)
Volcanic Soils	Andisols	124 (n = 12)	114 (n = 2)	124 (n = 12)	124 (n = 12)	124 (n = 12)	128 (n = 9)
Spodic Soils	Spodosols	86 (n=20)	74 (n = 13)	86 (n=20)	107 (n = 7)	86 (n=20)	86 (n=20)
Aquic Soils	Soils with Aquic suborder	86 (n = 4)	89 (n = 161)	48 (n = 26)	51 (n = 300)	63 (n = 503)	48 (n = 12)
Organic Soils[a]	Histosols	NA	NA	NA	NA	NA	NA

[a] C stocks are not needed for organic soils.

Notes: C stocks are for the top 30 cm of the soil profile, and are estimated from pedon data available in the National Soil Survey Characterization database (NRCS 1997); sample size provided in parentheses (i.e., 'n' values refer to sample size).

To estimate the land use, management and input factors, studies had to report SOC stocks (or information to compute stocks), depth of sampling, and the number of years since a management change to be included in the analysis. The data are analyzed using linear mixed-effect modeling, accounting for both fixed and random effects. Fixed effects included depth, number of years since a management change, climate, and the type of management change (e.g., reduced tillage vs. no-till). For depth increments, the data are not aggregated for the C stock measurements; each depth increment (e.g., 0-5 cm, 5-10 cm, and 10-30 cm) is included as a separate point in the dataset. Similarly, time series data are not aggregated in these datasets. Linear regression models assume that the underlying data are independent observations, but this is not the case with data from the same experimental site, or plot in a time series. These data are more related to each other than data from other sites (i.e., not independent). Consequently, random effects are needed to account for the dependence in time series data and the dependence among data points representing different depth increments from the same study. Factors are estimated for the effect of management practices at 20 years for the top 30 cm of the soil (Table A-237). Variance is calculated for each of the U.S. factor values, and used to construct PDFs with a normal density. In the IPCC method, specific factor values are given for improved grassland, high input cropland with organic amendments, and for wetland rice, each of which influences C stock changes in soils. Specifically, higher stocks are associated with increased productivity and C inputs (relative to native grassland) on improved grassland with both medium and high input.[102] Organic amendments in annual cropping systems also increase SOC stocks due to greater C inputs, while high SOC stocks in rice cultivation are associated with reduced decomposition due to periodic flooding. There are insufficient field studies to derive factor values for these systems from the published literature, and, thus, estimates from IPCC (2006) are used under the assumption that they would best approximate the impacts, given the lack of sufficient data to derive U.S.-specific factors. A measure of uncertainty is provided for these factors in IPCC (2006), which is used to construct PDFs.

[102] Improved grasslands are identified in the 2010 *National Resources Inventory* as grasslands that are irrigated or seeded with legumes, in addition to those reclassified as improved with manure amendments.

Table A-237: Soil Organic Carbon Stock Change Factors for the United States and the IPCC Default Values Associated with Management Impacts on Mineral Soils

		U.S. Factor			
	IPCC default	Warm Moist Climate	Warm Dry Climate	Cool Moist Climate	Cool Dry Climate
Land-Use Change Factors					
Cultivated[a]	1	1	1	1	1
General Uncult.[a,b] (n=251)	1.4	1.42±0.06	1.37±0.05	1.24±0.06	1.20±0.06
Set-Asidea (n=142)	1.25	1.31±0.06	1.26±0.04	1.14±0.06	1.10±0.05
Improved Grassland Factors					
Medium Input	1.1	1.14±0.06	1.14±0.06	1.14±0.06	1.14±0.06
High Input	NA	1.11±0.04	1.11±0.04	1.11±0.04	1.11±0.04
Wetland Rice Production Factor[b]	1.1	1.1	1.1	1.1	1.1
Tillage Factors					
Conv. Till	1	1	1	1	1
Red. Till (n=93)	1.05	1.08±0.03	1.01±0.03	1.08±0.03	1.01±0.03
No-till (n=212)	1.1	1.13±0.02	1.05±0.03	1.13±0.02	1.05±0.03
Cropland Input Factors					
Low (n=85)	0.9	0.94±0.01	0.94±0.01	0.94±0.01	0.94±0.01
Medium	1	1	1	1	1
High (n=22)	1.1	1.07±0.02	1.07±0.02	1.07±0.02	1.07±0.02
High with amendment[b]	1.2	1.38±0.06	1.34±0.08	1.38±0.06	1.34±0.08

[a] Factors in the IPCC documentation (IPCC 2006) are converted to represent changes in SOC storage from a cultivated condition rather than a native condition.
[b] U.S.-specific factors are not estimated for land improvements, rice production, or high input with amendment because of few studies addressing the impact of legume mixtures, irrigation, or manure applications for crop and grassland in the United States, or the impact of wetland rice production in the US. Factors provided in IPCC (2006) are used as the best estimates of these impacts.
Note: The "n" values refer to sample size.

Wetland restoration management also influences SOC storage in mineral soils, because restoration leads to higher water tables and inundation of the soil for at least part of the year. A stock change factor is estimated assessing the difference in SOC storage between restored and unrestored wetlands enrolled in the Conservation Reserve Program (Euliss and Gleason 2002), which represents an initial increase of C in the restored soils over the first 10 years (Table A-238). A PDF with a normal density is constructed from these data based on results from a linear regression model. Following the initial increase of C, natural erosion and deposition leads to additional accretion of C in these wetlands. The mass accumulation rate of organic C is estimated using annual sedimentation rates (cm/yr) in combination with percent organic C, and soil bulk density (g/cm^3) (Euliss and Gleason 2002). Procedures for calculation of mass accumulation rate are described in Dean and Gorham (1998); the resulting rate and standard deviation are used to construct a PDF with a normal density (Table A-238).

Table A-238: Rate and standard deviation for the Initial Increase and Subsequent Annual Mass Accumulation Rate (Mg C/ha-yr) in Soil Organic C Following Wetland Restoration of Conservation Reserve Program

Variable	Value
Factor (Initial Increase—First 10 Years)	1.22±0.18
Mass Accumulation (After Initial 10 Years)	0.79±0.05

Note: Mass accumulation rate represents additional gains in C for mineral soils after the first 10 years (Euliss and Gleason 2002).

Estimate Annual Changes in Mineral Soil Organic C Stocks: In accordance with IPCC methodology, annual changes in mineral soil C are calculated by subtracting the beginning stock from the ending stock and then dividing by 20.[103] For this analysis, stocks are estimated for each year and difference between years is the stock change. From the final distribution of 50,000 values, a 95 percent confidence interval is generated based on the simulated values at the 2.5 and 97.5 percentiles in the distribution (Ogle et al. 2003). Soil organic C stock changes are provided in Table A-239 through Table A-244.

[103] The difference in C stocks is divided by 20 because the stock change factors represent change over a 20-year time period.

Step 2e: Estimate Additional Changes in Soil Organic C Stocks Due to CRP Enrollment after 2010 and Sewage Sludge Amendments

There are two additional land use and management activities in U.S. agricultural lands that are not estimated in Steps 2a and 2b. The first activity involves the application of sewage sludge to agricultural lands. Minimal data exist on where and how much sewage sludge is applied to U.S. agricultural soils, but national estimates of mineral soil land area receiving sewage sludge can be approximated based on sewage sludge N production data, and the assumption that amendments are applied at a rate equivalent to the assimilative capacity from Kellogg et al. (2000). It is assumed that sewage sludge for agricultural land application is applied to grassland because of the high heavy metal content and other pollutants found in human waste, which limits its application to crops. The impact of organic amendments on SOC is calculated as 0.38 metric tonnes C/ha-yr. This rate is based on the IPCC default method and country-specific factors (see Table A-237), by calculating the effect of converting nominal, medium-input grassland to high input improved grassland. The assumptions are that reference C stock are 50 metric tonnes C/ha, which represents a mid-range value of reference C stocks for the cropland soils in the United States,[104] that the land use factor for grassland of 1.4 and 1.11 for high input improved grassland are representative of typical conditions, and that the change in stocks are occurring over a 20 year (default value) time period (i.e., [50 × 1.4 × 1.11 – 50 × 1.4] / 20 = 0.38). A nominal ±50 percent uncertainty is attached to these estimates due to limited information on application and the rate of change in soil C stock change with sewage sludge amendments. The influence of sewage sludge on soil organic C stocks are provided in Table A-245.

The second activity is the change in enrollment for the Conservation Reserve Program after 2010 for mineral soils. Relative to the enrollment in 2010, the total area in the Conservation Reserve Program has decreased from 2011 to 2014 (USDA-FSA 2014). An average annual change in SOC of 0.5 metric tonnes C/ha-yr is used to estimate the effect of the enrollment changes. This rate is based on the IPCC default method and country-specific factors (see Table A-237) by estimating the impact of setting aside a medium input cropping system in the Conservation Reserve Program. The assumptions are that reference C stock are 50 metric tonnes C/ha, which represents a mid-range value for the dominant cropland soils in the United States, and the average country-specific factor is 1.2 for setting-aside cropland from production, with the change in stocks occurring over a 20 year (default value) time period equal to 0.5 (i.e., [50 × 1.2 – 50] / 20 = 0.5). A nominal ±50 percent uncertainty is attached to these estimates due to limited information about the enrollment trends at subregional scales, which creates uncertainty in the rate of soil C stock change (stock change factors for set-aside lands vary by climate region). Estimates are provided in Table A-252.

[104] Reference C stocks are based on cropland soils for the Tier 2 method applied in this Inventory.

Table A-239: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Non-Federal Cropland Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values (MMT CO_2 Eq./yr)

Non-Federal Croplands:	Cropland Remaining Cropland		Grassland Converted to Cropland		Forest Converted to Cropland		Other Land Converted to Cropland		Settlements Converted to Cropland		Wetlands Converted to Cropland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils												
1990	-6.13	(8.66) to (3.71)	1.31	(0.43) to 2.22	0.20	(0.07) to 0.34	0.16	(0.05) to 0.27	0.06	(0.02) to 0.11	0.11	(0.04) to 0.18
1991	-6.69	(9.39) to (4.11)	1.25	(0.43) to 2.23	0.18	(0.06) to 0.32	0.15	(0.05) to 0.26	0.06	(0.02) to 0.11	0.10	(0.03) to 0.18
1992	-6.69	(10.35) to (4.40)	1.31	(0.42) to 2.32	0.18	(0.06) to 0.31	0.16	(0.05) to 0.28	0.07	(0.02) to 0.12	0.10	(0.03) to 0.18
1993	-7.05	(10.12) to (4.05)	1.44	(0.41) to 2.50	0.17	(0.05) to 0.30	0.18	(0.05) to 0.32	0.07	(0.02) to 0.12	0.13	(0.04) to 0.22
1994	-6.91	(9.98) to (3.91)	1.44	(0.38) to 2.56	0.16	(0.04) to 0.28	0.20	(0.05) to 0.35	0.07	(0.02) to 0.13	0.14	(0.04) to 0.25
1995	-6.39	(9.26) to (3.59)	1.55	(0.38) to 2.68	0.17	(0.04) to 0.30	0.21	(0.05) to 0.36	0.07	(0.02) to 0.13	0.15	(0.04) to 0.27
1996	-6.04	(8.84) to (3.32)	1.77	(0.37) to 2.97	0.18	(0.04) to 0.30	0.24	(0.05) to 0.40	0.08	(0.02) to 0.14	0.17	(0.04) to 0.29
1997	-7.50	(11.01) to (4.13)	1.46	(0.32) to 2.65	0.14	(0.03) to 0.26	0.20	(0.04) to 0.36	0.06	(0.01) to 0.12	0.14	(0.03) to 0.25
1998	-7.20	(10.72) to (3.83)	1.50	(0.35) to 2.78	0.13	(0.03) to 0.24	0.20	(0.05) to 0.37	0.07	(0.02) to 0.13	0.14	(0.03) to 0.26
1999	-6.53	(9.82) to (3.38)	1.51	(0.27) to 2.80	0.12	(0.02) to 0.22	0.21	(0.04) to 0.39	0.07	(0.01) to 0.13	0.14	(0.02) to 0.26
2000	-6.96	(10.25) to (3.85)	1.41	(0.27) to 2.63	0.10	(0.02) to 0.18	0.21	(0.04) to 0.39	0.07	(0.01) to 0.13	0.13	(0.03) to 0.25
2001	-6.78	(9.99) to (3.77)	1.32	(0.26) to 2.54	0.08	(0.02) to 0.16	0.19	(0.04) to 0.37	0.06	(0.01) to 0.12	0.12	(0.02) to 0.24
2002	-6.68	(9.74) to (3.85)	1.12	(0.24) to 2.25	0.07	(0.01) to 0.13	0.16	(0.03) to 0.32	0.06	(0.01) to 0.11	0.10	(0.02) to 0.21
2003	-6.04	(8.92) to (3.36)	1.02	(0.23) to 2.07	0.06	(0.01) to 0.12	0.15	(0.03) to 0.30	0.05	(0.01) to 0.09	0.09	(0.02) to 0.19
2004	-5.43	(8.35) to (2.73)	1.14	(0.23) to 2.29	0.06	(0.01) to 0.12	0.16	(0.03) to 0.32	0.05	(0.01) to 0.10	0.10	(0.02) to 0.20
2005	-5.51	(8.26) to (2.97)	1.11	(0.24) to 2.24	0.06	(0.01) to 0.11	0.15	(0.03) to 0.30	0.05	(0.01) to 0.10	0.09	(0.02) to 0.19
2006	-4.58	(7.18) to (2.24)	1.34	(0.23) to 2.41	0.06	(0.01) to 0.12	0.19	(0.03) to 0.34	0.06	(0.01) to 0.11	0.11	(0.02) to 0.20
2007	-4.49	(6.96) to (2.29)	1.38	(0.21) to 2.41	0.04	(0.01) to 0.08	0.19	(0.03) to 0.33	0.07	(0.01) to 0.12	0.11	(0.02) to 0.19
2008	-3.85	(6.11) to (1.86)	1.37	(0.20) to 2.34	0.04	(0.01) to 0.08	0.19	(0.03) to 0.33	0.06	(0.01) to 0.11	0.10	(0.01) to 0.17
2009	-3.85	(6.09) to (1.89)	1.23	(0.18) to 2.18	0.04	(0.01) to 0.07	0.18	(0.03) to 0.31	0.05	(0.01) to 0.09	0.08	(0.01) to 0.15
2010	-3.90	(6.13) to (1.94)	1.24	(0.17) to 2.15	0.04	(0.01) to 0.07	0.18	(0.02) to 0.32	0.06	(0.01) to 0.11	0.08	(0.01) to 0.15
2011	-3.60	(5.71) to (1.80)	1.24	(0.17) to 2.16	0.04	(0.01) to 0.07	0.18	(0.02) to 0.32	0.06	(0.01) to 0.11	0.09	(0.01) to 0.15
2012	-3.26	(5.31) to (1.53)	1.25	(0.16) to 2.17	0.04	(0.01) to 0.07	0.18	(0.02) to 0.32	0.06	(0.01) to 0.11	0.09	(0.01) to 0.15
2013	-3.08	(5.10) to (1.37)	1.26	(0.16) to 2.18	0.04	(0.01) to 0.07	0.19	(0.02) to 0.32	0.06	(0.01) to 0.11	0.09	(0.01) to 0.15
2014	-3.11	(5.14) to (1.40)	1.27	(0.16) to 2.18	0.04	(0.01) to 0.07	0.19	(0.02) to 0.32	0.06	(0.01) to 0.11	0.09	(0.01) to 0.15

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-240: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Federal Cropland Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values (MMT CO_2 Eq./yr)

Federal Croplands:	Cropland Remaining Cropland		Grassland Converted to Cropland		Forest Converted to Cropland		Other Land Converted to Cropland		Settlements Converted to Cropland		Wetlands Converted to Cropland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils												
1990	-0.02	(0.06) to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1991	-0.04	(0.09) to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1992	-0.04	(0.15) to 0.03	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1993	-0.09	(0.19) to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1994	-0.10	(0.23) to 0.03	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1995	-0.10	(0.23) to 0.03	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1996	-0.10	(0.23) to 0.03	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1997	-0.23	(0.43) to (0.03)	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1998	-0.11	(0.20) to (0.02)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
1999	-0.10	(0.19) to (0.03)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2000	-0.10	(0.18) to (0.03)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2001	-0.10	(0.18) to (0.03)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2002	-0.09	(0.17) to (0.03)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2003	-0.10	(0.18) to (0.03)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2004	-0.11	(0.18) to (0.04)	0.05	0.03 to 0.08	0.01	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2005	-0.10	(0.17) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2006	-0.10	(0.17) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2007	-0.10	(0.17) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2008	-0.10	(0.17) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2009	-0.09	(0.15) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2010	-0.09	(0.14) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2011	-0.07	(0.12) to (0.04)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2012	-0.06	(0.10) to (0.03)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2013	-0.05	(0.08) to (0.03)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07
2014	-0.06	(0.09) to (0.03)	0.06	0.03 to 0.09	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.05	0.02 to 0.07

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-241: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Total Cropland Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values (MMT CO_2 Eq./yr)

Total Croplands:	Cropland Remaining Cropland		Grassland Converted to Cropland		Forest Converted to Cropland		Other Land Converted to Cropland		Settlements Converted to Cropland		Wetlands Converted to Cropland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils												
1990	-6.15	(8.68) to (3.74)	1.31	(0.43) to 2.22	0.20	(0.07) to 0.34	0.16	(0.05) to 0.27	0.06	(0.02) to 0.11	0.11	(0.04) to 0.18
1991	-6.73	(9.43) to (4.14)	1.25	(0.43) to 2.23	0.18	(0.06) to 0.32	0.15	(0.05) to 0.26	0.06	(0.02) to 0.11	0.10	(0.03) to 0.18
1992	-6.73	(10.41) to (4.46)	1.31	(0.42) to 2.32	0.18	(0.06) to 0.31	0.16	(0.05) to 0.28	0.07	(0.02) to 0.12	0.10	(0.03) to 0.18
1993	-7.14	(10.21) to (4.14)	1.44	(0.41) to 2.50	0.17	(0.05) to 0.30	0.18	(0.05) to 0.32	0.07	(0.02) to 0.12	0.13	(0.04) to 0.22
1994	-7.01	(10.08) to (4.01)	1.44	(0.38) to 2.56	0.16	(0.04) to 0.28	0.20	(0.05) to 0.35	0.07	(0.02) to 0.13	0.14	(0.04) to 0.25
1995	-6.49	(9.36) to (3.68)	1.55	(0.38) to 2.68	0.17	(0.04) to 0.30	0.21	(0.05) to 0.36	0.07	(0.02) to 0.13	0.15	(0.04) to 0.27
1996	-6.14	(8.94) to (3.41)	1.77	(0.37) to 2.97	0.18	(0.04) to 0.30	0.24	(0.05) to 0.40	0.08	(0.02) to 0.14	0.17	(0.04) to 0.29
1997	-7.72	(11.24) to (4.35)	1.46	(0.32) to 2.65	0.14	(0.03) to 0.26	0.20	(0.04) to 0.36	0.06	(0.01) to 0.12	0.14	(0.03) to 0.25
1998	-7.30	(10.83) to (3.93)	1.55	(0.30) to 2.83	0.14	(0.02) to 0.25	0.20	(0.05) to 0.37	0.07	(0.02) to 0.13	0.19	0.01 to 0.31
1999	-6.63	(9.92) to (3.49)	1.56	(0.22) to 2.85	0.12	(0.01) to 0.22	0.21	(0.04) to 0.39	0.07	(0.01) to 0.13	0.19	0.02 to 0.31
2000	-7.06	(10.35) to (3.95)	1.46	(0.22) to 2.69	0.10	(0.01) to 0.19	0.21	(0.04) to 0.39	0.07	(0.01) to 0.13	0.18	0.02 to 0.30
2001	-6.88	(10.09) to (3.87)	1.37	(0.20) to 2.60	0.09	(0.01) to 0.17	0.19	(0.04) to 0.38	0.06	(0.01) to 0.12	0.17	0.02 to 0.29
2002	-6.78	(9.84) to (3.94)	1.17	(0.19) to 2.30	0.07	(0.01) to 0.14	0.16	(0.03) to 0.32	0.06	(0.01) to 0.12	0.15	0.02 to 0.26
2003	-6.15	(9.02) to (3.46)	1.07	(0.18) to 2.12	0.07	(0.01) to 0.13	0.15	(0.03) to 0.30	0.05	(0.01) to 0.09	0.14	0.02 to 0.24
2004	-5.53	(8.46) to (2.83)	1.19	(0.17) to 2.34	0.07	(0.01) to 0.13	0.16	(0.03) to 0.32	0.05	(0.01) to 0.10	0.15	0.03 to 0.25
2005	-5.61	(8.37) to (3.07)	1.17	(0.18) to 2.29	0.06	(0.01) to 0.11	0.15	(0.03) to 0.30	0.05	(0.01) to 0.10	0.14	0.02 to 0.24
2006	-4.68	(7.28) to (2.34)	1.40	(0.18) to 2.46	0.07	(0.01) to 0.12	0.19	(0.03) to 0.34	0.06	(0.01) to 0.11	0.16	0.02 to 0.25
2007	-4.59	(7.06) to (2.39)	1.44	(0.16) to 2.46	0.04	(0.01) to 0.08	0.19	(0.03) to 0.33	0.07	(0.01) to 0.12	0.15	0.03 to 0.24
2008	-3.95	(6.21) to (1.96)	1.42	(0.14) to 2.39	0.04	(0.01) to 0.08	0.19	(0.03) to 0.33	0.06	(0.01) to 0.11	0.15	0.03 to 0.22
2009	-3.95	(6.18) to (1.98)	1.29	(0.13) to 2.24	0.04	(0.01) to 0.07	0.18	(0.03) to 0.31	0.05	(0.01) to 0.09	0.13	0.03 to 0.20
2010	-3.98	(6.22) to (2.02)	1.29	(0.11) to 2.21	0.04	0.0 to 0.07	0.18	(0.02) to 0.32	0.06	(0.01) to 0.11	0.13	0.03 to 0.20
2011	-3.68	(5.78) to (1.87)	1.30	(0.11) to 2.22	0.04	0.0 to 0.07	0.18	(0.02) to 0.32	0.06	(0.01) to 0.11	0.13	0.03 to 0.20
2012	-3.32	(5.37) to (1.59)	1.31	(0.11) to 2.23	0.04	0.0 to 0.07	0.19	(0.02) to 0.32	0.06	(0.01) to 0.11	0.13	0.03 to 0.20
2013	-3.13	(5.16) to (1.42)	1.32	(0.10) to 2.23	0.04	0.0 to 0.07	0.19	(0.02) to 0.32	0.06	(0.01) to 0.11	0.13	0.03 to 0.20
2014	-3.17	(5.20) to (1.45)	1.32	(0.10) to 2.24	0.04	0.0 to 0.07	0.19	(0.02) to 0.32	0.06	(0.01) to 0.11	0.13	0.03 to 0.20
Organic Soils												
1990	18.41	40.41 to 3.19	1.90	4.94 to 0.10	0.04	0.18 to 0.11	0.01	0.25 to 0.02	0.00	0.06 to 0.61	0.30	1.04 to 6.09
1991	18.07	39.89 to 3.20	1.91	4.91 to 0.10	0.04	0.18 to 0.11	0.01	0.25 to 0.02	0.00	0.06 to 0.62	0.30	1.04 to 5.99
1992	18.00	39.96 to 3.18	1.90	4.90 to 0.09	0.04	0.17 to 0.04	0.00	0.14 to 0.02	0.00	0.06 to 0.62	0.30	1.04 to 5.87
1993	17.70	39.55 to 3.13	1.86	4.82 to 0.09	0.04	0.16 to 0.09	0.00	0.23 to 0.03	0.01	0.07 to 0.74	0.39	1.18 to 5.82
1994	17.68	39.57 to 3.37	2.03	5.16 to 0.09	0.04	0.16 to 0.09	0.00	0.23 to 0.05	0.01	0.10 to 0.87	0.50	1.34 to 5.74
1995	17.68	39.81 to 3.71	2.20	5.71 to 0.09	0.04	0.16 to 0.09	0.00	0.23 to 0.04	0.01	0.09 to 0.90	0.53	1.38 to 5.59
1996	17.57	39.49 to 3.74	2.27	5.69 to 0.09	0.04	0.16 to 0.09	0.00	0.23 to 0.05	0.01	0.10 to 0.91	0.54	1.39 to 5.53
1997	17.47	39.47 to 3.78	2.29	5.73 to 0.08	0.04	0.15 to 0.09	0.00	0.23 to 0.04	0.01	0.09 to 0.91	0.54	1.39 to 5.40
1998	17.67	39.35 to 4.28	1.68	8.56 to 0.08	0.03	0.14 to 0.06	0.00	0.20 to 0.05	0.01	0.11 to 0.97	0.50	1.57 to 5.30

1999	17.18	38.38 to 4.40	1.78	8.72 to 0.07	0.03	0.13 to 0.06	0.00	0.20 to 0.05	0.01	0.11 to 0.94	0.47	1.53 to 5.18
2000	17.13	38.39 to 4.07	1.66	8.27 to 0.07	0.02	0.12 to 0.06	0.00	0.20 to 0.05	0.01	0.11 to 0.77	0.42	1.22 to 5.15
2001	17.60	39.65 to 5.45	1.71	12.90 to 0.06	0.02	0.12 to 0.06	0.00	0.20 to 0.05	0.01	0.11 to 0.80	0.45	1.24 to 4.72
2002	17.84	39.86 to 5.29	1.62	12.67 to 0.05	0.01	0.10 to 0.06	0.00	0.20 to 0.06	0.01	0.12 to 0.70	0.37	1.12 to 4.64
2003	18.02	40.19 to 5.14	1.53	12.37 to 0.04	0.01	0.09 to 0.06	0.00	0.20 to 0.06	0.01	0.11 to 0.62	0.34	0.97 to 4.55
2004	17.78	43.90 to 4.22	1.30	10.74 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.05	0.01	0.09 to 0.51	0.23	0.88 to 4.49
2005	17.80	43.72 to 4.18	1.29	10.66 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.07	0.02	0.14 to 0.51	0.23	0.87 to 4.46
2006	17.66	43.26 to 4.16	1.24	10.72 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.07	0.02	0.14 to 0.51	0.23	0.88 to 4.43
2007	17.62	40.81 to 4.03	1.16	10.57 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.07	0.02	0.14 to 0.51	0.23	0.87 to 4.43
2008	17.42	40.10 to 3.88	1.06	10.37 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.06	0.01	0.12 to 0.46	0.23	0.75 to 4.44
2009	17.69	41.11 to 3.68	0.87	10.06 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.06	0.01	0.13 to 0.43	0.21	0.71 to 4.42
2010	17.72	40.96 to 3.81	0.87	10.25 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.07	0.02	0.13 to 0.43	0.21	0.71 to 4.38
2011	17.74	41.22 to 3.81	0.88	10.37 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.08	0.02	0.15 to 0.43	0.21	0.71 to 4.36
2012	17.69	40.91 to 3.78	0.88	10.20 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.08	0.02	0.15 to 0.43	0.21	0.71 to 4.33
2013	17.77	40.93 to 3.81	0.89	10.27 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.08	0.02	0.15 to 0.43	0.21	0.71 to 4.33
2014	17.79	40.98 to 3.82	0.86	10.25 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.08	0.02	0.15 to 0.43	0.21	0.71 to 4.33

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-242: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Non-Federal Grasslands Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values (MMT CO_2 Eq./yr)

Non-Federal Grasslands:	Grassland Remaining Grassland		Cropland Converted to Grassland		Forest Converted to Grassland		Other Land Converted to Grassland		Settlements Converted to Grassland		Wetlands Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils												
1990	-0.27	(0.60) to 0.01	-3.14	(4.54) to (1.90)	-0.48	(0.69) to (0.29)	-0.62	(0.90) to (0.38)	-0.09	(0.13) to (0.05)	-0.47	(0.68) to (0.28)
1991	-0.27	(0.60) to 0.0	-3.07	(4.41) to (1.87)	-0.47	(0.68) to (0.29)	-0.64	(0.93) to (0.39)	-0.09	(0.13) to (0.06)	-0.59	(0.85) to (0.36)
1992	-0.27	(0.58) to 0.01	-2.97	(4.27) to (1.80)	-0.45	(0.64) to (0.27)	-0.68	(0.98) to (0.41)	-0.09	(0.14) to (0.06)	-0.61	(0.87) to (0.37)
1993	-0.26	(0.57) to 0.0	-3.30	(4.74) to (1.99)	-0.47	(0.67) to (0.28)	-0.83	(1.19) to (0.50)	-0.11	(0.16) to (0.07)	-0.64	(0.92) to (0.39)
1994	-0.24	(0.53) to 0.0	-3.41	(4.90) to (2.07)	-0.45	(0.65) to (0.27)	-0.95	(1.37) to (0.58)	-0.12	(0.17) to (0.07)	-0.65	(0.94) to (0.40)
1995	-0.24	(0.52) to 0.0	-3.25	(4.68) to (1.97)	-0.47	(0.68) to (0.29)	-0.98	(1.40) to (0.59)	-0.12	(0.17) to (0.07)	-0.62	(0.90) to (0.38)
1996	-0.24	(0.51) to 0.0	-3.05	(4.39) to (1.85)	-0.45	(0.65) to (0.27)	-0.94	(1.36) to (0.57)	-0.12	(0.18) to (0.07)	-0.61	(0.88) to (0.37)
1997	-0.20	(0.44) to 0.0	-2.90	(4.14) to (1.79)	-0.43	(0.61) to (0.26)	-0.99	(1.40) to (0.61)	-0.13	(0.18) to (0.08)	-0.61	(0.87) to (0.38)
1998	-0.15	(0.48) to 0.16	-3.19	(4.64) to (1.93)	-0.41	(0.60) to (0.25)	-1.07	(1.56) to (0.65)	-0.14	(0.21) to (0.09)	-0.60	(0.87) to (0.36)
1999	-0.08	(0.37) to 0.19	-2.87	(4.16) to (1.74)	-0.40	(0.57) to (0.24)	-1.07	(1.55) to (0.65)	-0.15	(0.22) to (0.09)	-0.59	(0.86) to (0.36)
2000	-0.08	(0.37) to 0.20	-3.06	(4.44) to (1.85)	-0.38	(0.55) to (0.23)	-1.16	(1.68) to (0.70)	-0.16	(0.23) to (0.10)	-0.61	(0.88) to (0.37)
2001	-0.07	(0.34) to 0.20	-2.89	(4.20) to (1.74)	-0.36	(0.53) to (0.22)	-1.19	(1.73) to (0.71)	-0.16	(0.24) to (0.10)	-0.59	(0.86) to (0.35)
2002	-0.05	(0.32) to 0.20	-2.64	(3.86) to (1.57)	-0.33	(0.49) to (0.20)	-1.12	(1.63) to (0.66)	-0.16	(0.24) to (0.10)	-0.54	(0.80) to (0.32)
2003	-0.05	(0.31) to 0.21	-2.40	(3.55) to (1.41)	-0.27	(0.39) to (0.16)	-1.04	(1.54) to (0.61)	-0.15	(0.22) to (0.09)	-0.52	(0.76) to (0.30)

2004	-0.04	(0.30) to 0.21	-2.67	(3.94) to (1.57)	-0.28	(0.41) to (0.16)	-1.09	(1.60) to (0.64)	-0.15	(0.23) to (0.09)	-0.55	(0.81) to (0.32)
2005	-0.06	(0.32) to 0.19	-2.46	(3.63) to (1.45)	-0.28	(0.41) to (0.16)	-1.08	(1.60) to (0.64)	-0.15	(0.23) to (0.09)	-0.53	(0.79) to (0.31)
2006	-0.06	(0.31) to 0.18	-2.05	(3.10) to (1.15)	-0.24	(0.36) to (0.13)	-0.95	(1.44) to (0.53)	-0.14	(0.21) to (0.08)	-0.47	(0.71) to (0.26)
2007	-0.04	(0.28) to 0.20	-1.73	(2.66) to (0.95)	-0.18	(0.27) to (0.10)	-0.89	(1.36) to (0.49)	-0.13	(0.20) to (0.07)	-0.43	(0.66) to (0.24)
2008	-0.01	(0.25) to 0.23	-1.58	(2.43) to (0.87)	-0.16	(0.24) to (0.09)	-0.85	(1.30) to (0.46)	-0.13	(0.19) to (0.07)	-0.33	(0.51) to (0.18)
2009	0.00	(0.24) to 0.24	-1.52	(2.34) to (0.83)	-0.16	(0.24) to (0.09)	-0.84	(1.29) to (0.46)	-0.12	(0.19) to (0.07)	-0.27	(0.41) to (0.15)
2010	0.01	(0.22) to 0.24	-1.45	(2.22) to (0.79)	-0.16	(0.24) to (0.09)	-0.83	(1.28) to (0.45)	-0.13	(0.19) to (0.07)	-0.23	(0.35) to (0.12)
2011	0.01	(0.21) to 0.24	-1.44	(2.21) to (0.78)	-0.16	(0.24) to (0.08)	-0.83	(1.28) to (0.45)	-0.13	(0.19) to (0.07)	-0.22	(0.34) to (0.12)
2012	0.02	(0.21) to 0.24	-1.43	(2.20) to (0.76)	-0.15	(0.24) to (0.08)	-0.82	(1.27) to (0.44)	-0.12	(0.19) to (0.07)	-0.22	(0.34) to (0.12)
2013	0.02	(0.21) to 0.25	-1.42	(2.19) to (0.76)	-0.15	(0.24) to (0.08)	-0.82	(1.26) to (0.44)	-0.12	(0.19) to (0.07)	-0.22	(0.34) to (0.12)
2014	0.02	(0.20) to 0.26	-1.42	(2.19) to (0.76)	-0.15	(0.24) to (0.08)	-0.82	(1.26) to (0.43)	-0.12	(0.19) to (0.07)	-0.22	(0.34) to (0.12)

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-243: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Federal Grasslands Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values (MMT CO_2 Eq./yr)

Federal Grasslands:	Grassland Remaining Grassland		Cropland Converted to Grassland		Forest Converted to Grassland		Other Land Converted to Grassland		Settlements Converted to Grassland		Wetlands Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils												
1990	-0.21	(8.71) to 9.11	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1991	-0.30	(9.01) to 8.48	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1992	-0.30	(9.83) to 7.79	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1993	-1.17	(10.81) to 7.36	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1994	-1.46	(11.45) to 6.94	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1995	-1.46	(11.63) to 6.81	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1996	-0.81	(10.24) to 6.85	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1997	-0.74	(10.05) to 7.06	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1998	-1.42	(12.70) to 6.88	-0.02	(0.05) to 0.0	-0.68	(1.55) to 0.13	-0.04	(0.10) to 0.01	0.00	0.0 to 0.0	-0.04	(0.09) to 0.01
1999	-1.27	(12.52) to 6.99	-0.02	(0.05) to 0.0	-0.69	(1.56) to 0.13	-0.04	(0.10) to 0.01	0.00	0.0 to 0.0	-0.04	(0.09) to 0.01
2000	-1.46	(11.84) to 6.24	-0.02	(0.05) to 0.0	-0.69	(1.55) to 0.12	-0.04	(0.10) to 0.01	0.00	0.0 to 0.0	-0.04	(0.09) to 0.01
2001	-1.45	(11.92) to 6.34	-0.02	(0.05) to 0.0	-0.68	(1.55) to 0.12	-0.04	(0.10) to 0.01	0.00	0.0 to 0.0	-0.04	(0.09) to 0.01
2002	-2.46	(13.81) to 6.87	-0.02	(0.05) to 0.0	-0.70	(1.50) to 0.05	-0.05	(0.10) to 0.0	0.00	0.0 to 0.0	-0.04	(0.09) to 0.0
2003	-2.51	(13.94) to 7.52	-0.02	(0.05) to 0.0	-0.69	(1.49) to 0.05	-0.04	(0.10) to 0.0	0.00	0.0 to 0.0	-0.04	(0.09) to 0.0
2004	-1.21	(10.83) to 8.60	-0.02	(0.05) to 0.0	-0.69	(1.49) to 0.06	-0.04	(0.10) to 0.0	0.00	0.0 to 0.0	-0.04	(0.09) to 0.0
2005	-1.27	(10.93) to 8.31	0.00	0.0 to 0.0	-0.71	(1.68) to 0.20	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2006	-1.39	(11.27) to 8.31	0.00	0.0 to 0.0	-0.71	(1.68) to 0.19	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2007	-1.49	(11.36) to 7.92	0.00	0.0 to 0.0	-0.71	(1.67) to 0.20	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2008	-1.53	(11.51) to 8.04	0.00	0.0 to 0.0	-0.70	(1.67) to 0.20	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2009	-1.30	(10.95) to 7.01	0.00	0.0 to 0.0	-0.69	(1.66) to 0.21	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2010	-1.37	(10.93) to 7.36	0.00	0.0 to 0.0	-0.68	(1.65) to 0.22	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01

2011	-1.00	(10.18) to 7.87	0.00	0.0 to 0.0	-0.67	(1.64) to 0.23	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2012	-0.52	(9.34) to 8.61	0.00	0.0 to 0.0	-0.66	(1.63) to 0.24	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2013	-0.28	(8.76) to 9.05	0.00	0.0 to 0.0	-0.66	(1.63) to 0.25	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01
2014	-0.28	(8.84) to 9.23	0.00	0.0 to 0.0	-0.66	(1.63) to 0.25	-0.01	(0.02) to 0.0	0.00	0.0 to 0.0	-0.02	(0.05) to 0.01

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-244: Annual Change in Soil Organic Carbon Stocks (95% Confidence Interval) for the Total Grassland Land Base Estimated with the Tier 2 Analysis using U.S. Factor Values (MMT CO_2 Eq./yr)

Total Grasslands:	Grassland Remaining Grassland		Cropland Converted to Grassland		Forest Converted to Grassland		Other Land Converted to Grassland		Settlements Converted to Grassland		Wetlands Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils												
1990	-0.48	(8.98) to 8.84	-3.14	(4.54) to (1.90)	-0.48	(0.69) to (0.29)	-0.62	(0.90) to (0.38)	-0.09	(0.13) to (0.05)	-0.47	(0.68) to (0.28)
1991	-0.58	(9.29) to 8.21	-3.07	(4.41) to (1.87)	-0.47	(0.68) to (0.29)	-0.64	(0.93) to (0.39)	-0.09	(0.13) to (0.06)	-0.59	(0.85) to (0.36)
1992	-0.58	(10.09) to 7.53	-2.97	(4.27) to (1.80)	-0.45	(0.64) to (0.27)	-0.68	(0.98) to (0.41)	-0.09	(0.14) to (0.06)	-0.61	(0.87) to (0.37)
1993	-1.42	(11.08) to 7.10	-3.30	(4.74) to (1.99)	-0.47	(0.67) to (0.28)	-0.83	(1.19) to (0.50)	-0.11	(0.16) to (0.07)	-0.64	(0.92) to (0.39)
1994	-1.70	(11.69) to 6.71	-3.41	(4.90) to (2.07)	-0.45	(0.65) to (0.27)	-0.95	(1.37) to (0.58)	-0.12	(0.17) to (0.07)	-0.65	(0.94) to (0.40)
1995	-1.70	(11.87) to 6.57	-3.25	(4.68) to (1.97)	-0.47	(0.68) to (0.29)	-0.98	(1.40) to (0.59)	-0.12	(0.17) to (0.07)	-0.62	(0.90) to (0.38)
1996	-1.04	(10.48) to 6.62	-3.05	(4.39) to (1.85)	-0.45	(0.65) to (0.27)	-0.94	(1.36) to (0.57)	-0.12	(0.18) to (0.07)	-0.61	(0.88) to (0.37)
1997	-0.94	(10.25) to 6.86	-2.90	(4.14) to (1.79)	-0.43	(0.61) to (0.26)	-0.99	(1.40) to (0.61)	-0.13	(0.18) to (0.08)	-0.61	(0.87) to (0.38)
1998	-1.57	(12.85) to 6.73	-3.21	(4.66) to (1.95)	-1.09	(1.98) to (0.26)	-1.12	(1.61) to (0.69)	-0.15	(0.21) to (0.09)	-0.64	(0.91) to (0.40)
1999	-1.35	(12.60) to 6.91	-2.89	(4.18) to (1.76)	-1.09	(1.97) to (0.26)	-1.12	(1.60) to (0.69)	-0.15	(0.22) to (0.09)	-0.63	(0.90) to (0.39)
2000	-1.54	(11.92) to 6.16	-3.08	(4.46) to (1.88)	-1.07	(1.95) to (0.25)	-1.20	(1.72) to (0.74)	-0.16	(0.23) to (0.10)	-0.65	(0.93) to (0.40)
2001	-1.52	(12.0) to 6.27	-2.92	(4.23) to (1.76)	-1.05	(1.92) to (0.23)	-1.23	(1.77) to (0.76)	-0.16	(0.24) to (0.10)	-0.63	(0.90) to (0.39)
2002	-2.52	(13.87) to 6.82	-2.66	(3.89) to (1.59)	-1.03	(1.85) to (0.27)	-1.16	(1.68) to (0.71)	-0.16	(0.24) to (0.10)	-0.59	(0.84) to (0.36)
2003	-2.56	(13.99) to 7.48	-2.43	(3.57) to (1.44)	-0.96	(1.77) to (0.20)	-1.09	(1.58) to (0.65)	-0.15	(0.22) to (0.09)	-0.56	(0.81) to (0.34)
2004	-1.25	(10.87) to 8.56	-2.69	(3.96) to (1.59)	-0.97	(1.78) to (0.21)	-1.13	(1.65) to (0.68)	-0.15	(0.23) to (0.09)	-0.59	(0.85) to (0.36)
2005	-1.33	(10.99) to 8.25	-2.46	(3.63) to (1.45)	-0.99	(1.97) to (0.07)	-1.09	(1.61) to (0.65)	-0.15	(0.23) to (0.09)	-0.55	(0.81) to (0.33)
2006	-1.45	(11.33) to 8.26	-2.05	(3.10) to (1.15)	-0.95	(1.93) to (0.04)	-0.96	(1.45) to (0.54)	-0.14	(0.21) to (0.08)	-0.49	(0.73) to (0.28)
2007	-1.53	(11.40) to 7.89	-1.74	(2.66) to (0.95)	-0.88	(1.86) to 0.03	-0.90	(1.37) to (0.50)	-0.13	(0.20) to (0.07)	-0.45	(0.69) to (0.26)
2008	-1.54	(11.53) to 8.03	-1.58	(2.43) to (0.87)	-0.86	(1.83) to 0.05	-0.86	(1.31) to (0.47)	-0.13	(0.19) to (0.07)	-0.35	(0.54) to (0.20)
2009	-1.30	(10.95) to 7.01	-1.52	(2.34) to (0.83)	-0.85	(1.82) to 0.06	-0.85	(1.30) to (0.47)	-0.12	(0.19) to (0.07)	-0.29	(0.43) to (0.16)
2010	-1.36	(10.92) to 7.37	-1.45	(2.23) to (0.79)	-0.84	(1.81) to 0.07	-0.84	(1.29) to (0.46)	-0.13	(0.19) to (0.07)	-0.24	(0.37) to (0.14)
2011	-0.98	(10.17) to 7.89	-1.44	(2.22) to (0.78)	-0.83	(1.80) to 0.08	-0.84	(1.29) to (0.46)	-0.13	(0.19) to (0.07)	-0.24	(0.37) to (0.14)
2012	-0.51	(9.33) to 8.63	-1.43	(2.20) to (0.77)	-0.81	(1.78) to 0.09	-0.83	(1.28) to (0.45)	-0.12	(0.19) to (0.07)	-0.24	(0.36) to (0.13)
2013	-0.26	(8.75) to 9.07	-1.42	(2.20) to (0.76)	-0.81	(1.78) to 0.10	-0.83	(1.27) to (0.45)	-0.12	(0.19) to (0.07)	-0.24	(0.36) to (0.13)
2014	-0.26	(8.81) to 9.26	-1.42	(2.19) to (0.76)	-0.81	(1.78) to 0.10	-0.83	(1.27) to (0.44)	-0.12	(0.19) to (0.07)	-0.24	(0.36) to (0.13)
Organic Soils												
1990	3.46	9.59 to 0.54	0.23	.98 to 0.01	0.00	0.03 to 0.03	0.01	0.06 to 0.0	0.00	0.0 to 0.08	0.01	0.20 to 0.0
1991	3.39	9.47 to 0.53	0.23	.97 to 0.01	0.00	0.03 to 0.03	0.01	0.06 to 0.0	0.00	0.0 to 0.08	0.01	0.20 to 0.0
1992	3.31	9.25 to 0.53	0.23	.97 to 0.01	0.00	0.03 to 0.02	0.00	0.05 to 0.0	0.00	0.0 to 0.09	0.01	0.22 to 0.0

1993	3.29	9.19 to 0.64	0.29	1.15 to 0.02	0.01	0.04 to 0.02	0.00	0.06 to 0.01	0.00	0.02 to 0.15	0.05	0.30 to 0.0
1994	3.25	9.07 to 0.73	0.32	1.32 to 0.02	0.01	0.04 to 0.02	0.00	0.05 to 0.01	0.00	0.02 to 0.18	0.07	0.32 to 0.0
1995	3.15	8.84 to 0.74	0.33	1.34 to 0.02	0.01	0.04 to 0.02	0.00	0.05 to 0.01	0.00	0.02 to 0.18	0.07	0.33 to 0.0
1996	3.14	8.74 to 0.72	0.32	1.29 to 0.02	0.01	0.03 to 0.02	0.00	0.05 to 0.01	0.00	0.02 to 0.18	0.08	0.33 to 0.0
1997	3.06	8.53 to 0.70	0.31	1.27 to 0.02	0.01	0.03 to 0.01	0.00	0.04 to 0.01	0.00	0.02 to 0.18	0.08	0.34 to 0.0
1998	2.82	8.61 to 0.82	0.38	1.46 to 0.02	0.00	0.06 to 0.01	0.00	0.04 to 0.01	0.00	0.03 to 0.19	0.10	0.31 to 0.0
1999	2.74	8.44 to 0.76	0.35	1.35 to 0.02	0.00	0.05 to 0.01	0.00	0.04 to 0.01	0.00	0.03 to 0.19	0.10	0.31 to 0.0
2000	2.72	8.43 to 0.82	0.39	1.44 to 0.02	0.00	0.06 to 0.01	0.00	0.04 to 0.01	0.00	0.03 to 0.19	0.10	0.31 to 0.0
2001	2.54	7.63 to 0.89	0.43	1.57 to 0.02	0.00	0.06 to 0.01	0.00	0.04 to 0.01	0.00	0.03 to 0.19	0.10	0.31 to 0.0
2002	2.49	7.50 to 0.98	0.46	1.74 to 0.02	0.00	0.06 to 0.01	0.00	0.05 to 0.01	0.00	0.03 to 0.17	0.08	0.29 to 0.0
2003	2.43	7.35 to 0.91	0.42	1.62 to 0.02	0.00	0.06 to 0.01	0.00	0.04 to 0.01	0.00	0.03 to 0.15	0.08	0.24 to 0.0
2004	2.31	7.38 to 1.01	0.41	1.89 to 0.02	0.00	0.06 to 0.0	0.00	0.0 to 0.01	0.00	0.03 to 0.16	0.09	0.27 to 0.0
2005	2.30	7.38 to 1.02	0.41	1.91 to 0.02	0.00	0.06 to 0.0	0.00	0.0 to 0.01	0.00	0.03 to 0.19	0.10	0.31 to 0.0
2006	2.28	7.37 to 0.99	0.39	1.85 to 0.02	0.00	0.06 to 0.0	0.00	0.0 to 0.01	0.00	0.03 to 0.22	0.11	0.38 to 0.0
2007	2.26	7.34 to 0.97	0.38	1.82 to 0.01	0.00	0.05 to 0.0	0.00	0.0 to 0.01	0.00	0.03 to 0.25	0.13	0.43 to 0.0
2008	2.27	7.35 to 0.95	0.37	1.81 to 0.02	0.00	0.05 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.26	0.13	0.44 to 0.0
2009	2.28	7.35 to 1.18	0.43	2.33 to 0.0	0.00	0.01 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.30	0.15	0.52 to 0.0
2010	2.25	7.25 to 1.14	0.42	2.25 to 0.0	0.00	0.01 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.30	0.15	0.52 to 0.0
2011	2.23	7.20 to 1.16	0.43	2.29 to 0.0	0.00	0.01 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.30	0.15	0.52 to 0.0
2012	2.23	7.19 to 1.15	0.43	2.24 to 0.0	0.00	0.01 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.30	0.15	0.52 to 0.0
2013	2.23	7.16 to 1.16	0.44	2.27 to 0.0	0.00	0.01 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.30	0.15	0.52 to 0.0
2014	2.23	7.18 to 1.16	0.42	2.27 to 0.0	0.00	.01 to 0.01	0.00	0.03 to 0.01	0.00	0.03 to 0.30	0.15	0.52 to 0.0

Note: Estimates after 2010 are based on NRI data from 2010 and therefore do not fully reflect changes occurring in the latter part of the time series.

Step 3: Estimate Soil Organic C Stock Changes and Direct N_2O Emissions from Organic Soils

In this step, soil organic C losses and N_2O emissions are estimated for organic soils that are drained for agricultural production.

Step 3a: Direct N_2O Emissions Due to Drainage of Organic Soils in Cropland and Grassland

To estimate annual N_2O emissions from drainage of organic soils in cropland and grassland, the area of drained organic soils in croplands and grasslands for temperate regions is multiplied by the IPCC (2006) default emission factor for temperate soils and the corresponding area in sub-tropical regions is multiplied by the average (12 kg N_2O-N/ha cultivated) of IPCC (2006) default emission factors for temperate (8 kg N_2O-N/ha cultivated) and tropical (16 kg N_2O-N/ha cultivated) organic soils. The uncertainty is determined based on simple error propagation methods (IPCC 2006), including uncertainty in the default emission factor ranging from 2–24 kg N_2O-N/ha (IPCC 2006).

Step 3b: Soil Organic C Stock Changes Due to Drainage of Organic Soils in Cropland and Grassland

Change in soil organic C stocks due to drainage of cropland and grassland soils are estimated annually from 1990 through 2010, based on the land-use and management activity data in conjunction with appropriate loss rate emission factors. The activity data are based on annual data from 1990 through 2010 from the NRI. The results for 2010 are applied to the years 2011 through 2014. Organic Soil emission factors representative of U.S. conditions have been estimated from published studies (Ogle et al. 2003), based on subsidence studies in the United States and Canada (Table A-246). PDFs are constructed as normal densities based on the mean C loss rates and associated variances. Input values are randomly selected from PDFs in a Monte Carlo analysis to estimate SOC change for 50,000 times and produce a 95 percent confidence interval for the inventory results. Losses of soil organic C from drainage of cropland and grassland soils are provided in Table A-239 and Table A-242.

Step 4: Estimate Indirect N_2O Emissions for Croplands and Grasslands

In this step, N_2O emissions are estimated for the two indirect emission pathways (N_2O emissions due to volatilization, and N_2O emissions due to leaching and runoff of N), which are summed to yield total indirect N_2O emissions from croplands and grasslands.

Step 4a: Indirect Soil N_2O Emissions Due to Volatilization

Indirect emissions from volatilization of N inputs from synthetic and commercial organic fertilizers, and PRP manure, are calculated according to the amount of mineral N that is transported in gaseous forms from the soil profile and later emitted as soil N_2O following atmospheric deposition. See Step 1e for additional information about the methods used to compute N losses due to volatilization. The estimated N volatilized is multiplied by the IPCC default emission factor of 0.01 kg N_2O-N/kg N (IPCC 2006) to estimate total N_2O emissions from volatilization. The uncertainty is estimated using simple error propagation methods (IPCC 2006), by combining uncertainties in the amount of N volatilized, with uncertainty in the default emission factor ranging from 0.002–0.05 kg N_2O-N/kg N (IPCC 2006). The estimates and uncertainties are provided in Table A-247.

Step 4b: Indirect Soil N_2O Emissions Due to Leaching and Runoff

The amount of mineral N from synthetic fertilizers, commercial organic fertilizers, PRP manure, crop residue, N mineralization, asymbiotic fixation that is transported from the soil profile in aqueous form is used to calculate indirect emissions from leaching of mineral N from soils and losses in runoff of water associated with overland flow. See Step 1e for additional information about the methods used to compute N losses from soils due to leaching and runoff in overland water flows. The total amount of N transported from soil profiles through leaching and surface runoff is multiplied by the IPCC default emission factor of 0.0075 kg N_2O-N/kg N (IPCC 2006) to estimate emissions for this source. The emission estimates are provided in Table A-248. The uncertainty is estimated based on simple error propagation methods (IPCC 2006), including uncertainty in the default emission factor ranging from 0.0005 to 0.025 kg N_2O-N/kg N (IPCC 2006).

Step 5: Estimate Total Soil Organic C Stock Changes and N_2O Emissions for U.S. Soils

Step 5a: Estimate Total Soil N_2O Emissions

Total N_2O emissions are estimated by adding total direct emissions (from mineral cropland soils, drainage and cultivation of organic soils, and grassland management) to indirect emissions. Uncertainties in the final estimate are combined using simple error propagation methods (IPCC 2006), and expressed as a 95 percent confidence interval. Estimates are provided in Table A-249.

Direct and indirect simulated emissions of soil N_2O vary regionally in croplands as a function of N input amount and timing of fertilization, tillage intensity, crop rotation sequence, weather, and soil type. Note that there are other management practices, such as fertilizer formulation (Halvorson et al. 2013), that influence emissions but are not represented in the model simulations. The highest total N_2O emissions occur in Iowa, Illinois, Kansas, Minnesota, Nebraska and Texas (Table A-251). On a per area unit basis, direct N_2O emissions are high in the Midwest, Northeast and many of the Mississippi River Basin states where there are high N inputs to hay, corn and soybean crops, and in some western states where irrigated crops are grown that require high N inputs (Figure A-16). Note that although the total crop area in the northeast is relatively low, emissions are high on a per unit area basis because a large portion of the cropland area in these states is used for hay production that receives large N inputs from both fertilizer and symbiotic fixation. Indirect emissions also tend to be high on a per unit of area basis in the Midwest, some Northeastern states and Florida (Figure A-17). In Florida, the high emission rates are driven by relatively high rainfall and coarse textured soils that facilitate N losses from leaching and runoff. Some Great Plains states also have indirect emissions where irrigation can contribute to leaching and runoff.

Direct and indirect emissions from non-federal grasslands are typically lower than the emissions from croplands (Table A-251, Figure A-18, and Figure A-19) because N inputs tend to be lower, particularly from synthetic fertilizer. Texas, Oklahoma, Kansas, Nebraska, Missouri, South Dakota and Montana are the highest emitters for this category due to large land areas used for pastures and rangeland (Table A-251). On a per unit of area basis, direct N_2O emissions are higher in the Northeastern United States, Lower Mississippi River Basin, some of the Great Lakes and Midwestern states because these grasslands are more intensively managed (legume seeding, fertilization) while western rangelands receive few, if any, N inputs (Figure A-18). Also, rainfall is limited in most of the western United States, and grasslands are not typically irrigated so minimal leaching and runoff of N occurs in these grasslands, and therefore there are lower indirect N_2O emissions (Figure A-19).

Figure A-16: Tier 3 Cropland,2014 Annual Direct N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)

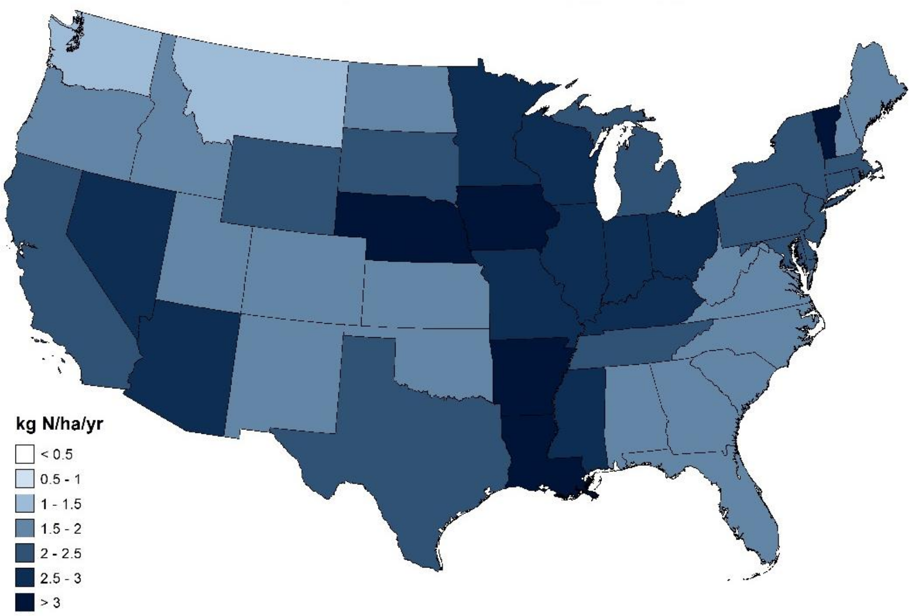


Figure A-17: Tier 3 Crops, 2014 Annual N Losses Leading to Indirect N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)

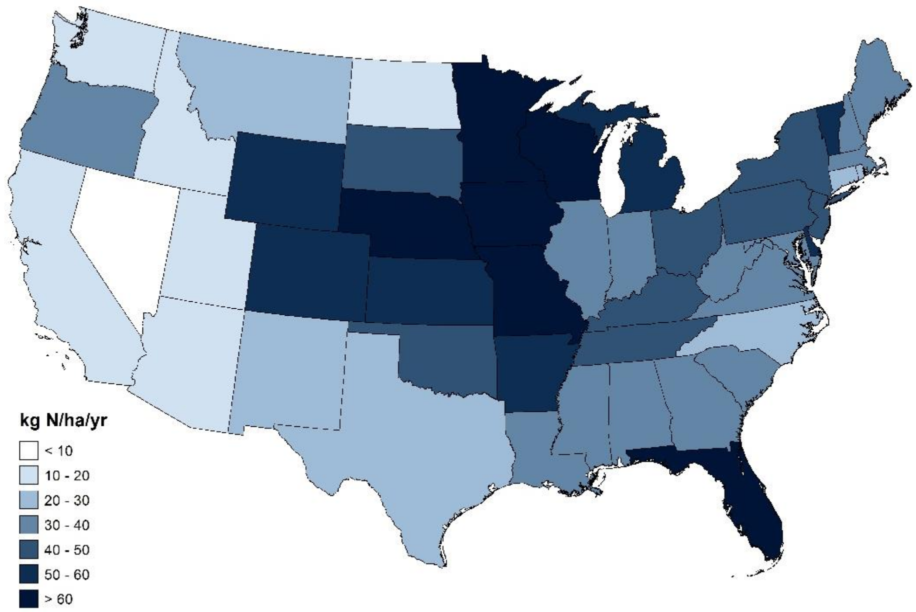


Figure A-18: Non-federal Grasslands, 2014 Annual Direct N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)

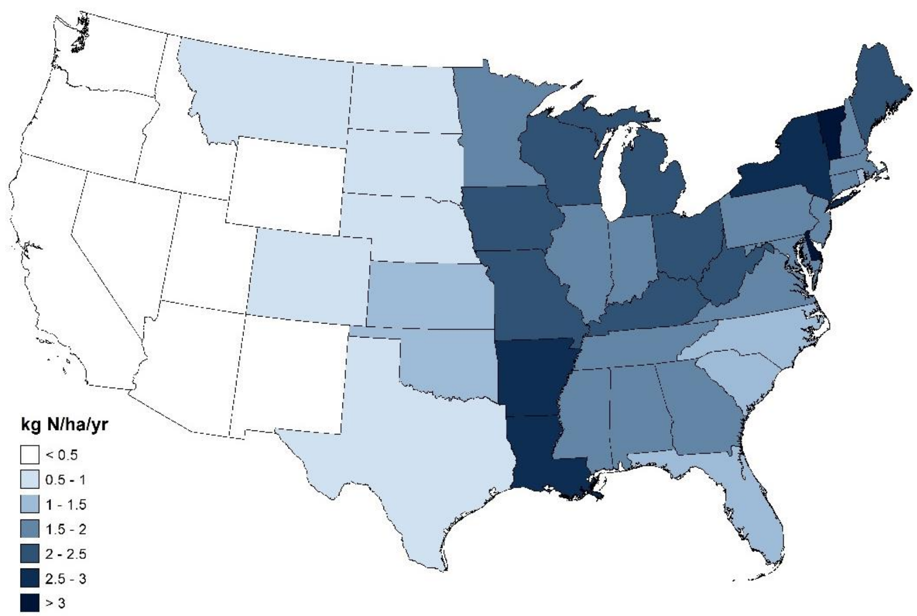
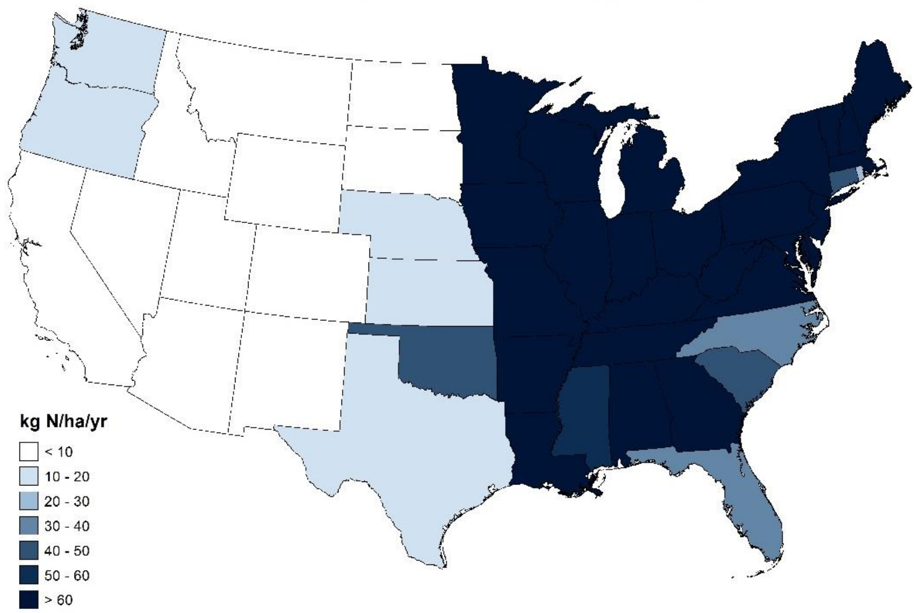


Figure A-19: Non-federal Grasslands, 2014 Annual N Losses Leading to Indirect N_2O Emissions, Estimated Using the DAYCENT Model, (kg N/ha/year)



Step 5b: Estimate Total Soil Organic Stock Change

The sum of total CO_2 emissions and removals from the Tier 3 DAYCENT Model Approach, Tier 2 IPCC Methods and additional land-use and management considerations are provided in Table A-252. The total change in soil organic C stocks (as seen in the *Land Use, Land-Use Change, and Forestry* chapter) as well as per hectare rate of change varies among the states (Figure A-20 and Figure A-21). The states with highest total amounts of C sequestration are California, Illinois, Iowa, Kentucky, Missouri, North Dakota and Tennessee (Table A-253). On a per hectare basis, the highest rates of C accumulation occur in states found in the Southeast, Northeast, Midwest and Pacific Coast. For organic soils, emission rates are highest in the regions that contain the majority of drained organic soils, including California, Florida, Indiana, Michigan, Minnesota, North Carolina and Wisconsin. On a per unit of area basis, the emission rate patterns are very similar to the total emissions in each state, with the highest rates in coastal states of the Southeast, states surrounding the Great Lakes, and California.

Figure A-20: Net C Stock Change, per Hectare, for Mineral Soils Under Agricultural Management, 2014

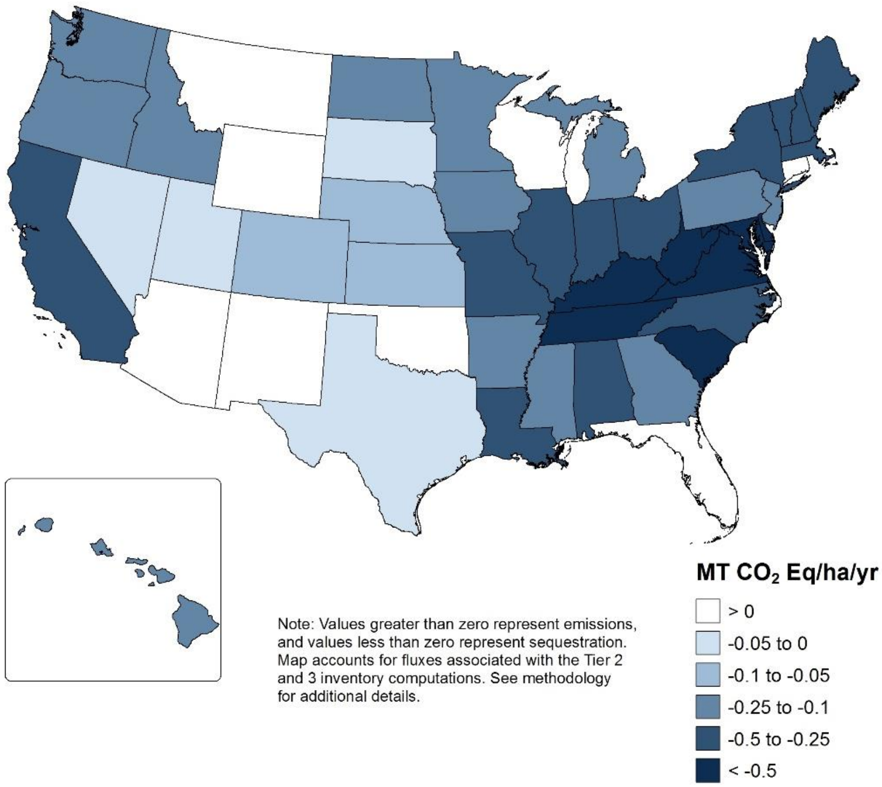
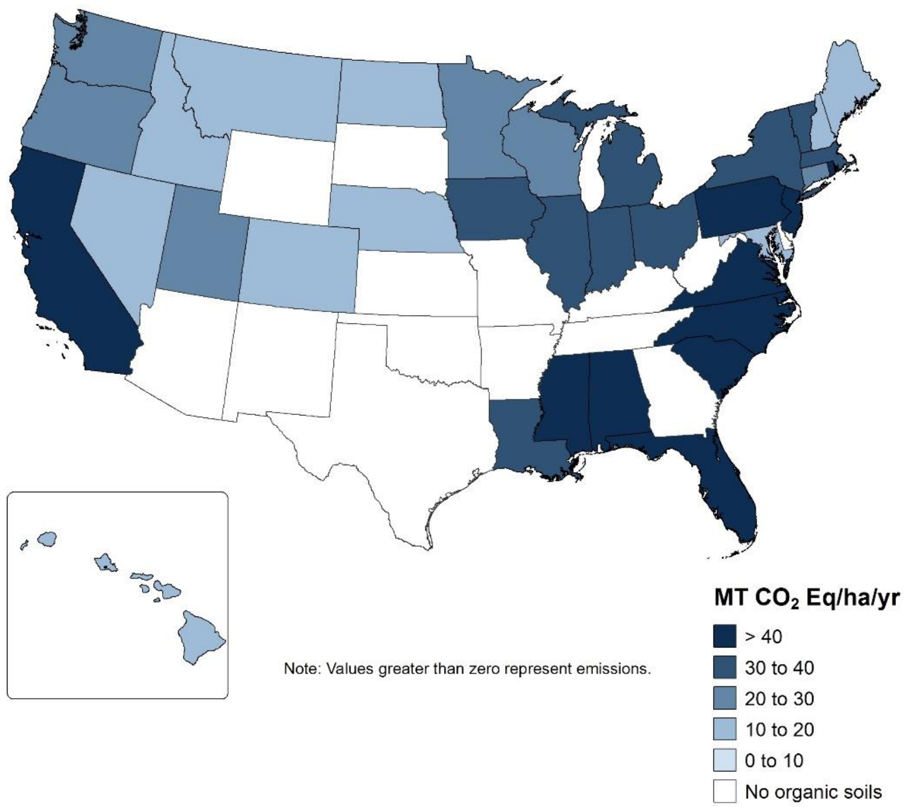


Figure A-21: Net C Stock Change, per Hectare, for Organic Soils Under Agricultural Management, 2014



Step 5c: Estimate Total CH_4 Emissions from Rice Cultivation

The sum of total CH_4 emissions from the Tier 3 DAYCENT Model Approach and Tier 1 IPCC Methods are provided in Table A-250. The states with highest total emissions are Arkansas, California, Louisiana and Texas (Table A-254). These states also have the largest areas of rice cultivation, and Louisiana and Texas have a relatively large proportion of fields with a second ratoon crop each year. Ratoon crops extend the period of time under flooded conditions, which leads to more CH_4 emissions.

Table A-245: Assumptions and Calculations to Estimate the Contribution to Soil Organic Carbon Stocks from Application of Sewage Sludge to Mineral Soils

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Sewage Sludge N Applied to Agricultural Land (Mg N)[a]	51,848	55,107	58,480	61,971	64,721	67,505	72,081	75,195	78,353	80,932	83,523	86,124
Assimilative Capacity (Mg N/ha)b	0.120	0.120	0.120	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
Area covered by Available Sewage Sludge N (ha)[c]	432,067	459,226	487,336	507,957	530,503	553,322	590,828	616,357	642,240	663,381	684,612	705,932
Average Annual Rate of C storage (Mg C/ha-yr)[d]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Contribution to Soil C (MMT CO_2/yr)[e,f]	**(0.60)**	**(0.64)**	**(0.68)**	**(0.71)**	**(0.74)**	**(0.77)**	**(0.82)**	**(0.86)**	**(0.89)**	**(0.92)**	**(0.95)**	**(0.98)**

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Sewage Sludge N Applied to Agricultural Land (Mg N)[a]	88,736	91,358	93,991	98,400	101,314	104,222	107,123	110,018	112,909	115,797	118,681	121,563	121,563
Assimilative Capacity (Mg N/ha)[b]	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
Area covered by Available Sewage Sludge N (ha)[c]	727,341	748,836	770,418	806,559	830,447	854,276	878,055	901,790	925,487	949,154	972,796	996,417	996,417
Average Annual Rate of C storage (Mg C/ha-yr)[d]	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Contribution to Soil C (MMT CO_2/yr)[e,f]	**(1.01)**	**(1.04)**	**(1.07)**	**(1.12)**	**(1.16)**	**(1.19)**	**(1.22)**	**(1.26)**	**(1.29)**	**(1.32)**	**(1.36)**	**(1.39)**	**(1.39)**

[a] N applied to soils described in Step 1d.
[b] Assimilative Capacity is the national average amount of manure-derived N that can be applied on cropland without buildup of nutrients in the soil (Kellogg et al., 2000).
[c] Area covered by sewage sludge N available for application to soils is the available N applied at the assimilative capacity rate. The 1992 assimilative capacity rate was applied to 1990 – 1992 and the 1997 rate was applied to 1993-2014.
[d] Annual rate of C storage based on national average increase in C storage for grazing lands that is attributed to organic matter amendments (0.38 Mg/ha-yr)
[e] Contribution to Soil C is estimated as the product of the area covered by the available sewage sludge N and the average annual C storage attributed to an organic matter amendment.
[f] Some small, undetermined fraction of this applied N is probably not applied to agricultural soils, but instead is applied to forests, home gardens, and other lands.
Note: Values in parentheses indicate net C storage.

Table A-246: Carbon Loss Rates for Organic Soils Under Agricultural Management in the United States, and IPCC Default Rates (Metric Ton C/ha-yr)

		Cropland		Grassland
Region	**IPCC**	**U.S. Revised**	**IPCC**	**U.S. Revised**
Cold Temperate, Dry & Cold Temperate, Moist	1	11.2±2.5	0.25	2.8±0.5[a]
Warm Temperate, Dry & Warm Temperate, Moist	10	14.0±2.5	2.5	3.5±0.8[a]
Sub-Tropical, Dry & Sub-Tropical, Moist	1	11.2±2.5	0.25	2.8±0.5[a]

[a] There are not enough data available to estimate a U.S. value for C losses from grassland. Consequently, estimates are 25 percent of the values for cropland, which is an assumption that is used for the IPCC default organic soil C losses on grassland.

Table A-247: Indirect N_2O Emissions from Volatilization (MMT CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Croplands	13.0	13.2	12.8	12.8	13.8	14.3	14.0	14.1	14.5	13.6	13.4	13.5	13.7	14.1	13.8	13.8	14.4	14.0	14.1	13.4	13.9	14.3	14.5	14.2	14.2
Grasslands	4.4	4.4	4.4	4.4	4.5	4.7	4.7	4.7	4.8	4.4	4.2	4.3	4.4	4.6	4.9	4.7	4.7	4.7	4.7	4.7	4.8	4.7	4.6	4.5	4.5
Total	**17.3**	**17.5**	**17.2**	**17.3**	**18.3**	**19.0**	**18.7**	**18.7**	**19.3**	**18.0**	**17.7**	**17.9**	**18.0**	**18.7**	**18.7**	**18.5**	**19.1**	**18.7**	**18.7**	**18.1**	**18.6**	**18.9**	**19.1**	**18.8**	**18.7**

Table A-248: Indirect N_2O Emissions from Leaching and Runoff (MMT CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Croplands	23.2	18.7	21.7	32.0	14.7	24.5	22.2	19.2	26.0	20.8	16.4	20.8	19.4	18.6	24.5	20.2	22.1	25.1	22.6	22.4	25.8	26.4	26.6	26.0	26.0
Grasslands	17.7	13.5	15.5	16.2	13.0	14.6	18.7	12.6	15.9	12.3	13.1	16.9	16.3	14.6	19.2	10.2	16.3	13.7	15.5	20.2	12.4	13.2	12.9	12.6	12.6
Total	**40.9**	**32.1**	**37.1**	**48.2**	**27.8**	**39.1**	**40.9**	**31.7**	**41.9**	**33.0**	**29.6**	**37.6**	**35.7**	**33.3**	**43.7**	**30.4**	**38.3**	**38.7**	**38.1**	**42.6**	**38.2**	**39.6**	**39.4**	**38.7**	**38.6**

Table A-249: Total N_2O Emissions from Agricultural Soil Management (MMT CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Total Direct	**245.0**	**241.9**	**243.5**	**245.1**	**243.0**	**243.7**	**248.8**	**246.8**	**261.5**	**241.8**	**245.4**	**242.2**
Direct Emissions from Mineral Cropland Soils	**168.6**	**165.5**	**166.2**	**167.2**	**168.0**	**166.2**	**168.4**	**167.2**	**177.7**	**169.0**	**171.1**	**167.7**
Synthetic Fertilizer	59.2	58.8	60.8	58.3	63.3	57.3	62.4	60.7	61.4	59.5	61.7	58.6
Organic Amendment[a]	11.9	12.0	12.2	11.9	12.4	12.3	12.4	12.5	12.7	12.7	13.0	12.8
Residue N[b]	25.9	28.1	25.9	26.3	25.5	27.5	26.7	26.4	25.6	28.9	27.6	26.3
Mineralization and Asymbiotic Fixation	71.6	66.6	67.3	70.7	66.8	69.1	67.0	67.5	78.0	67.9	68.7	70.1
Direct Emissions from Drained Organic Cropland Soils	**3.2**	**3.2**	**3.2**	**3.1**	**3.1**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.3**
Direct Emissions from Mineral Grassland Soils	**70.3**	**70.4**	**71.4**	**71.9**	**69.0**	**71.5**	**74.4**	**73.7**	**77.8**	**66.8**	**68.3**	**68.2**
Synthetic Mineral Fertilizer	1.1	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.4	1.1	1.2	1.2
PRP Manure	13.4	12.8	13.3	13.9	14.7	15.3	16.0	14.6	14.7	12.3	12.5	12.0
Managed Manure	+	+	+	+	+	+	+	+	+	+	+	+
Sewage Sludge	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4
Residue[b]	19.7	20.1	20.3	20.5	18.3	20.3	19.8	20.4	20.2	20.3	19.3	19.8
Mineralization and Asymbiotic Fixation	35.8	36.1	36.3	35.8	34.4	34.4	36.9	37.1	41.1	32.5	34.7	34.6
Direct Emissions from Drained Organic Grassland Soils	**2.9**	**2.8**	**2.8**	**2.8**	**2.9**	**2.9**	**2.9**	**2.8**	**2.8**	**2.8**	**2.8**	**3.0**
Total Indirect	**58.2**	**49.7**	**54.4**	**65.4**	**46.1**	**58.1**	**59.6**	**50.5**	**61.2**	**51.1**	**47.2**	**55.5**
Volatilization	17.3	17.5	17.2	17.3	18.3	19.0	18.7	18.7	19.3	18.0	17.7	17.9
Leaching/Runoff	40.9	32.1	37.1	48.2	27.8	39.1	40.9	31.7	41.9	33.0	29.6	37.6
Total Emissions	**303.3**	**291.5**	**297.9**	**310.5**	**289.1**	**301.8**	**308.4**	**297.3**	**322.8**	**292.9**	**292.6**	**297.6**

Table A-249 continued: Total N_2O Emissions from Agricultural Soil Management (MMT CO_2 Eq.)

Activity	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total Direct	**245.4**	**249.7**	**268.7**	**248.3**	**252.2**	**260.4**	**251.2**	**253.5**	**263.8**	**264.5**	**264.5**	**261.2**	**261.0**
Direct Emissions from Mineral Cropland Soils	**168.4**	**172.4**	**181.3**	**171.2**	**172.2**	**178.8**	**172.1**	**171.8**	**182.6**	**183.9**	**184.9**	**182.2**	**182.0**
Synthetic Fertilizer	60.3	61.2	63.8	61.4	62.3	65.6	61.7	59.9	59.3	61.0	61.8	59.5	59.3
Organic Amendment[a]	13.0	13.1	12.9	12.9	13.4	13.5	13.3	13.2	13.4	13.5	13.6	13.5	13.5
Residue N[b]	26.7	27.6	25.5	26.6	26.1	26.3	25.6	25.2	27.8	27.6	27.5	27.5	27.6
Mineralization and Asymbiotic Fixation	68.3	70.5	79.1	70.3	70.3	73.3	71.5	73.4	82.2	81.8	82.0	81.6	81.6
Direct Emissions from Drained Organic Cropland Soils	**3.3**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.1**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**
Direct Emissions from Mineral Grassland Soils	**70.8**	**71.2**	**81.3**	**71.0**	**74.0**	**75.6**	**73.1**	**75.9**	**75.5**	**74.9**	**74.0**	**73.3**	**73.3**
Synthetic Mineral Fertilizer	1.3	1.3	1.5	1.3	1.4	1.3	1.3	1.4	1.3	1.2	1.2	1.2	1.4
PRP Manure	12.2	12.5	12.9	12.3	13.6	12.8	12.8	13.1	12.5	11.9	11.0	10.3	10.3
Managed Manure	+	+	+	+	+	+	+	+	+	+	+	+	+
Sewage Sludge	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6
Residue[b]	20.1	20.2	20.9	21.0	20.3	21.5	20.7	20.3	21.8	21.7	21.7	21.7	21.6
Mineralization and Asymbiotic Fixation	36.7	36.6	45.3	35.8	38.0	39.3	37.7	40.5	39.1	39.4	39.4	39.4	39.2
Direct Emissions from Drained Organic Grassland Soils	**3.0**	**2.9**	**2.9**	**2.9**	**2.8**	**2.8**	**2.8**	**2.7**	**2.7**	**2.7**	**2.7**	**2.7**	**2.7**
Total Indirect	**53.7**	**51.9**	**62.4**	**48.9**	**57.4**	**57.5**	**56.8**	**60.8**	**56.9**	**58.6**	**58.5**	**57.4**	**57.3**
Volatilization	18.0	18.7	18.7	18.5	19.1	18.7	18.7	18.1	18.6	18.9	19.1	18.8	18.7
Leaching/Runoff	35.7	33.3	43.7	30.4	38.3	38.7	38.1	42.6	38.2	39.6	39.4	38.7	38.6
Total Emissions	**299.1**	**301.7**	**331.1**	**297.2**	**309.6**	**317.8**	**308.0**	**314.2**	**320.7**	**323.1**	**323.1**	**318.6**	**318.4**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Organic amendment inputs include managed manure amendments, daily spread manure and other commercial organic fertilizer (i.e., dried blood, tankage, compost, and other).

[b] Residue N inputs include unharvested fixed N from legumes as well as crop residue N.

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

Table A-250: Total CH_4 Emissions from Cultivation of Rice Estimated with Tier 1 and 3 Inventory Approaches (MMT CO_2 Eq.)

	Rice Methane (MMT CO_2 Eq)																								
Approach	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Tier 1	1.05	1.04	1.10	0.98	1.07	0.71	0.95	0.81	1.09	1.21	1.56	1.08	1.18	1.13	1.33	1.08	1.02	0.99	1.10	1.08	1.14	1.13	1.18	1.20	1.18
Tier 3	12.08	11.93	11.91	12.65	9.32	12.41	11.45	10.47	12.39	11.37	12.83	10.97	14.01	9.87	9.70	11.93	9.25	8.95	7.84	9.88	10.71	10.71	10.72	10.71	10.72
Total	**13.13**	**12.97**	**13.01**	**13.64**	**10.39**	**13.12**	**12.40**	**11.28**	**13.48**	**12.59**	**14.39**	**12.05**	**15.18**	**11.01**	**11.03**	**13.01**	**10.27**	**9.95**	**8.94**	**10.96**	**11.85**	**11.84**	**11.90**	**11.91**	**11.89**

Table A-251: Total 2014 N_2O Emissions (Direct and Indirect) from Agricultural Soil Management by State (MMT CO_2 Eq.)

State	Croplands[a]	Grasslands[b]		Total	Lower Bound	Upper Bound
AL	1.45	1.46		2.94	2.34	4.16
AR	5.53	2.88		8.48	6.80	11.62
AZ	1.00	1.00		2.07	1.60	3.44
CA	7.12	0.84		8.41	5.88	17.07
CO	4.37	2.96		7.37	6.09	9.86
CT	0.09	0.04		0.13	0.09	0.21
DE	0.26	0.02		0.29	0.21	0.43
FL	2.45	2.98		5.52	4.29	9.63
GA	1.98	1.00		3.01	2.42	4.43
HI[c4]	0.02	0.15		0.17	0.06	0.33
IA	22.77	3.05		25.93	19.94	37.32
ID	2.90	0.71		3.67	2.91	5.63
IL	14.98	1.17		16.17	12.84	21.28
IN	8.08	0.77		8.93	7.27	11.78
KS	13.39	4.15		17.61	14.42	23.72
KY	2.63	2.97		5.64	4.49	7.93
LA	3.24	1.46		4.77	3.91	6.16
MA	0.12	1.24		0.19	0.15	0.28
MD	0.83	0.19		1.04	0.80	1.53
ME	0.20	0.26		0.32	0.23	0.54
MI	4.91	0.95		6.01	4.89	8.58
MN	14.61	1.88		17.10	13.83	23.42
MO	9.21	6.43		15.69	12.52	22.12
MS	3.42	1.14		4.53	3.72	6.05
MT	4.54	4.98		9.55	7.94	12.10
NC	2.05	0.64		2.79	1.95	5.02
ND	9.14	1.53		10.62	8.61	13.49
NE	16.40	3.63		20.11	15.93	28.48
NH	0.06	0.04		0.11	0.08	0.25
NJ	0.24	0.07		0.32	0.25	0.45
NM	1.08	2.61		3.61	2.86	5.21
NV	0.37	0.95		0.76	0.56	1.25
NY	3.20	1.39		4.65	3.73	6.75
OH	7.75	0.93		8.89	7.09	12.93
OK	3.99	5.54		9.52	7.65	13.22
OR	1.37	1.13		2.51	2.08	3.35
PA	2.92	0.93		3.89	3.09	5.81
RI	0.02	0.01		0.02	0.02	0.05
SC	0.91	0.32		1.25	1.01	1.83
SD	9.59	3.93		13.51	11.17	17.30
TN	2.15	2.50		4.69	3.69	6.77
TX	13.55	14.02		27.68	23.39	35.40
UT	0.78	0.73		1.53	1.22	2.22
VA	1.06	1.55		2.61	2.10	3.61
VT	0.54	0.34		0.89	0.70	1.37
WA	2.44	0.66		3.19	2.62	4.56
WI	9.50	1.91		11.81	9.10	18.40
WV	0.28	0.70		0.98	0.71	1.56
WY	1.49	2.60		4.13	3.37	5.47

[a] Emissions from non-manure organic N inputs for crops not simulated by DAYCENT were not estimated (NE) at the state level.
[b] Emissions from sewage sludge applied to grasslands and were not estimated (NE) at the state level
[c] N_2O emissions are not reported for Hawaii except from cropland organic soils.

Table A-252: Annual Soil C Stock Change in Cropland Remaining Cropland (CRC), Land Converted to Cropland (LCC), Grassland Remaining Grassland (GRG), and Land Converted to Grassland (LCG), in U.S. Agricultural Soils (MMT CO_2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Net emissions based on Tier 3 Century-based analysis (Step 2)																									
CRC	(56.2)	(57.0)	(58.3)	(37.1)	(48.5)	(43.0)	(50.6)	(47.1)	(33.5)	(46.5)	(51.1)	(50.9)	(42.2)	(33.0)	(38.1)	(37.2)	(37.7)	(37.8)	(29.7)	(22.3)	(22.0)	(36.7)	(36.7)	(36.7)	(36.7)
GCC	12.9	12.8	13.6	11.6	6.5	13.6	11.2	13.1	7.6	8.5	8.4	8.2	8.6	7.7	6.9	7.9	7.9	5.8	6.8	5.8	6.6	4.5	4.5	4.5	4.5
GRG	(17.9)	(8.4)	(9.3)	(8.7)	(24.2)	(7.4)	(16.5)	(9.9)	(13.1)	(3.8)	(19.2)	(8.5)	(6.8)	(5.1)	(7.4)	(5.3)	(14.4)	1.3	(8.4)	(10.8)	(9.0)	1.1	1.1	1.1	1.1
CCG	(3.8)	(4.7)	(4.7)	(5.1)	(5.4)	(5.6)	(6.0)	(6.6)	(6.8)	(6.9)	(7.1)	(7.6)	(8.2)	(7.3)	(8.0)	(7.2)	(8.0)	(7.9)	(8.1)	(8.0)	(7.7)	(7.2)	(7.2)	(7.2)	(7.2)
Net emissions based on the IPCC Tier 2 analysis (Step 3)																									
Mineral Soils																									
CRC	(6.2)	(6.7)	(7.4)	(7.1)	(7.0)	(6.5)	(6.1)	(7.7)	(7.3)	(6.6)	(7.1)	(6.9)	(6.8)	(6.1)	(5.5)	(5.6)	(4.7)	(4.6)	(4.0)	(3.9)	(4.0)	(3.7)	(3.3)	(3.1)	(3.2)
GCC	1.3	1.2	1.3	1.4	1.4	1.5	1.8	1.5	1.6	1.6	1.5	1.4	1.2	1.1	1.2	1.2	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3
FCC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCC	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SCC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
WCC	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GRG	(0.5)	(0.6)	(0.9)	(1.4)	(1.7)	(1.7)	(1.0)	(0.9)	(1.6)	(1.3)	(1.5)	(1.5)	(2.5)	(2.6)	(1.2)	(1.3)	(1.5)	(1.5)	(1.5)	(1.3)	(1.4)	(1.0)	(0.5)	(0.3)	(0.3)
CCG	(3.1)	(3.1)	(3.0)	(3.3)	(3.4)	(3.3)	(3.1)	(2.9)	(3.2)	(2.9)	(3.1)	(2.9)	(2.7)	(2.4)	(2.7)	(2.5)	(2.1)	(1.7)	(1.6)	(1.5)	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)
FCG	(0.5)	(0.5)	(0.4)	(0.5)	(0.4)	(0.5)	(0.4)	(0.4)	(1.1)	(1.1)	(1.1)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
OCG	(0.6)	(0.6)	(0.7)	(0.8)	(1.0)	(1.0)	(0.9)	(1.0)	(1.1)	(1.1)	(1.2)	(1.2)	(1.2)	(1.1)	(1.1)	(1.1)	(1.0)	(0.9)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
SCG	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
WCG	(0.5)	(0.6)	(0.6)	(0.6)	(0.7)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.5)	(0.5)	(0.4)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Organic Soils																									
CRC	28.0	27.5	27.5	27.2	27.2	27.1	27.0	26.9	27.1	26.4	26.3	27.1	27.4	27.6	28.8	28.7	28.5	27.6	27.2	27.7	27.8	27.8	27.8	27.8	27.8
GCC	3.2	3.2	3.2	3.1	3.4	3.7	3.7	3.8	4.3	4.4	4.1	5.4	5.3	5.1	4.2	4.2	4.2	4.0	3.9	3.7	3.8	3.8	3.8	3.8	3.8
FCC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCC	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
WCC	0.6	0.6	0.6	0.7	0.9	0.9	0.9	0.9	1.0	0.9	0.8	0.8	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
GRG	6.1	6.0	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.2	4.7	4.6	4.5	4.5	4.5	4.4	4.4	4.4	4.4	4.4	4.4	4.3	4.3	4.3
CCG	0.5	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.2	1.1	1.2	1.2	1.2	1.2
FCG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OCG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WCG	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Additional changes in net emissions from mineral soils based on application of sewage sludge to agricultural land (Step 4)																									
GRG	(0.6)	(0.6)	(0.7)	(0.7)	(0.7)	(0.8)	(0.8)	(0.9)	(0.9)	(0.9)	(1.0)	(1.0)	(1.0)	(1.0)	(1.1)	(1.1)	(1.2)	(1.2)	(1.2)	(1.3)	(1.3)	(1.3)	(1.4)	(1.4)	(1.4)
Additional changes in net emissions from mineral soils based on additional enrollment of CRP land (Step 4)																									
CRC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	1.1	2.8	3.7
Total Stock Changes by Land Use/Land-Use Change Category (Step 5)																									
CRC	(34.3)	(36.2)	(38.2)	(17.0)	(28.3)	(22.3)	(29.7)	(27.9)	(13.7)	(26.8)	(31.8)	(30.6)	(21.6)	(11.5)	(14.8)	(14.1)	(13.8)	(14.7)	(6.5)	1.5	1.8	(12.5)	(11.2)	(9.3)	(8.4)
GCC	17.4	17.3	18.1	16.2	11.3	18.9	16.7	18.4	13.5	14.5	13.9	15.0	15.1	13.9	12.3	13.3	13.5	11.3	12.1	10.7	11.8	9.6	9.6	9.7	9.7
FCC	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
OCC	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SCC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
WCC	0.7	0.7	0.7	0.9	1.0	1.1	1.1	1.1	1.2	1.1	1.0	1.0	0.9	0.8	0.7	0.6	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
GRG	(12.9)	(3.7)	(5.1)	(5.0)	(20.9)	(4.2)	(12.8)	(6.3)	(10.3)	(0.9)	(16.6)	(6.2)	(5.7)	(4.2)	(5.2)	(3.3)	(12.5)	3.0	(6.8)	(8.9)	(7.3)	3.1	3.6	3.8	3.8

CCG	(6.4)	(7.3)	(7.1)	(7.8)	(8.1)	(8.1)	(8.3)	(8.8)	(9.2)	(9.0)	(9.4)	(9.7)	(9.8)	(8.8)	(9.7)	(8.7)	(9.0)	(8.6)	(8.8)	(8.3)	(8.0)	(7.4)	(7.4)	(7.4)	(7.4)
FCG	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.5)	(0.4)	(0.4)	(1.1)	(1.1)	(1.1)	(1.0)	(1.0)	(0.9)	(0.9)	(1.0)	(0.9)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
OCG	(0.6)	(0.6)	(0.7)	(0.8)	(0.9)	(1.0)	(0.9)	(1.0)	(1.1)	(1.1)	(1.2)	(1.2)	(1.1)	(1.1)	(1.1)	(1.1)	(1.0)	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
SCG	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
WCG	(0.4)	(0.5)	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.5)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)	(0.3)	(0.2)	(0.1)	0.0	0.1	0.1	0.1	0.1	0.1
Total *	**(36.4)**	**(30.2)**	**(32.7)**	**(13.9)**	**(46.3)**	**(16.0)**	**(34.2)**	**(25.0)**	**(20.8)**	**(23.2)**	**(45.1)**	**(32.9)**	**(23.5)**	**(12.1)**	**(19.0)**	**(14.3)**	**(23.1)**	**(10.1)**	**(10.8)**	**(5.9)**	**(2.5)**	**(7.9)**	**(6.2)**	**(4.0)**	**(3.1)**

Note: Totals may not sum due to independent rounding.

Table A-253: Soil C Stock Change for Mineral and Organic Soils in 2014 within individual states (MMT CO_2 Eq.)

State	Mineral Soil	Organic Soil	Total
AL	(1.29)	0.01	(1.27)
AR	(0.78)	-	(0.78)
AZ	1.14	-	1.14
CA	(3.88)	1.58	(2.29)
CO	(0.84)	0.00	(0.83)
CT	0.00	0.01	0.01
DE	(0.10)	-	(0.10)
FL	0.21	12.21	12.42
GA	(0.75)	-	(0.75)
HI	(0.10)	0.77	0.67
IA	(2.33)	0.73	(1.60)
ID	(0.76)	0.03	(0.73)
IL	(3.15)	0.52	(2.63)
IN	(1.68)	2.36	0.68
KS	(1.41)	-	(1.41)
KY	(2.74)	-	(2.74)
LA	(1.44)	0.51	(0.93)
MA	(0.07)	0.28	0.22
MD	(0.42)	0.01	(0.42)
ME	(0.11)	0.01	(0.10)
MI	(0.62)	3.40	2.78
MN	(1.79)	7.65	5.86
MO	(3.77)	-	(3.77)
MS	(0.55)	0.01	(0.53)
MT	0.46	0.15	0.61
NC	(1.24)	1.89	0.65
ND	(3.45)	0.01	(3.44)
NE	(1.44)	0.00	(1.43)
NH	(0.03)	0.02	(0.01)
NJ	(0.07)	0.12	0.05
NM	0.24	-	0.24
NV	(0.08)	0.00	(0.08)
NY	(1.14)	0.53	(0.61)
OH	(1.45)	0.48	(0.97)
OK	0.48	-	0.48
OR	(0.73)	0.30	(0.43)
PA	(0.46)	0.05	(0.41)
RI	0.01	0.02	0.03
SC	(0.90)	0.02	(0.88)
SD	(0.84)	-	(0.84)
TN	(2.23)	-	(2.23)
TX	(0.07)	-	(0.07)
UT	(0.02)	0.08	0.06
VA	(1.46)	0.00	(1.46)
VT	(0.12)	0.06	(0.05)
WA	(1.02)	0.38	(0.64)
WI	0.55	2.90	3.45
WV	(0.55)	-	(0.55)
WY	0.30	-	0.30

Note: Parentheses indicate net C accumulation. Estimates do not include soil C stock change associated with federal croplands and grasslands, CRP enrollment after 2010, or sewage sludge application to soils, which were only estimated at the national scale. The sum of state results will not match the national results because state results are generated in a separate programming package, the sewage sludge and CRP enrollment after 2010 are not included, and differences arise due to rounding of values in this table.

Table A-254: Total 2014 CH_4 Emissions from Rice Cultivation by State (MMT CO_2 Eq.)

State	Total
AL	-
AR	4.55
AZ	-
CA	2.36
CO	-

CT	-
DE	-
FL	-
GA	-
HI	-
IA	-
ID	-
IL	-
IN	-
KS	-
KY	-
LA	2.66
MA	-
MD	-
ME	-
MI	-
MN	0.01
MO	0.72
MS	0.25
MT	-
NC	-
ND	-
NE	-
NH	-
NJ	-
NM	-
NV	-
NY	-
OH	-
OK	-
OR	-
PA	-
RI	-
SC	-
SD	-
TN	-
TX	1.34
UT	-
VA	-
VT	-
WA	-
WI	-
WV	-
WY	-

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3.13. Methodology for Estimating Net Carbon Stock Changes in *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*

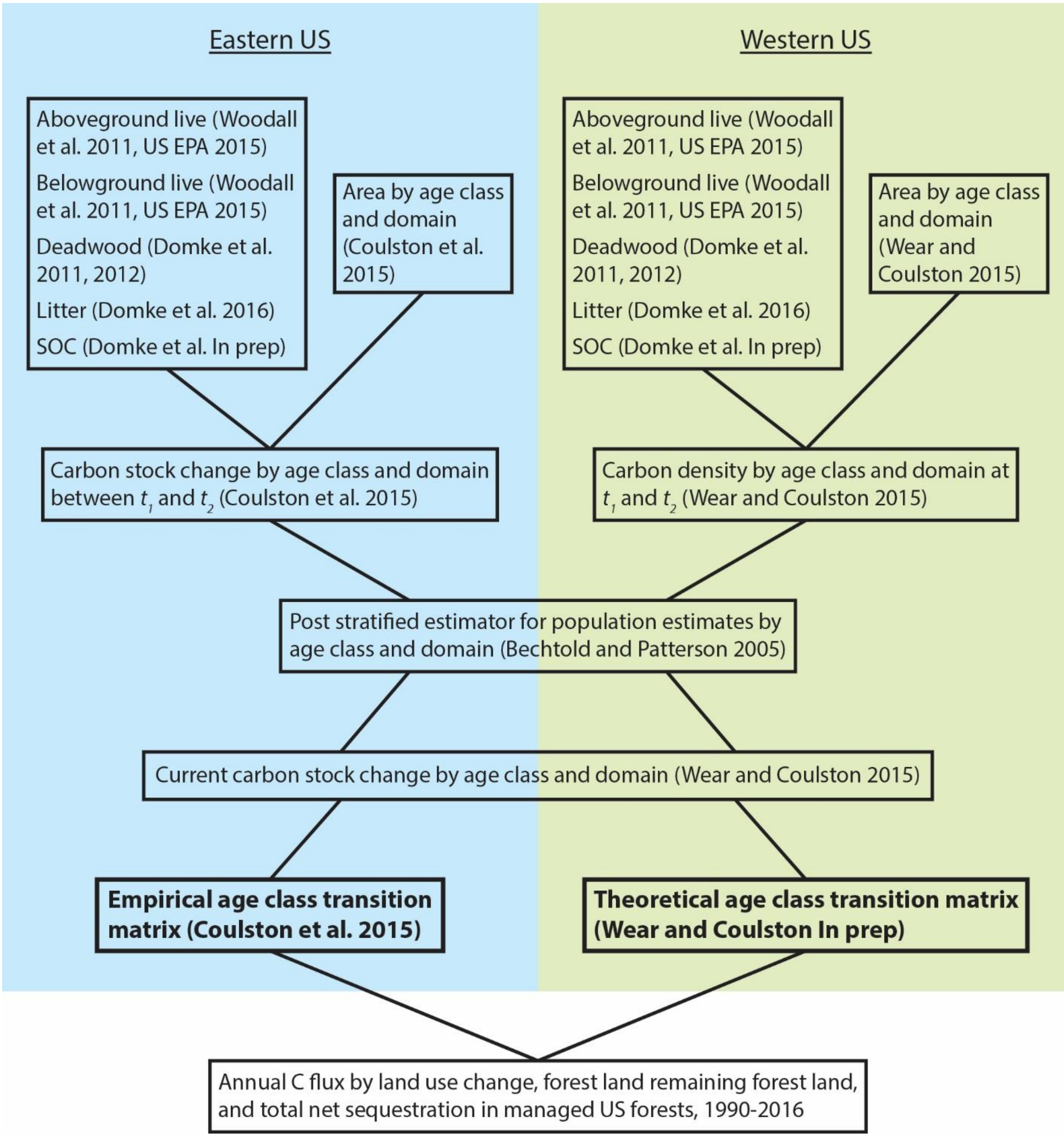
This sub-annex expands on the methodology used to estimate net changes in carbon (C) stocks in forest ecosystems and harvested wood products for *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* as well as non-CO_2 emissions from forest fires. Full details of the C conversion factors and procedures may be found in the cited references. For details on the methods used to estimate changes in soil C stocks in the *Land Converted to Forest Land* section please refer to Annex 3.12.

Carbon stocks and net stock change in forest ecosystems

The inventory-based methodologies for estimating forest C stocks are based on Woodall et al. (2015a) and are consistent with IPCC (2003, 2006) stock-difference methods. Estimates of ecosystem C are based on data from the a network of annual inventory plots established and measured by the Forest Inventory and Analysis program within the USDA Forest Service; either direct measurements or attributes of forest inventories are the basis for estimating metric tons of C per hectare in IPCC pools (i.e., above- and belowground biomass, dead wood, litter, and soil organic carbon). Plot-level estimates are used to inform land area (by use) and stand age transition matrices across time which can be summed annually for an estimate of forest C stock change for *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Recent publications (Coulston et al. 2015; Woodall et al. 2015a) detail the land use and stand age transition matrices that are informed by the annual forest inventory of the U.S. and were used in the accounting framework used in this Inventory. The annual forest inventories in the eastern U.S. have been remeasured which allows for empirical estimation of forest C stock net change within the accounting framework. In contrast, as numerous western states have not yet been remeasured, theoretical age transition matrices have been developed (Figure A-22).

A new accounting approach (Woodall et al. 2015a) was used to in this Inventory to be compliant with IPCC (2006) and UNFCCC reporting requirements. The United States' prior approach of comparing spatially and temporally inconsistent forest inventories of the 1980's and 1990's to the nationally consistent inventories of the 2000's not only resulted in highly uncertain estimates of individual forest C pools (see standing dead trees, Woodall et al. 2012), but also had an inability to disaggregate C stock changes by *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* across the entire baseline (i.e., 1990 to the present) (Woodall et al. 2015a). The following subsections of this annex will describe the accounting framework used this year (Figure A-22) including the methods for estimating individual pools of forest C in addition to the eastern versus western approach to informing land use and stand age transitions.

Figure A-22: Flowchart of the inputs necessary in the accounting framework, including the methods for estimating individual pools of forest C in the eastern and western conterminous U.S. states and coastal Alaska



Note: An empirical age class transition matrix was used in the Eastern U.S. while a theoretical age class transition matrix was used in the Western U.S.

Forest Land Definition

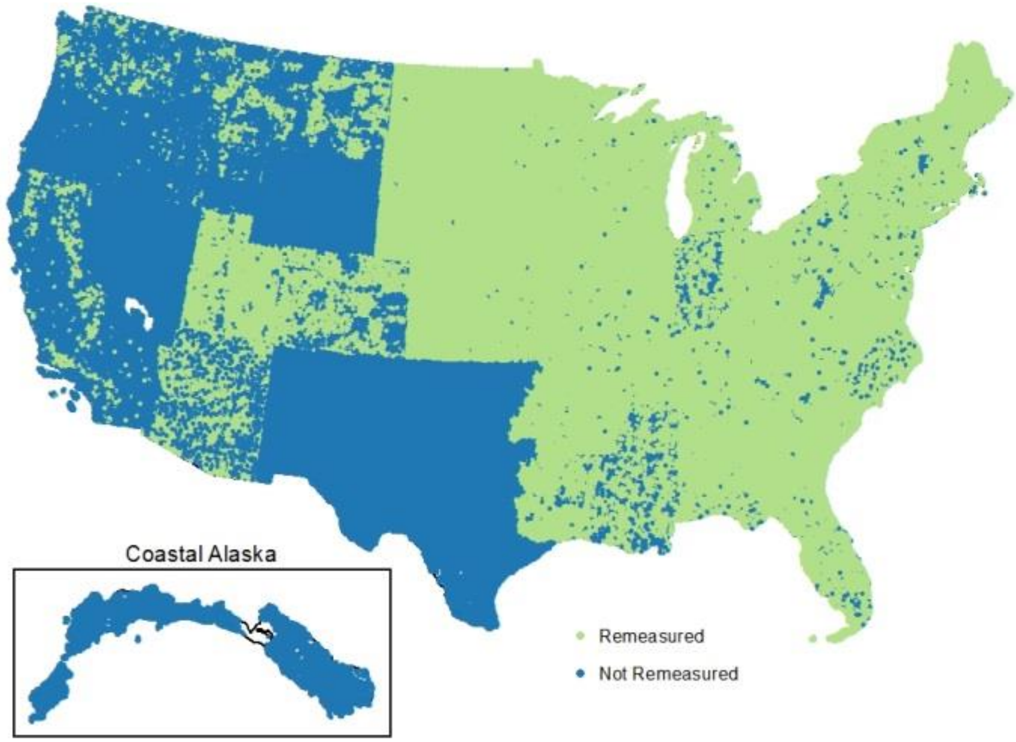
The definition of forest land within the U.S. and used for this Inventory is defined in Oswalt et al. (2014) as "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectare) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (36.6 meters) wide or an acre (0.4 hectare) in size. Forest land does not include land that is predominantly under agricultural or urban land use." Timberland is productive forest land, which is on unreserved land and is producing or capable of producing crops of industrial wood. This is an important subclass of forest land because timberland is the primary source of C incorporated into harvested wood products. Productivity for timberland is at a minimum rate of 20 cubic feet per acre (1.4 cubic meters per hectare) per year of industrial wood (Woudenberg and Farrenkopf 1995). There are about 205 million hectares of timberland in the conterminous U.S., which represents 80 percent of all forest lands over the same area (Oswalt et al. 2014).

Forest Inventory Data

The estimates of forest C stocks are based on data from forest inventory surveys. Forest inventory data were obtained from the USDA Forest Service, Forest Inventory and Analysis (FIA) Program (Frayer and Furnival 1999; USDA Forest Service 2015a; USDA Forest Service 2015b). Forest Inventory and Analysis data include remote sensing information and a collection of measurements in the field at sample locations called plots. Tree measurements include diameter at breast height, height, and species. On a subset of plots, additional measurements or samples are taken of downed dead wood, litter, and soil attributes. The technical advances needed to estimate C stocks from these data are ongoing (Woodall et al. 2015a) with the latest research incorporated on an annual basis (see Domke et al. 2016). The field protocols are thoroughly documented and available for download from the USDA Forest Service (2015c). Bechtold and Patterson (2005) provide the estimation procedures for standard forest inventory results. The data are freely available for download at USDA Forest Service (2011b) as the FIA Database (FIADB) Version 6.0 (USDA Forest Service 2015b; USDA Forest Service 2015c); these data are the primary sources of forest inventory data used to estimate forest C stocks. In addition to the field sampling component, fine-scale remotely sensed imagery (National Agriculture Imagery Program; NAIP 2015; Woodall et al. 2015b) is used to assign the land use at each sample location which has a nominal spatial resolution (raster cell size) of 1 m^2. Prior to field measurement of each year's collection of annual plots due for measurement (i.e., panel), each sample location in the panel (i.e., systematic distribution of plots within each state each year) is photo-interpreted manually by a forester to determine land use. As annual forest inventories have only just begun in the U.S. territories and in Hawaii, there is an assumption that these areas account for a net C change of zero. Survey data are available for the temperate oceanic ecoregion of Alaska (southeast and south central). These inventory data are publicly available for 6 million hectares of forest land, and these inventoried lands, representing an estimated 12 percent of the total forest land in Alaska, contribute to the forest C stocks presented here. Agroforestry systems are also not currently accounted for in the U.S. Inventory, since they are not explicitly inventoried by either of the two primary national natural resource inventory programs: the FIA program of the USDA Forest Service and the National Resources Inventory (NRI) of the USDA Natural Resources Conservation Service (Perry et al. 2005). The majority of these tree-based practices do not meet the size and definitions for forests within each of these resource inventories.

A national plot design and annualized sampling (USDA Forest Service 2015a) were introduced by FIA with most new annual inventories beginning after 1998. These are the only forest inventories used in the current accounting framework and subsequently in this submission. These surveys involve the sampling of all forest land including reserved and lower productivity lands. Almost all states have annualized inventory data available with substantial remeasurement in the eastern US (Figure A-23). Annualized sampling means that a portion of plots throughout the state is sampled each year, with the goal of measuring all plots once every 5 to 10 years, depending on the region of the U.S. The full unique set of data with all measured plots, such that each plot has been measured one time, is called a cycle. Sampling is designed such that partial inventory cycles provide usable, unbiased samples of forest inventory within the state, but with higher sampling errors than the full cycle. After all plots have been measured once, the sequence continues with remeasurement of the first year's plots, starting the next new cycle. Most eastern states have completed one or two cycles of the annualized inventories, and some western states have begun remeasuring with a second annual cycle. Annually updated estimates of forest C stocks are affected by the redundancy in the data used to generate the annual updates of C stock. For example, a typical annual inventory update for an eastern state will include new data from remeasurement on 20 percent of plots; data from the remaining 80 percent of plots is identical to that included in the previous year's annual update. The interpretation and use of the annual inventory data can affect trend estimates of C stocks and stock changes (e.g., estimates based on 60 percent of an inventory cycle will be different than estimates with a complete (100 percent) cycle). In general, the C stock and stock change calculations use annual inventory summaries (updates) with unique sets of plot-level data (that is, without redundant sets); the most-recent annual update (i.e., 2015) is the exception because it is included in stock change calculations in order to include the most recent available data for each state. The specific inventories used in this report are listed in Table A-255 and this list can be compared with the full set of summaries available for download (USDA Forest Service 2015b).

Figure A-23: Annual FIA plots (remeasured and not remeasured) across the U.S. including coastal Alaska through the 2014 field season



Note: Due to the vast number of plots (where land use is measured even if no forest is present) they appear as spatially contiguous when displayed at the scale and resolution presented in this figure.

It should be noted that as the FIA program explores expansion of its vegetation inventory beyond the forest land use to other land uses (e.g., woodlands and urban areas) subsequent inventory observations will need to be delineated between forest and other land uses as opposed to a strict forest land use inventory. The forest C estimates provided here represent C stocks and stock change on managed forest lands (IPCC 2006, see Section 6.1 Representation of the U.S. Land Base), which is how all forest lands are classified on the 48 conterminous states. However, Alaska is considered to have significant areas of both managed and unmanaged forest lands. A new model delineating managed versus unmanaged lands for the U.S. (Ogle et al. in preparation), and used in this Inventory, is consistent with the assumption of managed forest lands on the 48 states. However, the model of Ogle et al. (in preparation) identifies some of the forest land in south central and southeastern coastal Alaska as unmanaged; this is in contrast to past assumptions of "managed" for these forest lands included in the FIADB. Therefore, the estimates for coastal Alaska as included here reflect that adjustment, which effectively reduces the forest area included here by about 5 percent. A second modification to the use of the FIADB-defined forest land introduced this year is to identify plots that do not meet the height component of the definition of forestland (Coulston et al. in preparation). These plots were identified as "other wooded lands" (i.e., not forest land use) and were removed from forest estimates and classified as grassland.[105] Note that minor differences in identifying and classifying

[105] Efforts are underway to account for the C stock changes in these "other wooded lands" that have been reclassified as grassland. The estimates should be included in the 2017 submission.

woodland as "forest" versus "other wooded" exist between the current Resources Planning Act Assessment (RPA) data (Oswalt et al. 2014) and the FIADB (USDA Forest Service 2015b) due to a refined modelling approach developed specifically for this submission (Coulston et al. in preparation).

Table A-255: Specific annual forest inventories by state used in development of forest C stock and stock change estimates

Remeasured Annual Plots			Split Annual Cycle Plots		
State	Time 1 Year Range	Time 2 Year Range	State	Time 1 Year Range	Time 2 Year Range
Alabama	2001 - 2009	2006 - 2014	Alaska (Coastal)	2004 - 2008	2009 - 2013
Arkansas	2000, 2002, 2004 - 2010	2009 - 2014	Arizona	2004 - 2008	2009 - 2013
Connecticut	2004 - 2008	2009 - 2013	California	2001 - 2005	2006 - 2010
Delaware	2004 - 2008	2009 - 2013	Colorado	2004 - 2008	2009 - 2013
Florida	2002 - 2004, 2006 - 2007	2009 - 2013	Idaho	2004 - 2008	2009 - 2013
Georgia	1998 - 2009	2005 - 2007, 2009 - 2013	Montana	2004 - 2008	2009 - 2013
Illinois	2004 - 2009	2009 - 2014	Nevada	2004 - 2008	2009 - 2013
Indiana	2004 - 2008	2009 - 2013	New Mexico	1999	2005 - 2013
Iowa	2004 - 2009	2009 - 2014	Oklahoma (West)	2009 - 2010	2011 - 2013
Kansas	2004 - 2009	2009 - 2014	Oregon	2001 - 2005	2006 - 2010
Kentucky	2000 - 2009	2005 - 2006, 2008 - 2012	Texas (West)	2004 - 2007	2008 - 2012
Louisiana	2001 - 2005, 2008	2009 - 2013	Utah	2004 - 2008	2009 - 2013
Maine	2004 - 2008	2009 - 2013	Washington	2002 - 2006	2007 - 2011
Maryland	2004 - 2008	2009 - 2013	Wyoming	2000	2011 - 2013
Massachusetts	2004 - 2008	2009 - 2013			
Michigan	2004 - 2009	2009 - 2014			
Minnesota	2005 - 2009	2010 - 2014			
Mississippi	2006	2009 - 2014			
Missouri	2004 - 2009	2009 - 2014			
Nebraska	2004 - 2008	2009 - 2013			
New Hampshire	2003 - 2008	2009 - 2013			
New Jersey	2004 - 2008	2009 - 2013			
New York	2003 - 2008	2009 - 2013			
North Carolina	2002 - 2007	2003, 2005 - 2007, 2009 - 2014			
North Dakota	2004 - 2009	2009 - 2014			
Ohio	2003 - 2008	2009 - 2013			
Oklahoma (East)	2008	2010 - 2013			
Pennsylvania	2004 - 2008	2009 - 2013			
Rhode Island	2004 - 2008	2009 - 2013			
South Carolina	2002 - 2010	2007 - 2013			
South Dakota	2004 - 2009	2009 - 2014			
Tennessee	2000 - 2009	2005 - 2012			
Texas (East)	2002 - 2008	2005, 2007 - 2012			
Vermont	2004 - 2008	2009 - 2013			
Virginia	2002 - 2003, 2005 - 2010	2008 - 2013			
West Virginia	2004 - 2008	2009 - 2013			
Wisconsin	2004 - 2009	2009 - 2014			

Note: Remeasured annual plots represent a complete inventory cycle between measurements of the same plots while spilt annual cycle plots represent a single inventory cycle of plots that are split where remeasurements have yet to occur.

Estimating Forest Inventory Plot-Level C-Density

For each inventory plot in each state, field data from the FIA program are used alone or in combination with auxiliary information (e.g., climate, surficial geology, elevation) to predict C density for each IPCC pool (i.e., aboveground and belowground biomass, dead wood, litter, SOC). In the past, most of the conversion factors and models used for inventory-based forest C estimates (Smith et al. 2010; Heath et al. 2011) were initially developed as an offshoot of the forest C simulation model FORCARB (Heath et al. 2010). The conversion factors and model coefficients were usually categorized by region and forest type. Thus, region and type are specifically defined for each set of estimates. More recently, the coarse approaches of the past have been updated with empirical information regarding C attributes of individual forest C pools such as dead wood and litter (e.g., Domke et al. 2013 and Domke et al. 2016). Factors are applied to the forest inventory data at the scale of FIA inventory plots which are a systematic sample of all forests attributes and land uses within each state. The results are estimates of C density (T per hectare) for the various forest pools. Carbon density for live trees, standing dead trees, understory vegetation, downed dead wood, litter, and soil organic matter are estimated. All non-soil C pools except litter can be separated into aboveground and belowground components. The live tree and understory C pools are combined into the biomass pool in this inventory. Similarly, standing dead trees and downed dead wood are pooled as dead wood in this inventory. C stocks and fluxes for *Forest Land Remaining Forest Land* are reported in pools following IPCC (2006).

Live tree C pools

Live tree C pools include aboveground and belowground (coarse root) biomass of live trees with diameter at diameter breast height (d.b.h.) of at least 2.54 cm at 1.37 m above the forest floor. Separate estimates are made for above- and below-ground biomass components. If inventory plots include data on individual trees, tree C is based on Woodall et al. (2011), which is also known as the component ratio method (CRM), and is a function of volume, species, diameter, and, in some regions, tree height and site quality. The estimated sound volume (i.e., after rotten/missing deductions) provided in the tree table of the FIADB is the principal input to the CRM biomass calculation for each tree (Woodall et al. 2011). The estimated volumes of wood and bark are converted to biomass based on the density of each. Additional components of the trees such as tops, branches, and coarse roots, are estimated according to adjusted component estimates from Jenkins et al. (2003). Live trees with d.b.h of less than 12.7 cm do not have estimates of sound volume in the FIADB, and CRM biomass estimates follow a separate process (see Woodall et al. 2011 for details). An additional component of foliage, which was not explicitly included in Woodall et al. (2011), was added to each tree following the same CRM method. Carbon is estimated by multiplying the estimated oven-dry biomass by a C constant of 0.5 because biomass is 50 percent of dry weight (IPCC 2006). Further discussion and example calculations are provided in Woodall et al. 2011 and Domke et al. 2012.

Understory vegetation

Understory vegetation is a minor component of total forest ecosystem biomass. Understory vegetation is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than one-inch d.b.h. In this inventory, it is assumed that 10 percent of understory C mass is belowground. This general root-to-shoot ratio (0.11) is near the lower range of temperate forest values provided in IPCC (2006) and was selected based on two general assumptions: ratios are likely to be lower for light-limited understory vegetation as compared with larger trees, and a greater proportion of all root mass will be less than 2 mm diameter.

Estimates of C density are based on information in Birdsey (1996), which was applied to FIA permanent plots. These were fit to the model:

$$\text{Ratio} = e^{(A - B \times \ln(\text{live tree C density}))} \tag{1}$$

In this model, the ratio is the ratio of understory C density (T C/ha) to live tree C density (above- and below-ground) according to Jenkins et al. (2003) and expressed in T C/ha. An additional coefficient is provided as a maximum ratio; that is, any estimate predicted from the model that is greater than the maximum ratio is set equal to the maximum ratio. A full set of coefficients are in Table A-256. Regions and forest types are the same classifications described in Smith et al. (2003). As an example, the basic calculation for understory C in aspen-birch forests in the Northeast is:

$$\text{Understory (T C/ha)} = (\text{live tree C density}) \times e^{(0.855 - 1.03 \times \ln(\text{tree C density}))} \tag{2}$$

This calculation is followed by three possible modifications. First, the maximum value for the ratio is set to 2.02 (see value in column "maximum ratio"); this also applies to stands with zero tree C, which is undefined in the above model. Second, the minimum ratio is set to 0.005 (Birdsey 1996). Third, nonstocked (i.e., currently lacking tree cover but still in the forest land use) and pinyon/juniper forest types (see Table A-256) are set to coefficient A, which is a C density (T C/ha) for these types only.

Table A-256: Coefficients for Estimating the Ratio of C Density of Understory Vegetation (above- and belowground, T C/ha)[a] by Region and Forest Type

Region[b]	Forest Type[b]	A	B	Maximum ratio[c]
NE	Aspen-Birch	0.855	1.032	2.023
	MBB/Other Hardwood	0.892	1.079	2.076
	Oak-Hickory	0.842	1.053	2.057
	Oak-Pine	1.960	1.235	4.203
	Other Pine	2.149	1.268	4.191
	Spruce-Fir	0.825	1.121	2.140
	White-Red-Jack Pine	1.000	1.116	2.098
	Nonstocked	2.020	2.020	2.060
NLS	Aspen-Birch	0.777	1.018	2.023
	Lowland Hardwood	0.650	0.997	2.037
	Maple-Beech-Birch	0.863	1.120	2.129
	Oak-Hickory	0.965	1.091	2.072
	Pine	0.740	1.014	2.046
	Spruce-Fir	1.656	1.318	2.136
	Nonstocked	1.928	1.928	2.117
NPS	Conifer	1.189	1.190	2.114
	Lowland Hardwood	1.370	1.177	2.055
	Maple-Beech-Birch	1.126	1.201	2.130
	Oak-Hickory	1.139	1.138	2.072
	Oak-Pine	2.014	1.215	4.185
	Nonstocked	2.052	2.052	2.072
PSW	Douglas-fir	2.084	1.201	4.626
	Fir-Spruce	1.983	1.268	4.806
	Hardwoods	1.571	1.038	4.745
	Other Conifer	4.032	1.785	4.768
	Pinyon-Juniper	4.430	4.430	4.820
	Redwood	2.513	1.312	4.698
	Nonstocked	4.431	4.431	4.626
PWE	Douglas-fir	1.544	1.064	4.626
	Fir-Spruce	1.583	1.156	4.806
	Hardwoods	1.900	1.133	4.745
	Lodgepole Pine	1.790	1.257	4.823
	Pinyon-Juniper	2.708	2.708	4.820
	Ponderosa Pine	1.768	1.213	4.768
	Nonstocked	4.315	4.315	4.626
PWW	Douglas-fir	1.727	1.108	4.609
	Fir-Spruce	1.770	1.164	4.807
	Other Conifer	2.874	1.534	4.768
	Other Hardwoods	2.157	1.220	4.745
	Red Alder	2.094	1.230	4.745
	Western Hemlock	2.081	1.218	4.693
	Nonstocked	4.401	4.401	4.589
RMN	Douglas-fir	2.342	1.360	4.731
	Fir-Spruce	2.129	1.315	4.749
	Hardwoods	1.860	1.110	4.745
	Lodgepole Pine	2.571	1.500	4.773
	Other Conifer	2.614	1.518	4.821
	Pinyon-Juniper	2.708	2.708	4.820
	Ponderosa Pine	2.099	1.344	4.776
	Nonstocked	4.430	4.430	4.773
RMS	Douglas-fir	5.145	2.232	4.829
	Fir-Spruce	2.861	1.568	4.822
	Hardwoods	1.858	1.110	4.745
	Lodgepole Pine	3.305	1.737	4.797
	Other Conifer	2.134	1.382	4.821
	Pinyon-Juniper	2.757	2.757	4.820
	Ponderosa Pine	3.214	1.732	4.820
	Nonstocked	4.243	4.243	4.797
SC	Bottomland Hardwood	0.917	1.109	1.842
	Misc. Conifer	1.601	1.129	4.191
	Natural Pine	2.166	1.260	4.161

	Oak-Pine	1.903	1.190	4.173
	Planted Pine	1.489	1.037	4.124
	Upland Hardwood	2.089	1.235	4.170
	Nonstocked	4.044	4.044	4.170
SE	Bottomland Hardwood	0.834	1.089	1.842
	Misc. Conifer	1.601	1.129	4.191
	Natural Pine	1.752	1.155	4.178
	Oak-Pine	1.642	1.117	4.195
	Planted Pine	1.470	1.036	4.141
	Upland Hardwood	1.903	1.191	4.182
	Nonstocked	4.033	4.033	4.182

[a] Prediction of ratio of understory C to live tree C is based on the model: Ratio=exp(A − B × ln(tree_carbon_tph)), where "ratio" is the ratio of understory C density to live tree (above-and below- ground) C density, and "tree_carbon_density" is live tree (above-and below- ground) C density in T C/ha. Note that this ratio is multiplied by tree C density on each plot to produce understory vegetation.
[b] Regions and types as defined in Smith et al. (2003).
[c] Maximum ratio: any estimate predicted from the model that is greater than the maximum ratio is set equal to the maximum ratio.

Dead Wood

The standing dead tree estimates are primarily based on plot-level measurements (Domke et al. 2011; Woodall et al. 2011). This C pool includes aboveground and belowground (coarse root) mass and includes trees of at least 12.7 cm d.b.h. Calculations follow the basic CRM method applied to live trees (Woodall et al. 2011) with additional modifications to account for decay and structural loss. In addition to the lack of foliage, two characteristics of standing dead trees that can significantly affect C mass are decay, which affects density and thus specific C content (Domke et al. 2011; Harmon et al. 2011), and structural loss such as branches and bark (Domke et al. 2011). Dry weight to C mass conversion is by multiplying by 0.5.

Downed dead wood, inclusive of logging residue, are sampled on a subset of FIA plots. Despite a reduced sample intensity, a single down woody material population estimate (Woodall et al. 2010; Domke et al. 2013; Woodall et al. 2013) per state is now incorporated into these empirical downed dead wood estimates. Downed dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. It also includes stumps and roots of harvested trees. Ratio estimates of downed dead wood to live tree biomass were developed using FORCARB2 simulations and applied at the plot level (Smith et al. 2004). Estimates for downed dead wood correspond to the region and forest type classifications described in Smith et al. (2003). A full set of ratios is provided in Table A-257. An additional component of downed dead wood is a regional average estimate of logging residue based on Smith et al. (2006) applied at the plot level. These are based on a regional average C density at age zero and first order decay; initial densities and decay coefficients are provided in Table A-258. These amounts are added to explicitly account for downed dead wood following harvest. The sum of these two components are then adjusted by the ratio of population totals; that is, the ratio of plot-based to modeled estimates (Domke et al. 2013). An example of this 3-part calculation for downed dead wood in a 25-year-old naturally regenerated loblolly pine forest with 82.99 T C/ha in live trees (Jenkins et al. 2003) in Louisiana is as follows:

First, an initial estimate from live tree C density and Table A-257 (SC, Natural Pine)

$$\text{C density} = 82.99 \times 0.068 = 5.67\ (\text{T C/ha})$$

Second, an average logging residue from age and Table A-257 (SC, softwood)

$$\text{C density} = 5.5 \times e^{(-25/17.9)} = 1.37\ (\text{T C/ha})$$

Third, adjust the sum by the downed dead wood ratio plot-to-model for Louisiana, which was 27.6/31.1 = 0.886

$$\text{C density} = (5.67 + 1.37) \times 0.886 = 6.24\ (\text{T C/ha})$$

Table A-257: Ratio for Estimating Downed Dead Wood by Region and Forest Type

Region[a]	Forest type[a]	Ratio[b]	Region (cont'd)	Forest type (cont'd)	Ratio[b] (cont'd)
	Aspen-Birch	0.078		Douglas-fir	0.100
	MBB/Other Hardwood	0.071		Fir-Spruce	0.090
	Oak-Hickory	0.068		Other Conifer	0.073
NE	Oak-Pine	0.061	PWW	Other Hardwoods	0.062
	Other Pine	0.065		Red Alder	0.095
	Spruce-Fir	0.092		Western Hemlock	0.099
	White-Red-Jack Pine	0.055		Nonstocked	0.020

	Nonstocked	0.019
NLS	Aspen-Birch	0.081
	Lowland Hardwood	0.061
	Maple-Beech-Birch	0.076
	Oak-Hickory	0.077
	Pine	0.072
	Spruce-Fir	0.087
	Nonstocked	0.027
NPS	Conifer	0.073
	Lowland Hardwood	0.069
	Maple-Beech-Birch	0.063
	Oak-Hickory	0.068
	Oak-Pine	0.069
	Nonstocked	0.026
PSW	Douglas-fir	0.091
	Fir-Spruce	0.109
	Hardwoods	0.042
	Other Conifer	0.100
	Pinyon-Juniper	0.031
	Redwood	0.108
	Nonstocked	0.022
PWE	Douglas-fir	0.103
	Fir-Spruce	0.106
	Hardwoods	0.027
	Lodgepole Pine	0.093
	Pinyon-Juniper	0.032
	Ponderosa Pine	0.103
	Nonstocked	0.024
RMN	Douglas-fir	0.062
	Fir-Spruce	0.100
	Hardwoods	0.112
	Lodgepole Pine	0.058
	Other Conifer	0.060
	Pinyon-Juniper	0.030
	Ponderosa Pine	0.087
	Nonstocked	0.018
RMS	Douglas-fir	0.077
	Fir-Spruce	0.079
	Hardwoods	0.064
	Lodgepole Pine	0.098
	Other Conifer	0.060
	Pinyon-Juniper	0.030
	Ponderosa Pine	0.082
	Nonstocked	0.020
SC	Bottomland Hardwood	0.063
	Misc. Conifer	0.068
	Natural Pine	0.068
	Oak-Pine	0.072
	Planted Pine	0.077
	Upland Hardwood	0.067
	Nonstocked	0.013
SE	Bottomland Hardwood	0.064
	Misc. Conifer	0.081
	Natural Pine	0.081
	Oak-Pine	0.063
	Planted Pine	0.075
	Upland Hardwood	0.059
	Nonstocked	0.012

[a] Regions and types as defined in Smith et al. (2003).
[b] The ratio is multiplied by the live tree C density on a plot to produce downed dead wood C density (T C/ha).

Table A-258: Coefficients for Estimating Logging Residue Component of Downed Dead Wood

Region[a]	Forest Type Group[b] (softwood/ hardwood)	Initial C Density (T/ha)	Decay Coefficient
Alaska	hardwood	6.9	12.1
Alaska	softwood	8.6	32.3
NE	hardwood	13.9	12.1
NE	softwood	12.1	17.9
NLS	hardwood	9.1	12.1
NLS	softwood	7.2	17.9
NPS	hardwood	9.6	12.1
NPS	softwood	6.4	17.9
PSW	hardwood	9.8	12.1
PSW	softwood	17.5	32.3
PWE	hardwood	3.3	12.1
PWE	softwood	9.5	32.3
PWW	hardwood	18.1	12.1
PWW	softwood	23.6	32.3
RMN	hardwood	7.2	43.5
RMN	softwood	9.0	18.1
RMS	hardwood	5.1	43.5
RMS	softwood	3.7	18.1
SC	hardwood	4.2	8.9
SC	softwood	5.5	17.9
SE	hardwood	6.4	8.9
SE	softwood	7.3	17.9

[a] Regions are defined in Smith et al. (2003) with the addition of coastal Alaska.
[b] Forest types are according to majority hardwood or softwood species.

Litter carbon

Carbon in the litter layer is currently sampled on a subset of the FIA plots. Litter C is the pool of organic C (including material known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Because litter attributes are only collected on a subset of FIA plots, a model was developed to predict C density based on plot/site attributes for plots that lacked litter information (Domke et al. 2016).

As the litter, or forest floor, estimates are an entirely new model this year, a more detailed overview of the methods is provided here. The first step in model development was to evaluate all relevant variables—those that may influence the formation, accumulation, and decay of forest floor organic matter—from annual inventories collected on FIADB plots (P2) using all available estimates of forest floor C (n = 4,530) from the P3 plots (hereafter referred to as the research dataset) compiled from 2000 through 2014 (Domke et al. 2016).

Random forest, a machine learning tool (Domke et al. 2016), was used to evaluate the importance of all relevant forest floor C predictors available from P2 plots in the research dataset. Given many of the variables were not available due to regional differences in sampling protocols during periodic inventories, the objective was to reduce the random forest regression model to the minimum number of relevant predictors without substantial loss in explanatory power. The form of the full random forest model was:

$$P(FFC_{Full}) = f(lat, lon, elev, fortypgrp, above, ppt, t\max, gmi) + u \qquad (3)$$

where: *lat* = latitude, *lon* = longitude, *elev* = elevation, *fortypgrp* = forest type group, *above* = aboveground live tree C (trees ≥ 2.54 cm dbh), *ppt* = mean annual precipitation, *tmax* = average maximum temperature, *gmi* = the ratio of precipitation to potential evapotranspiration, *u* = the uncertainty in the prediction resulting from the sample-based estimates of the model parameters and observed residual variability around this prediction.

For each replacement, u was independently and randomly generated from a N(0,σ) distribution with σ incorporating the variability from both sources. This process of randomly selecting and incorporating u may be considered an imputation. Each model prediction was replaced independently m times and m separate estimates were combined where m = 1,000 in this analysis.

Due to data limitation in certain regions and inventory periods a series of reduced random forest regression models were used rather than replacing missing variables with imputation techniques in random forest. Database records used to compile estimates for this report were grouped by variable availability and the approaches described herein were applied to replace forest floor model predictions from Smith and Heath (2002). Forest floor C predictions are expressed in $T\bullet ha^{-1}$.

Soil organic carbon

Soil organic carbon (SOC) is the largest terrestrial C sink, and management of this pool is a critical component of efforts to mitigate atmospheric C concentrations. In the U.S., SOC in forests is monitored by the national forest inventory conducted by the FIA program (O'Neill et al. 2005). In previous C inventory submissions, SOC predictions were based, in part, on a model using the State Soil Geographic (STATSGO) database compiled by the Natural Resources Conservation Service (NRCS) (Amichev and Glabraith 2004), hereafter referred to as the country-specific (CS_{soc}) model. Estimates of forest SOC found in the STATSGO database may be based on expert opinion and/or lack systematic field observations, but these country-specific model predictions have been used in past C inventory submissions. The FIA program has been consistently measuring soil attributes as part of the inventory since 2001 and has amassed an extensive inventory of SOC in forest land in the conterminous U.S. and coastal Alaska (O'Neill et al. 2005). More than 5,000 profile observations of SOC on forest land from FIA and the International Soil Carbon Monitoring Network (ISCN 2015) were used to develop and implement a modeling framework used for UNFCCC reporting that includes site-, stand-, and climate-specific variables that yield predictions of SOC stocks and stock changes specific to forest land in the U.S. This section provides a summary of the methodology used to predict SOC for this report. A complete description of the approach is being written by Domke et al. (In prep.).

The data used to develop the new modeling framework to predict SOC on forest land came from the FIA program and the ISCN. Since 2001, the FIA program has collected soil samples on every 16^{th} base intensity plot distributed approximately every 38,848 ha, where at least one forested condition exists (Woodall et al. 2010). On fully forested plots, mineral and organic soils were sampled adjacent to subplots 2, 3, and 4 by taking a single core at each location from two layers: 0 to 10.16 cm and 10.16 to 20.32 cm. The texture of each soil layer was estimated in the field, and physical and chemical properties were determined in the laboratory (U.S. Forest Service 2011). For this analysis, estimates of SOC from the FIA program were calculated following O'Neill et al. (2005):

$$\sum SOC_{FIA\_TOTAL} = C_i \cdot BD_i \cdot t_i \cdot ucf \quad (4)$$

Where $\sum SOC_{FIA\_TOTAL}$ = total mass (Mg C ha^{-1}) of the mineral and organic soil C over all *i*th layers, C_i = percent organic C in the *i*th layer, BD_i = bulk density calculated as weight per unit volume of soil (g·cm^{-3}) at the *i*th soil layer, t_i = thickness (cm) of the *i*th soil layer (either 0 to 10.16 cm or 10.16 to 20.32 cm), and ucf = unit conversion factor (100).

The $SOC_{FIA-TOTAL}$ estimates from each plot were assigned by forest condition on each plot, resulting in 3,667 profiles with SOC layer observations at 0 to 10.16 and 10.16 to 20.32 cm depths. Since the U.S. has historically reported SOC estimates to a depth of 100 cm (Heath et al. 2011, USEPA 2015), ISCN data from forests in the U.S. were harmonized with the FIA soil layer observations to develop model functions of SOC by soil order to a depth of 100 cm. All observations used from the ISCN were contributed by the Natural Resources Conservation Service. A total of 16,504 soil layers from 2,037 profiles were used from ISCN land uses defined as deciduous, evergreen, or mixed forest. The FIA-ISCN harmonized dataset used for model selection and prediction included a total of 5,704 profiles with 23,838 layer observations at depths ranging from 0 to 1,148 cm.

The modeling framework developed to predict SOC for this report was built around strategic-level forest and soil inventory information and auxiliary variables available for all FIA plots in the U.S. The first phase of the new estimation approach involved fitting models using the midpoint of each soil layer from the harmonized dataset and SOC estimates at those midpoints. Several linear and nonlinear models were evaluated, and a log-log model provided the optimal fit to the harmonized data:

$$\log_{10} SOC_i = I + \log_{10} Depth \quad (5)$$

Where $\log_{10} SOC_i$ = SOC density (Mg C ha^{-1} cm depth^{-1}) at the midpoint depth, I = intercept, $\log_{10} Depth$ = profile midpoint depth (cm).

The model was validated by partitioning the complete harmonized dataset multiple times into training and testing groups and then repeating this step for each soil order to evaluate model performance by soil order. Extra sum of squares F tests were used to evaluate whether there were statistically significant differences between the model coefficients from the model fit to the complete harmonized dataset and models fit to subsets of the data by soil order. Model coefficients for each soil order were used to predict SOC for the 20.32 to 100 cm layer for all FIA plots with soil profile observations. Next, the SOC layer observations from the FIA and predictions over the 100 cm profile for each FIA plot were summed:

$$SOC_{100} = SOC_{FIA\_TOTAL} + SOC_{20-100} \quad (6)$$

Where SOC_{100} = total estimated SOC density from 0-100 cm for each forest condition with a soil sample in the FIA database, SOC_{FIA_TOTAL} as previously defined in model (1), SOC_{20-100} = predicted SOC from 20.32 to 100 cm from model (2). Note that bias correction factors will be incorporated into the SOC_{20-100} predictions and evaluated in Domke et al. (In prep.) but were not included in the SOC_{100} estimates used in this analysis.

In the second phase of the modeling framework, SOC_{100} estimates for FIA plots were used to predict SOC for plots lacking SOC_{100} estimates using Random forests , a machine learning tool that uses bootstrap aggregating (i.e., bagging) to develop models to improve prediction (Breimen 2001). Random forests also relies on random variable selection to develop a forest of uncorrelated regression trees. These trees recognize the relationship between a dependent variable, in this case SOC_{100}, and a set of predictor variables. All relevant predictor variables—those that may influence the formation, accumulation, and loss of SOC—from annual inventories collected on all base intensity plots and auxiliary climate, soil, and topographic variables obtained from the PRISM climate group (Northwest Alliance 2015), Natural Resources Conservation Service (NRCS 2015), and U.S. Geological Survey (Danielson and Gesch 2011), respectively, were included in the RF analysis. Due to regional differences in sampling protocols, many of the predictor variables included in the RF variable selection process were not available for all base intensity plots. To avoid problems with data limitations, pruning was used to reduce the RF models to the minimum number of relevant predictors (including both continuous and categorical variables) without substantial loss in explanatory power or increase in root mean squared error (RMSE). The general form of the full RF models were:

$$P(SOC) = f(lat, lon, elev, fortypgrp, ppt, t\max, gmi, order, surfgeo) + u \quad (7)$$

where lat = latitude, lon = longitude, $elev$ = elevation, $fortypgrp$ = forest type group, ppt = mean annual precipitation, $t\max$ = average maximum temperature, gmi = the ratio of precipitation to potential evapotranspiration, $order$ = soil order, $surfgeo$ = surficial geological description, and u = the uncertainty in the prediction resulting from the sample-based estimates of the model parameters and observed residual variability around this prediction. For each replacement, u was independently and randomly generated from a N(0,σ) distribution, with σ incorporating the variability from both sources. This process of randomly selecting and incorporating u may be considered an imputation. Each model prediction was replaced independently m times, and m separate predictions were combined following Rubin (1987):

$$\hat{\hat{C}} = \frac{1}{m}\sum_{k=1}\hat{C}^k \quad (8)$$

where $\hat{\hat{C}}$ is the estimate for the kth completion of the data set. In this analysis, m = 1000, which is markedly larger than the m recommended by Rubin (1987), but given the extremely high level of replacement in this study, it was deemed necessary (Bodner 2008).

Moving the Annual Forest Inventory Backwards and Forwards in Time: Transition Matrices

The accounting framework used this year is fundamentally driven by the annual forest inventory system conducted by the FIA program of the U.S. Forest Service (2015a-d). Unfortunately, the annual inventory system does not extend into the 1990's and the periodic data are not consistent (e.g., different plot design) with the annual inventory necessitating the adoption of a system to "backcast" the annual C estimates. Likewise, forecasting the annual inventory can enable the monitoring of U.S. greenhouse gas emission reduction targets, however, that is an activity beyond the scope of this document. To facilitate the backcasting of the U.S. annual forest inventory C estimates, the accounting framework is comprised of a forest dynamics module (age transition matrices) and a land use dynamics module (land area transition matrices). The forest dynamics module assesses forest sequestration, forest aging, and disturbance effects (i.e., disturbances such as wind, fire, and floods identified by foresters on inventory plots). The land use dynamics module assesses C stock transfers associated with afforestation and deforestation (e.g., Woodall et al. 2015b). Both modules are developed from land use area statistics and C stock change or C stock transfer by age class. The required inputs are estimated from more than 625,000 forest and nonforest observations in the FIA national database (U.S. Forest Service 2015a-c). Model predictions for before or after the annual inventory period are constructed from the accounting framework using only the annual observations. This modeling framework includes opportunities for user-defined scenarios to evaluate the impacts of land use change and disturbance rates on future C stocks and stock changes. As annual forest inventories in the eastern U.S. have largely completed at least one cycle and been remeasured, age and area transition matrices can be empirically informed. In contrast, as annual inventories in western states are still undergoing their first complete cycle they are still in the process of being remeasured, and as a result theoretical transition matrices need to be developed.

Wear and Coulston (2015) and Coulston et al. (2015) provide the framework for the projection model. The overall objective is to estimate unmeasured historical changes and future changes in forest C consistent with annual forest inventory measurements. For most regions, forest conditions are observed at time t_0 and at a subsequent time $t_1=t_{0+s}$, where s is the time step (time measured in years) and is indexed by discrete (5 year) forest age classes. The inventory from t_0 is then backcasted to the year 1990 (on average about 16 years) and projected from t_1 to 2016 (about 5 years for the next inventory report). This backcasting/projection approach requires simulating changes in the age-class distribution resulting from forest aging and disturbance events and then applying C density estimates for each age class. For the North, South (except for west Texas and west Oklahoma), and Rocky Mountains regions of the country, age class transition matrices are estimated from observed changes in age classes between t_0 and t_1. In the remainder of the regions (Pacific Coast including Alaska, west Texas, and west Oklahoma), only one inventory was available (t_0) so transition matrices were derived from theory but informed by the condition of the observed inventory to backcast from t_0 to 1990 and project from t_0 to 2016.

Theoretical Age Transition Matrices

Without any mortality-inducing disturbance, a projection of forest conditions would proceed by increasing all forest ages by the length of the time step until all forest resided in a terminal age class where the forest is retained indefinitely (this is by assumption, where forest C per unit area reaches a stable maximum). For the most basic case, disturbances (e.g., wildfire or timber harvesting) can reset some of the forest to the first age class. Disturbance can also alter the age class in more subtle ways. If a portion of trees in a multiple-age forest dies, the trees comprising the average age calculation change, thereby shifting the average age higher or lower (generally by one age class).

With *n* age classes**,** the age transition matrix (**T)** is an n x n matrix, and each element ($\mathbf{T}_{qr}$) defines the proportion of forest area in class *q* transitioning to class *r* during the time step (*s*). The values of the elements of **T** depend on a number of factors, including forest disturbances such as harvests, fire, storms, and the value of s, especially relative to the span of the age classes. For example, holding area fixed, allowing for no mortality, defining the time step *s* equivalent to the span of age classes, and defining five age classes results in:

$$\boldsymbol{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{pmatrix} \qquad (9)$$

where all forest area progresses to the next age class and forests within the terminal age class are retained forever. With this version of **T**, after five time steps all forests would be in the terminal age class. Relaxing these assumptions changes the structure of **T**. If all disturbances, including harvesting and fire, that result in stand regeneration are accounted for and stochastic elements in forest aging are allowed, **T** defines a traditional Lefkovitch matrix population model (e.g., Caswell 2001) and becomes:

$$\boldsymbol{T} = \begin{pmatrix} 1 - t_1 - d_1 & d_2 & d_3 & d_4 & d_5 \\ t_1 & 1 - t_2 - d_2 & 0 & 0 & 0 \\ 0 & t_2 & 1 - t_3 - d_3 & 0 & 0 \\ 0 & 0 & t_3 & 1 - t_4 - d_4 & 0 \\ 0 & 0 & 0 & t_4 & 1 - d_5 \end{pmatrix} \qquad (10)$$

Where $\mathrm{t_q}$ is the proportion of forest of age class q transitioning to age class *q*+1, d_q is the proportion of age class *q* that experiences a stand-replacing disturbance, and $(1 - t_q - d_q)$ is the proportion retained within age class *q* ($\mathbf{T}_{qr}$).

Projections and Backcast for Pacific Coast, Rocky Mountains, West Texas, and West Oklahoma

Projections of forest C in the Pacific (including Alaska), Rocky Mountains, west Texas and west Oklahoma are based on a life stage model:

$$\Delta \mathrm{C_t} = \mathrm{C_{t+m}} - \mathrm{C_t} = (\mathbf{F_t T} - \mathbf{F_t}) \cdot \mathbf{Den} + \mathbf{L_t} \cdot \mathbf{Den} \qquad (11)$$

In this framework **T** is an age transition matrix that shifts the age distribution of the forest **F**. The difference in forest area by age class between time *t* and *t+s* is $\mathbf{F}_t\mathbf{T}$-$\mathbf{F}_t$. This quantity is multiplied by C density by age class (**Den**) to estimate C stock change of forest remaining forest between *t* and *t+s*. Land use change is accounted for by the addition of $\mathbf{L}_t$·**Den,** where $\mathbf{L}_t$ identifies the age distribution of net land shifts into or out of forests. A query of the forest inventory databases provides estimates of **F** and **Den**, while inventory observations and modeling assumptions are used to estimate **T**. By expanding **Den** to a matrix of C contained in all the constituent pools of forest carbon, projections for all pools are generated.

Land use change is incorporated as a 1 x n vector **L,** with positive entries indicating increased forest area and negative entries indicating loss of forest area, which provides insights of net change only. Implementing a forest area change requires some information and assumptions about the distribution of the change across age classes (the n dimension of **L**). In the eastern states, projections are based on the projection of observed gross area changes by age class. In western states, total forest area changes are applied using rules. When net gains are positive, the area is added to the youngest forest age class; when negative, area is subtracted from all age classes in proportion to the area in each age class category.

Backcasting forest C inventories generally involve the same concepts as forecasting. An initial age class distribution is shifted at regular time steps backwards through time, using a transition matrix (B):

$$\boldsymbol{F}_{t-s} = \boldsymbol{F}_t \cdot \boldsymbol{B} \tag{12}$$

B is constructed based on similar logic used for creating **T**. The matrix cannot simply be derived as the inverse of **T** ($\boldsymbol{F_{t-s}} = \boldsymbol{F_t T^{-1}}$) because of the accumulating final age class (i.e., **T** does not contain enough information to determine the proportion of the final age class derived from the n-1 age class and the proportion that is retained in age class n from the previous time step).[106] However, **B** can be constructed using observed changes from the inventory and assumptions about transition/accumulation including nonstationary elements of the transition model:

$$\boldsymbol{B} = \begin{pmatrix} 1-\sum_q d_q & \mathrm{b}_2 & 0 & 0 & 0 \\ d_1 & 1-b_2 & \mathrm{b}_3 & 0 & 0 \\ d_2 & 0 & 1-b_3 & \mathrm{b}_4 & 0 \\ d_3 & 0 & 0 & 1-b_4 & \mathrm{b}_r \\ d_4 & 0 & 0 & 0 & 1-\mathrm{b}_r \end{pmatrix} \tag{13}$$

Forest area changes need to be accounted for in the backcasts as well:

$$\boldsymbol{F}_{t-s} = \boldsymbol{F_t B} - \boldsymbol{L_t} \tag{14}$$

Where $\mathbf{L_t}$ is the forest area change between t_1 and t_0 as previously defined.

In the Rocky Mountains, age class transition matrices were empirically derived from observed changes in age classes between t_0 and t_1. The frequency of transitions was constructed between age classes observed at t_0 and t_1 to define **T** and between age classes t_1 and t_0 to define **B.** In the Pacific Coast region, including Alaska, west Texas, and west Oklahoma, the theoretical life-stage models described by matrices (9) and (10) were applied. The disturbance factors (d) in both **T** and **B** are derived from the current inventory by assuming that the area of forest in age class 1 resulted from disturbance in the previous period, the area in age class 2 resulted from disturbance in the period before that, and so on. The source of disturbed forest was assumed to be proportional to the area of forest in each age class. For projections (**T**), the average of implied disturbance for the previous two periods was applied. For the backcast (**B**), we move the disturbance frequencies implied by the age class distribution for each time step. For areas with empirical transition matrices, change in forest area ($\mathbf{L}_t$) was backcasted/projected using the change in forest area observed for the period t_0 to t_1. In the Pacific, including Alaska, west Texas, and west Oklahoma, it was assumed that total forest land area remained constant for the time period examined.

Projections and Backcast for North, South, east Texas, and east Oklahoma

For the eastern U.S. a full set of remeasured plots were available. When remeasured data are available, the previously described approach is extended to estimate change more directly; in this case $\Delta C_t = F_t \cdot \delta C$ where ΔC is net stock change by pool within the analysis area, F is as previously defined, and δC is an *n* x cp matrix of per unit area forest C stock change per year by pool (cp) arrayed by forest age class. Inter-period forest C dynamics are previously described, and the age transition matrix (T) is estimated from the observed data directly. Forest C change at the end of the next period is defined as: $\Delta C_{t+s} = F_t \cdot T \cdot \delta C$. Land use change and disturbances such as cutting, fire, weather, insects, and diseases were incorporated by generalizing to account for the change vectors and undisturbed forest remaining as undisturbed forest:

[106] Simulation experiments show that a population that evolves as a function of **T** can be precisely backcast using $\mathbf{T}^{-1}$. However, applying the inverse to a population that is not consistent with the long-run outcomes of the transition model can result in projections of negative areas within some stage age classes.

$$\Delta C_{t+s} = \sum_{d \in L} (A_{td} \cdot T_d \cdot \delta C_d) \quad (15)$$

Where A_{td} = area by age class of each mutually exclusive land category in L which includes d disturbances at time t.

L = (FF, NFF, FNF, F_{cut}, F_{fire}, $F_{weather}$, F_{id}) where FF=undisturbed forest remaining as undisturbed forest, NFF=nonforest to forest conversion, FNF=forest to nonforest conversion, F_{cut}=cut forest remaining as forest, F_{fire}=forest remaining as forest disturbed by fire, $F_{weather}$=forest remaining as forest disturbed by weather, and F_{id}=forest remaining as forest disturbed by insects and diseases. In the case of land transfers (FNF and NFF), T_d is an n x n identity matrix and δC_d is a C stock transfer rate by age. Paired measurements for all plots in the inventory provide direct estimates of all elements of $\delta C, T_d,$ and A_{td} matrices.

Projections are developed by specifying either F_{t+s} or A_{t+sd} for either a future or a past state. To move the system forward, T is specified so that the age transition probabilities are set up as the probability between a time 0 and a time 1 transition. To move the system backward, T is replaced by B so that the age transition probabilities are for transitions from time 1 to time 0. Forecasts were developed by assuming the observed land use transitions and disturbance rates would continue for the next 5 years. Backcasts were developed using a Markov Chain process for land use transitions, observed disturbance rates for fire, weather, and insects. Historical forest cutting was incorporated by using the relationship between the area of forest cutting estimated from the inventory plots and the volume of roundwood production from the Timber Products Output program (U.S. Forest Service 2015d). This relationship allowed for the modification of F_{cut} such that it followed trends described by Oswalt et al. (2014).

Carbon in Harvested Wood Products

Estimates of the Harvested Wood Product (HWP) contribution to forest C sinks and emissions (hereafter called "HWP Contribution") are based on methods described in Skog (2008) using the WOODCARB II model and the U.S. forest products module (Ince et al. 2011). These methods are based on IPCC (2006) guidance for estimating HWP C. The *2006 IPCC Guidelines* provide methods that allow Parties to report HWP Contribution using one of several different accounting approaches: production, stock change, and atmospheric flow, as well as a default method. The various approaches are described below. The approaches differ in how HWP Contribution is allocated based on production or consumption as well as what processes (atmospheric fluxes or stock changes) are emphasized.

- **Production approach**: Accounts for the net changes in C stocks in forests and in the wood products pool, but attributes both to the producing country.
- **Stock-change approach**: Accounts for changes in the product pool within the boundaries of the consuming country.
- **Atmospheric-flow approach**: Accounts for net emissions or removals of C to and from the atmosphere within national boundaries. Carbon removal due to forest growth is accounted for in the producing country while C emissions to the atmosphere from oxidation of wood products are accounted for in the consuming country.
- **Default approach**: Assumes no change in C stocks in HWP. IPCC (2006) requests that such an assumption be justified if this is how a Party is choosing to report.

The U.S. uses the production accounting approach (as in previous years) to report HWP Contribution (Table A-259). Annual estimates of change are calculated by tracking the additions to and removals from the pool of products held in end uses (i.e., products in use such as housing or publications) and the pool of products held in solid waste disposal sites (SWDS).

The annual HWP variables that were used to estimate HWP contribution using the production approach are:

(1) annual change of C in wood and paper products in use in the U.S. and other countries where the wood came from trees harvested in the U.S., and

(2) annual change of C in wood and paper products in SWDS in the U.S. and other countries where the wood came from trees harvested in the U.S.

The sum of these variables yield estimates for HWP contribution under the production accounting approach.

Table A-259: Harvested Wood Products from Wood Harvested in the U.S.—Annual Additions of C to Stocks and Total Stocks Under the Production Approach (Parentheses Indicate Net C Sequestration (i.e., a Net Removal of C from the Atmosphere)

Year	Net C additions per year (MMT C per year)			Total C stocks (MMT C)		
	Total	Products in use	Products in SWDS			
		Total	Total	Total	Products in use	Products in SWDS
1990	-34.0	-18.8	-15.2	1,897	1,250	647
1991	-33.8	-17.4	-16.4	1,931	1,265	665
1992	-33.0	-18.0	-15.1	1,964	1,282	683
1993	-33.5	-17.5	-16.0	1,997	1,297	701
1994	-32.6	-17.3	-15.4	2,031	1,313	718
1995	-30.9	-16.6	-14.3	2,064	1,328	736
1996	-32.2	-17.3	-14.9	2,094	1,342	752
1997	-31.2	-17.8	-13.5	2,127	1,357	769
1998	-32.6	-18.4	-14.2	2,158	1,371	787
1999	-30.9	-18.0	-12.9	2,190	1,385	806
2000	-25.7	-16.8	-8.9	2,221	1,398	824
2001	-26.8	-17.2	-9.5	2,247	1,407	840
2002	-25.6	-16.2	-9.4	2,274	1,416	858
2003	-28.3	-16.3	-12.0	2,299	1,426	874
2004	-28.0	-16.3	-11.7	2,328	1,438	890
2005	-29.3	-17.3	-12.1	2,356	1,449	906
2006	-28.0	-17.4	-10.6	2,385	1,461	924
2007	-20.9	-17.1	-3.8	2,413	1,472	941
2008	-14.8	-16.7	1.9	2,434	1,476	958
2009	-25.2	-17.2	-8.0	2,449	1,474	975
2010	-25.9	-17.6	-8.3	2,474	1,482	992
2011	-27.0	-17.9	-9.0	2,500	1,490	1,010
2012	-28.2	-18.3	-9.9	2,527	1,499	1,028
2013	-29.4	-18.6	-10.8	2,555	1,509	1,046
2014	-30.6	-19.0	-11.7	2,584	1,520	1,065
2015	-	-	-	2,615	1,531	1,084

- Not reported or zero

Table A-260: Harvested Wood Products Sectoral Background Data for LULUCF—U.S. (Production Approach)

Inventory year	1A Annual Change in stock of HWP in use produced from domestic harvest	1B Annual Change in stock of HWP in SWDS produced from domestic harvest	2 HWP Contribution to AFOLU CO_2 emissions/ removals
	$\Delta C_{HWP\ IU\ DH}$	$\Delta C_{HWP\ SWDS\ DH}$	kt CO_2/yr
1990	-15,162	-18,845	-124,692
1991	-16,393	-17,446	-124,076
1992	-15,059	-17,971	-121,110
1993	-16,001	-17,500	-122,836
1994	-15,361	-17,269	-119,644
1995	-14,339	-16,552	-113,267
1996	-14,864	-17,294	-117,911
1997	-13,456	-17,765	-114,476
1998	-14,176	-18,384	-119,389
1999	-12,946	-18,001	-113,469
2000	-8,877	-16,817	-94,213
2001	-9,527	-17,236	-98,131
2002	-9,414	-16,198	-93,910
2003	-12,042	-16,297	-103,910
2004	-11,674	-16,315	-102,626
2005	-12,059	-17,289	-107,609
2006	-10,604	-17,408	-102,711
2007	-3,830	-17,110	-76,779
2008	1,888	-16,663	-54,175
2009	-7,968	-17,222	-92,364
2010	-8,286	-17,578	-94,835
2011	-9,034	-17,937	-98,894
2012	-9,919	-18,289	-103,431
2013	-10,790	-18,630	-107,873
2014	-11,650	-18,965	-112,254

Annual estimates of variables 1A and1B were calculated by tracking the additions to and removals from the pool of products held in end uses (e.g., products in uses such as housing or publications) and the pool of products held in SWDS. The pools include products exported and held in other countries and the pools in the U.S. exclude products made from wood harvested in other countries. Solidwood products added to pools include lumber and panels. End-use categories for solidwood include single and multifamily housing, alteration and repair of housing, and other end uses. There is one product category and one end-use category for paper. Additions to and removals from pools are tracked beginning in 1900, with the exception that additions of softwood lumber to housing begins in 1800. Solidwood and paper product production and trade data are from USDA Forest Service and other sources (Hair and Ulrich 1963; Hair 1958; USDC Bureau of Census 1976; Ulrich, 1985, 1989; Steer 1948; AF&PA 2006a, 2006b; Howard 2003).

The rate of removals from products in use and the rate of decay of products in SWDS are specified by first order (exponential) decay curves with given half-lives (time at which half of amount placed in use will have been discarded from use). Half-lives for products in use, determined after calibration of the model to meet two criteria, are shown in Table A-261. The first criterion is that the WOODCARB II model estimate of C in houses standing in 2001 needed to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. The second criterion is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needed to match EPA estimates of discards over the period 1990 to 2000. This calibration influences the estimate of variable 2A. The calibration also determines the amounts going to SWDS. In addition, WOODCARB II landfill decay rates have been validated by making sure that estimates of methane emissions from landfills based on EPA data are reasonable in comparison to methane estimates based on WOODCARB II landfill decay rates. Decay parameters for products in SWDS are shown in Table A-262.

A key assumption for estimating these variables is that products exported from the U.S. and held in pools in other countries have the same half-lives for products in use, the same percentage of discarded products going to SWDS, and the same decay rates in SWDS. Summaries of net fluxes and stocks for harvested wood in products and SWDS are in Land Converted to Forest Land – Soil C Methods.

Table A-261: Half-life of Solidwood and Paper Products in End-Uses

Parameter	Value	Units
Half-life of wood in single family housing 1920 and before	78.0	Years
Half-life of wood in single family housing 1920–1939	78.0	Years
Half-life of wood in single family housing 1940–1959	80.0	Years
Half-life of wood in single family housing 1960–1979	81.9	Years
Half-life of wood in single family housing 1980 +	83.9	Years
Ratio of multifamily half live to single family half life	0.61	
Ratio of repair and alterations half-life to single family half life	0.30	
Half-life for other solidwood product in end uses	38.0	Years
Half-life of paper in end uses	2.54	Years

Source: Skog, K.E. (2008) “Sequestration of C in harvested wood products for the U.S.” *Forest Products Journal* 58:56–72.

Table A-262: Parameters Determining Decay of Wood and Paper in SWDS

Parameter	Value	Units
Percentage of wood and paper in dumps that is subject to decay	100	Percent
Percentage of wood in landfills that is subject to decay	23	Percent
Percentage of paper in landfills that is subject to decay	56	Percent
Half-life of wood in landfills / dumps (portion subject to decay)	29	Years
Half-life of paper in landfills/ dumps (portion subject to decay)	14.5	Years

Source: Skog, K.E. (2008) “Sequestration of C in harvested wood products for the U.S.” *Forest Products Journal* 58:56–72

Table A-263: Net CO_2 Flux from Forest Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT CO_2 Eq.)

Carbon Pool	1990	1991	1992	1993	1994	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Forest	**(598.8)**	**(605.4)**	**(605.0)**	**(605.1)**	**(598.8)**	**(594.1)**	**(563.6)**	**(560.8)**	**(564.4)**	**(568.6)**	**(570.7)**	**(584.3)**	**(596.0)**	**(605.5)**	**(613.2)**	**(619.9)**	**(647.2)**	**(637.8)**	**(632.4)**	**(631.2)**	**(630.1)**
Aboveground Biomass	(312.4)	(312.3)	(312.1)	(312.0)	(307.5)	(311.3)	(259.1)	(264.5)	(267.1)	(269.5)	(272.1)	(310.3)	(310.4)	(316.4)	(321.0)	(324.5)	(331.2)	(329.4)	(324.6)	(323.5)	(322.5)
Belowground Biomass	(66.6)	(66.6)	(66.5)	(66.4)	(65.5)	(66.5)	(54.3)	(55.6)	(56.0)	(56.5)	(57.0)	(65.7)	(65.4)	(66.7)	(67.6)	(68.2)	(69.6)	(69.3)	(68.2)	(67.9)	(67.6)
Dead Wood	(34.8)	(36.3)	(36.7)	(37.0)	(37.2)	(39.9)	(47.9)	(37.7)	(38.0)	(38.6)	(37.6)	(44.0)	(46.2)	(46.7)	(47.4)	(48.2)	(50.2)	(52.9)	(53.7)	(53.9)	(54.2)
Litter	(35.9)	(35.3)	(35.2)	(35.1)	(34.8)	(34.4)	(24.5)	(26.2)	(26.5)	(26.8)	(27.1)	(28.5)	(28.0)	(28.6)	(29.2)	(29.0)	(34.5)	(33.9)	(33.1)	(32.9)	(32.7)
Soil Organic Carbon	(149.2)	(154.8)	(154.5)	(154.6)	(153.8)	(142.1)	(177.8)	(176.8)	(176.8)	(177.3)	(176.8)	(135.8)	(145.9)	(147.1)	(148.1)	(150.0)	(161.7)	(152.4)	(152.8)	(152.9)	(153.1)
Harvested Wood	**(124.7)**	**(124.1)**	**(121.1)**	**(122.8)**	**(119.6)**	**(113.3)**	**(94.2)**	**(98.1)**	**(93.9)**	**(103.9)**	**(102.6)**	**(107.6)**	**(102.7)**	**(76.8)**	**(54.2)**	**(92.4)**	**(94.8)**	**(98.9)**	**(103.4)**	**(107.9)**	**(112.3)**
Products in Use	(55.6)	(60.1)	(55.2)	(58.7)	(56.3)	(52.6)	(32.6)	(34.9)	(34.5)	(44.2)	(42.8)	(44.2)	(38.9)	(14.0)	6.9	(29.2)	(30.4)	(33.1)	(36.4)	(39.6)	(42.7)
SWDS	(69.1)	(64.0)	(65.9)	(64.2)	(63.3)	(60.7)	(61.7)	(63.2)	(59.4)	(59.8)	(59.8)	(63.4)	(63.8)	(62.7)	(61.1)	(63.1)	(64.5)	(65.8)	(67.1)	(68.3)	(69.5)
Total Net Flux	**(723.5)**	**(729.4)**	**(726.1)**	**(728.0)**	**(718.5)**	**(707.4)**	**(657.8)**	**(658.9)**	**(658.3)**	**(672.5)**	**(673.3)**	**(691.9)**	**(698.7)**	**(682.2)**	**(667.4)**	**(712.3)**	**(742.0)**	**(736.7)**	**(735.8)**	**(739.1)**	**(742.3)**

Table A-264: Net C Flux from Forest Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

Carbon Pool	1990	1991	1992	1993	1994	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Forest	**(163.3)**	**(165.1)**	**(165.0)**	**(165.0)**	**(163.3)**	**(162.0)**	**(153.7)**	**(152.9)**	**(153.9)**	**(155.1)**	**(155.6)**	**(159.3)**	**(162.5)**	**(165.1)**	**(167.2)**	**(169.1)**	**(176.5)**	**(173.9)**	**(172.5)**	**(172.2)**	**(171.8)**
Aboveground Biomass	(85.2)	(85.2)	(85.1)	(85.1)	(83.9)	(84.9)	(70.7)	(72.1)	(72.8)	(73.5)	(74.2)	(84.6)	(84.7)	(86.3)	(87.5)	(88.5)	(90.3)	(89.8)	(88.5)	(88.2)	(88.0)
Belowground Biomass	(18.2)	(18.2)	(18.1)	(18.1)	(17.9)	(18.1)	(14.8)	(15.2)	(15.3)	(15.4)	(15.6)	(17.9)	(17.8)	(18.2)	(18.4)	(18.6)	(19.0)	(18.9)	(18.6)	(18.5)	(18.4)
Dead Wood	(9.5)	(9.9)	(10.0)	(10.1)	(10.2)	(10.9)	(13.1)	(10.3)	(10.4)	(10.5)	(10.2)	(12.0)	(12.6)	(12.7)	(12.9)	(13.1)	(13.7)	(14.4)	(14.6)	(14.7)	(14.8)
Litter	(9.8)	(9.6)	(9.6)	(9.6)	(9.5)	(9.4)	(6.7)	(7.2)	(7.2)	(7.3)	(7.4)	(7.8)	(7.6)	(7.8)	(8.0)	(7.9)	(9.4)	(9.3)	(9.0)	(9.0)	(8.9)
Soil Organic Carbon	(40.7)	(42.2)	(42.1)	(42.2)	(41.9)	(38.8)	(48.5)	(48.2)	(48.2)	(48.3)	(48.2)	(37.0)	(39.8)	(40.1)	(40.4)	(40.9)	(44.1)	(41.6)	(41.7)	(41.7)	(41.7)
Harvested Wood	**(34.0)**	**(33.8)**	**(33.0)**	**(33.5)**	**(32.6)**	**(30.9)**	**(25.7)**	**(26.8)**	**(25.6)**	**(28.3)**	**(28.0)**	**(29.3)**	**(28.0)**	**(20.9)**	**(14.8)**	**(25.2)**	**(25.9)**	**(27.0)**	**(28.2)**	**(29.4)**	**(30.6)**
Products in Use	(15.2)	(16.4)	(15.1)	(16.0)	(15.4)	(14.3)	(8.9)	(9.5)	(9.4)	(12.0)	(11.7)	(12.1)	(10.6)	(3.8)	1.9	(8.0)	(8.3)	(9.0)	(9.9)	(10.8)	(11.7)
SWDS	(18.8)	(17.4)	(18.0)	(17.5)	(17.3)	(16.6)	(16.8)	(17.2)	(16.2)	(16.3)	(16.3)	(17.3)	(17.4)	(17.1)	(16.7)	(17.2)	(17.6)	(17.9)	(18.3)	(18.6)	(19.0)
Total Net Flux	**(197.3)**	**(198.9)**	**(198.0)**	**(198.5)**	**(196.0)**	**(192.9)**	**(179.4)**	**(179.7)**	**(179.5)**	**(183.4)**	**(183.6)**	**(188.7)**	**(190.5)**	**(186.1)**	**(182.0)**	**(194.3)**	**(202.4)**	**(200.9)**	**(200.7)**	**(201.6)**	**(202.5)**

Table A-265: Forest area (1,000 ha) and C Stocks in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Forest Area (1000 ha)	**261,796**	**263,780**	**265,918**	**266,336**	**266,754**	**267,179**	**267,604**	**268,029**	**268,454**	**268,874**	**269,271**	**269,668**	**270,065**	**270,462**	**270,871**	**271,280**	**271,719**	**272,158**
Carbon Pools (MMT C)																		
Forest	**84,891**	**85,713**	**86,500**	**86,653**	**86,806**	**86,960**	**87,115**	**87,271**	**87,430**	**87,593**	**87,758**	**87,925**	**88,094**	**88,271**	**88,445**	**88,617**	**88,789**	**88,961**
Aboveground Biomass	11,896	12,321	12,713	12,784	12,856	12,929	13,002	13,076	13,161	13,246	13,332	13,419	13,508	13,598	13,688	13,777	13,865	13,953
Belowground Biomass	2,442	2,532	2,615	2,630	2,645	2,660	2,676	2,691	2,709	2,727	2,745	2,764	2,782	2,801	2,820	2,839	2,857	2,876
Dead Wood	2,404	2,454	2,519	2,532	2,543	2,553	2,564	2,574	2,586	2,599	2,611	2,624	2,637	2,651	2,665	2,680	2,695	2,710
Litter	5,833	5,881	5,922	5,929	5,936	5,943	5,950	5,958	5,966	5,973	5,981	5,989	5,997	6,006	6,016	6,025	6,034	6,042
Soil Organic Carbon	62,316	62,525	62,730	62,779	62,827	62,875	62,923	62,972	63,009	63,048	63,089	63,129	63,170	63,214	63,255	63,297	63,339	63,381
Harvested Wood	**1,897**	**2,064**	**2,221**	**2,247**	**2,274**	**2,299**	**2,328**	**2,356**	**2,385**	**2,413**	**2,434**	**2,449**	**2,474**	**2,500**	**2,527**	**2,555**	**2,584**	**2,615**
Products in Use	1,250	1,328	1,398	1,407	1,416	1,426	1,438	1,449	1,461	1,472	1,476	1,474	1,482	1,490	1,499	1,509	1,520	1,531
SWDS	647	736	824	840	858	874	890	906	924	941	958	975	992	1,010	1,028	1,046	1,065	1,084
Total Stock	**86,788**	**87,777**	**88,721**	**88,900**	**89,080**	**89,260**	**89,443**	**89,627**	**89,815**	**90,006**	**90,192**	**90,374**	**90,568**	**90,771**	**90,972**	**91,172**	**91,374**	**91,576**

Land Converted to Forest Land – Soil C Methods

A Tier 2 method is applied to estimate soil C stock changes for *Land Converted to Forest Land* (Ogle et al. 2003, 2006; IPCC 2006). For this method, land is stratified by climate, soil types, land-use, and land management activity, and then assigned reference C levels and factors for the forest land and the previous land use. The difference between the stocks is reported as the stock change under the assumption that the change occurs over 20 years. Reference C stocks have been estimated from data in the National Soil Survey Characterization Database (USDA-NRCS 1997), and U.S.-specific stock change factors have been derived from published literature (Ogle et al. 2003; Ogle et al. 2006). Land use and land use change patterns are determined from a combination of the Forest Inventory and Analysis Dataset (FIA), the 2010 National Resources Inventory (NRI) (USDA-NRCS 2013), and National Land Cover Dataset (NLCD) (Homer et al. 2007). See Annex 3.12 for more information about this method (Methodology for Estimating N_2O Emissions, CH_4 Emissions and Soil Organic C Stock Changes from Agricultural Soil Management).

Table A-266 summarizes the annual change in mineral soil C stocks from U.S. soils that were estimated using a Tier 2 method (Tg C/yr). The range is a 95 percent confidence interval from 50,000 simulations (Ogle et al. 2003, 2006). Table A-267 summarizes the total land areas by land use/land use change subcategory for mineral soils between 1990 and 2014 estimated with a Tier 2 approach and based on analysis of USDA National Resources Inventory data (USDA-NRCS 2013).

Table A-266: Annual change in Mineral Soil C stocks from U.S. agricultural soils that were estimated using a Tier 2 method (Tg C/yr)

Category	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cropland Converted to Forest Land	0.04	0.05	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.07
	(0.02 to 0.07)	(0.02 to 0.08)	(0.01 to 0.08)	(0.02 to 0.09)	(0.02 to 0.09)	(0.02 to 0.1)	(0.02 to 0.1)	(0.02 to 0.1)	(0.02 to 0.11)	(0.02 to 0.12)
Grassland Converted to Forest Land	0.12	0.13	0.12	0.14	0.15	0.17	0.16	0.17	0.17	0.18
	(0.06 to 0.19)	(0.05 to 0.22)	(0.03 to 0.21)	(0.05 to 0.25)	(0.05 to 0.26)	(0.07 to 0.28)	(0.06 to 0.27)	(0.07 to 0.29)	(0.05 to 0.29)	(0.06 to 0.32)
Other Lands Converted to Forest Land	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
	(0.01 to 0.03)	(0.01 to 0.03)	(0.01 to 0.03)	(0.01 to 0.04)	(0.01 to 0.04)	(0.01 to 0.04)	(0.01 to 0.04)	(0.01 to 0.04)	(0.01 to 0.05)	(0.01 to 0.05)
Settlements Converted to Forest Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0 to 0)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)
Wetlands Converted to Forest Land	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
	(0 to 0)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)
Total Lands Converted to Forest Lands	**0.18**	**0.20**	**0.19**	**0.22**	**0.23**	**0.26**	**0.25**	**0.27**	**0.27**	**0.29**

Note: The range is a 95 percent confidence interval from 50,000 simulations (Ogle et al. 2003, 2006).

Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cropland Converted to Forest Land	0.06	0.06	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02
	(0.02 to 0.11)	(0.02 to 0.11)	(0.02 to 0.09)	(0.01 to 0.1)	(0.01 to 0.1)	(0.01 to 0.09)	(0 to 0.05)	(0.01 to 0.05)	(0 to 0.04)	(0 to 0.04)
Grassland Converted to Forest Land	0.17	0.17	0.15	0.15	0.14	0.14	0.07	0.07	0.07	0.07
	(0.05 to 0.31)	(0.05 to 0.31)	(0.04 to 0.27)	(0.04 to 0.28)	(0.03 to 0.26)	(0.03 to 0.26)	(0.01 to 0.13)	(0.02 to 0.14)	(0.01 to 0.13)	(0.01 to 0.13)
Other Lands Converted to Forest Land	0.03	0.03	0.03	0.03	0.02	0.03	0.01	0.01	0.01	0.01
	(0.01 to 0.05)	(0.01 to 0.05)	(0.01 to 0.05)	(0.01 to 0.05)	(0.01 to 0.05)	(0.01 to 0.05)	(0 to 0.02)	(0 to 0.02)	(0 to 0.02)	(0 to 0.02)
Settlements Converted to Forest Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)
Wetlands Converted to Forest Land	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)
Total Lands Converted to Forest Lands	**0.27**	**0.27**	**0.24**	**0.24**	**0.23**	**0.22**	**0.11**	**0.11**	**0.10**	**0.10**

Note: The range is a 95 percent confidence interval from 50,000 simulations (Ogle et al. 2003, 2006).

Category	**2010**	**2011**	**2012**	**2013**	**2014**
Cropland Converted to Forest Land	0.02	0.02	0.02	0.02	0.02
	(0 to 0.04)	(0 to 0.04)	(0 to 0.04)	(0 to 0.04)	(0 to 0.04)
Grassland Converted to Forest Land	0.07	0.07	0.06	0.06	0.06
	(0.01 to 0.13)	(0.01 to 0.13)	(0 to 0.13)	(0 to 0.13)	(0 to 0.13)
Other Lands Converted to Forest Land	0.01	0.01	0.01	0.01	0.01
	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)	(0 to 0.01)
Settlements Converted to Forest Land	0.00	0.00	0.00	0.00	0.00
	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)
Wetlands Converted to Forest Land	0.00	0.00	0.00	0.00	0.00
	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)
Total Lands Converted to Forest Lands	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**

Note: The range is a 95 percent confidence interval from 50,000 simulations (Ogle et al. 2003, 2006).

Table A-267: Total land areas (hectares) by land use/land use change subcategory for mineral soils between 1990 and 2014

Conversion Land Areas (Hectares x 10^6)	1990	1991	1992	1993	1994	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cropland Converted to Forest Land	0.22	0.21	0.21	0.22	0.21	0.25	0.23	0.23	0.23	0.23	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20
Grassland Converted to Forest Land	0.58	0.59	0.59	0.62	0.64	0.70	0.65	0.66	0.66	0.64	0.64	0.64	0.65	0.63	0.64	0.65	0.65	0.65	0.66	0.66	0.66
Other Lands Converted to Forest Land	0.09	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07
Settlements Converted to Forest Land	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Wetlands Converted to Forest Land	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total Lands Converted to Forest Lands	**0.91**	**0.91**	**0.92**	**0.97**	**0.98**	**1.09**	**1.03**	**1.03**	**1.04**	**1.02**	**1.02**	**1.02**	**1.03**	**0.96**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**	**0.97**

Note: Estimated with a Tier 2 approach and based on analysis of USDA National Resources Inventory data (USDA-NRCS 2013).

Uncertainty Analysis

The uncertainty analyses for total net flux of forest C (see Table 6-14 in the FLRFL section) are consistent with the IPCC-recommended Tier 1 methodology (IPCC 2006). Specifically, they are considered approach 1 (propagation of error [Section 3.2.3.1]) (IPCC 2006). To better understand the effects of covariance, the contributions of sampling error and modeling error were parsed out. In addition, separate analyses were produced for forest ecosystem and HWP flux.

Estimates of forest C stocks in the U.S. are based on C estimates assigned to each of several thousand inventory plots from a regular grid. Uncertainty in these estimates and uncertainty associated with change estimates arise from many sources including sampling error and modeling error. Here we focus on these two types of error but acknowledge several other sources of error are present in the overall stock and stock change estimates. In terms of sampling based uncertainty, Design based estimators described by Bechtold and Patterson (2005) were used to quantify the variance of C stock estimates. In this section we denote the estimate of C stock at time *t* as C_t and the variances of the estimate of C stock for time *t* as $Var(C_t)$. These calculations follow Bechtold and Patterson (2005). The variance of stock change is then:

$$Var(C_{t2}-C_{t1})=Var(C_{t2})+Var(C_{t1})-2\cdot Cov(C_{t2},C_{t1}) \quad (16)$$

The uncertainty of a stock estimate associated with sampling error is $U(C_t)_s= Var(C_t)^{0.5}$. The uncertainty of a stock changes estimate associated with sampling error is $U(\Delta C)_s=Var(C_{t2}-C_{t1})^{0.5}$.

Model-based uncertainty is important because the pool-level C models have error. The total modeling mean-squared error (MSE_m) is approximately 1,622 $(Mg/ha)^2$. The percent modeling error at time *t* is

$$\%U(C_t)_m = 100\cdot MSE_m/d_t \quad (17)$$

Where d_t is the total C stock density at time $_t$ calculated as C_t/A_t where A_t is the forest area at time *t*.

The uncertainty of C_t from modeling error is

$$U(C_t)_m=C_t\cdot\%U(C_t)_m/100 \quad (18)$$

The model-based uncertainty with respect to stock change is then

$$U(\Delta C)_m=(\ U(C_{t1})_m + U(C_{t2})_m - 2\cdot Cov(U(C_{t1m},C_{t2m})))^{0.5} \quad (19)$$

The sampling and model based uncertainty are combined for an estimate of total uncertainty. We considered these sources of uncertainty independent and combined as follow for stock change for stock change (ΔC):

$$U(\Delta C)=(\ U(\Delta C)_m{}^2+ U(\Delta C)_s{}^2)^{0.5} \text{ and the 95 percent confidence bounds was } +\text{-}\ 2\cdot U(\Delta C) \quad (20)$$

The mean square error (MSE) of pool models was (MSE, $[Mg\ C/ha]^2$): soil C (1,143.0), litter (78.0), live tree (259.6), dead trees (101.5), understory (0.9), down dead wood (38.9), total MSE (1,621.9).

Numerous assumptions were adopted for creation of the forest ecosystem uncertainty estimates. Potential pool error correlations were ignored. Given the magnitude of the MSE for soil, including correlation among pool error would not appreciably change the modeling error contribution. Modeling error correlation between time 1 and time 2 was assumed to be 1. Because the MSE was fixed over time we assumed a linear relationship dependent on either the measurements at two points in time or an interpolation of measurements to arrive at annual flux estimates. Error associated with interpolation to arrive at annual flux is not included.

Uncertainty about net C flux in HWP is based on Skog et al. (2004) and Skog (2008). Latin hypercube sampling is the basis for the HWP Monte Carlo simulation. Estimates of the HWP variables and HWP Contribution under the production approach are subject to many sources of uncertainty. An estimate of uncertainty is provided that evaluated the effect of uncertainty in 13 sources, including production and trade data and parameters used to make the estimate. Uncertain data and parameters include data on production and trade and factors to convert them to C, the census-based estimate of C in housing in 2001, the EPA estimate of wood and paper discarded to SWDS for 1990 to 2000, the limits on decay of wood and paper in SWDS, the decay rate (half-life) of wood and paper in SWDS, the proportion of products produced in the United States made with wood harvested in the United States, and the rate of storage of wood and paper C in other countries that came from U.S. harvest, compared to storage in the United States.

The uncertainty about HWP and forest ecosystem net C flux were combined and assumed to be additive. Typically when propagating error from two estimates the variances of the estimates are additive. However, the uncertainty around the HWP flux was approximated using a Monte Carlo approach which resulted in the lack of a variance estimate for HWP C flux. Therefore, we considered the uncertainty additive between the HWP sequestration and the *Forest Land Remaining Forest Land* sequestration. Further, we assumed there was no covariance between the two estimates which is plausible as the observations used to construct each estimate are independent.

Emissions from Forest Fires

CO_2 Emissions from Forest Fires

As stated in other sections, the forest inventory approach implicitly accounts for emissions due to disturbances. Net C stock change is estimated from successive C stock estimates. A disturbance, such as a forest fire, removes C from the forest. The inventory data, on which net C stock estimates are based, already reflects the C loss from such disturbances because only C remaining in the forest is estimated. Estimating the CO_2 emissions from a disturbance such as fire and adding those emissions to the net CO_2 change in forests would result in double-counting the loss from fire because the inventory data already reflect the loss. There is interest, however, in the size of the CO_2, CH_4, and N_20 emissions from disturbances such as fire. These estimated emissions from forest fires are based on IPCC (2006) methodology, which includes a combination of U.S. specific data on area burned and potential fuel available for combustion along with IPCC default combustion and emission factors.

Emissions were calculated following IPCC (2006) methodology, according to equation 2.27 of IPCC (2006, Volume 4, Chapter 2), which in general terms is:

$$\text{Emissions} = \text{Area burned} \times \text{Fuel available} \times \text{Combustion factor} \times \text{Emission factor} \times 10^{-3} \quad (21)$$

Where the estimate for emissions is in units of metric tons (MT), which is generally summarized as million metric tons (MMT) per year. Area burned is the annual total area of forest fire in hectares. Fuel available is the mass of fuel available for combustion in metric tons dry weight per hectare. Combustion factor is the proportion of fuel consumed by fire and is unitless. The emission factor is gram of emission (in this case CO_2) per kilogram dry matter burnt, and the "10^{-3}" balances units. The first two factors are based on datasets specific to U.S. forests, whereas the last two factors employ IPCC (2006) default values.

Area burned is based on annual area of forest fires according to Monitoring Trends in Burn Severity (MTBS) MTBS Data Summaries 2015; Eidenshink et al. 2007) dataset summaries,[107] which include fire data for all 49 states that are a part of these estimates. That is, the MTBS data used here include the 48 conterminous states as well as Alaska, including interior Alaska; but note that the fire data used are also reduced to only include managed land. Summary information includes fire identity, year, location, area burned, fire intensity, and other fire characteristics. In addition to forest fires, the MTBS data include all wildland and prescribed fires on other ecosystems such as grasslands and rangelands; the "forest fire" distinction is not included as a part of identifying information for each fire. An additional spatial dataset – National MTBS Burned Area Boundaries – provides information to locate fires.[108] These individual-fire boundary data were used to partition the area burned in each fire to forest versus non-forest.

The MTBS fire data records include land cover information from the National Land Cover (NLCD) dataset (Homer et al. 2015), which can be used to distinguish forest fires from other wildland fires within the MTBS data. However, the forest land cover of the NLCD data, including the 2011 land cover (Homer et al. 2015) provides an estimate of forest land that is approximately 20 percent lower than forest area identified by the forest inventory of the USDA Forest Service (USDA Forest Service 2015b, e.g., data as of 2 June 2015) for the conterminous U.S. This suggests that annual area of forest fires identified with the NLCD cover data may underestimate area of forest burned, but the difference between USDA Forest Service (2015) and Homer et al. (2015) for each individual fire, if any, is dependent on specific areas where the fires actually occur. As an alternative data source, forest area for conterminous U.S. and Alaska are defined by Ruefenacht et al. (2008). The forest area for the conterminous states representative of approximately 2002 is within 2 percent of the forest areas estimated for 1990 through 2014 in US EPA (2015). These data were used to partition the perimeter data to forest for each fire (that is, area of forest relative to entire area of the fire for each MTBS fire). We assume that while changes in forests have occurred both before and since the data for Ruefenacht et al. (2008) were compiled, changes in forest versus non-forest status on lands subject to wildfires are likely minimal enough to make this dataset appropriate for this use. In addition, the Alaska forest area was allocated to managed and unmanaged areas according to Ogle et al. (in preparation), as discussed in more detail above.

The burned area perimeter dataset also was used to identify Alaska fires that were co-located with the area of permanent inventory plots of the USDA Forest Service's (2015b) forest inventory along the southern coastal portion of the state. The only MTBS-identified burned forest areas in Alaska that coincide with the Forest Service's permanent plot

[107] See <http://www.mtbs.gov/dataaccess.html>.

[108] See <http://www.mtbs.gov/dataaccess.html>.

inventoried area were on the northern (or Cook Inlet) side of the Kenai Peninsula, which is generally identified as boreal forest. From this, all MTBS fires of interest identified in Alaska are considered boreal forests.

Estimates of fuel availability are based on plot level forest inventory data, which are summarized by state and applied to all fires within the respective states. Plot level C stocks are defined by C conversion factors applied to current USDA Forest Service inventory data (USDA Forest Service 2015b; US EPA 2015; Smith et al. 2010) and summarized by state. We assume that while changes in forests have occurred over the years since the 1990 start of the reporting interval, the current general range of plot level C densities as determined by forest types and stand structures can be used as a representation of the potential fuel availability over the forest lands of a given state. We use the current forest inventory data[109] and the distribution of metric tons dry matter per hectare as the inputs for fuel availability. Fuel estimated for wildfires included all aboveground biomass (live trees and understory) as well as standing dead trees, down dead wood, and forest floor litter; whereas, fuel estimated for prescribed fires was based on the non-living components only.

The combustion factor used here for temperate forests is 0.45 (see Table 2.6 Volume 4, Chapter 2 of IPCC 2006). Similarly, the emission factor is an IPCC (2006) default, which for CO_2 is 1,569 g CO_2 per kg dry matter of fuel (see Table 2.5 Volume 4, Chapter 2 of IPCC 2006). With the application of equation 2.27 of IPCC (2006, in Volume 4, Chapter 2) defaults were used for mass of fuel available for the Alaska estimates because of the very limited coverage of boreal forests in the available U.S. forest inventories (see Table 2.4 Volume 4, Chapter 2 of IPCC 2006). Note that the values used for Alaska (Table 2.4 of IPCC 2006) represent the product of fuel available and the combustion factor.

Table A-268 provides summary values of annual area burned, area identified as forest fire, and emissions calculated according to equation 2.27 of IPCC (2006, in Volume 4, Chapter 2). The emission factor for CO_2 from Table 2.5 Volume 4, Chapter 2 of IPCC (2006) is provided in Table A-269. Separate calculations were made for each wild and prescribed fire in each state for each year. The results as MT CO_2 were summed to the MMT CO_2 per year values represented in Table A-268, and C emitted per year (Table A-268 and Table A-271) was based on multiplying by the conversion factor 12/44 (IPCC 2006).

Table A-268: Areas (Hectares) from Wildfire Statistics and Corresponding Estimates of C and CO_2 (MMT/yr) Emissions for Wildfires and Prescribed Fires[a]

	Conterminous 48 States - Wildfires				Alaska - Wildfires				Prescribed Fires (all 49 states)			
Year	Reported area burned (1000 ha)	Forest area burned (1000 ha)	C emitted (MMT/yr)	CO_2 emitted (MMT/yr)	Reported area burned (1000 ha)	Forest area burned (1000 ha)	C emitted (MMT/yr)	CO_2 emitted (MMT/yr)	Reported area burned (1000 ha)	Forest area burned (1000 ha)	C emitted (MMT/yr)	CO_2 emitted (MMT/yr)
1990	464	185	5.8	21.3	572	304	5.3	19.5	10	6	0.0	0.2
1991	549	309	9.3	34.2	308	186	3.3	12.0	12	8	0.1	0.2
1992	598	180	5.5	20.3	12	8	0.1	0.5	5	4	0.0	0.1
1993	422	80	1.2	4.4	161	114	2.0	7.3	4	2	0.0	0.0
1994	1,305	629	19.1	70.2	97	68	1.2	4.4	16	10	0.1	0.2
1995	544	131	2.5	9.0	13	10	0.2	0.6	16	11	0.1	0.2
1996	2,047	509	13.0	47.7	0	0	0.0	0.0	25	18	0.1	0.5
1997	233	74	1.6	6.0	0	0	0.0	0.0	40	10	0.1	0.3
1998	648	271	6.4	23.5	71	51	0.9	3.3	52	21	0.1	0.5
1999	1,743	463	13.6	49.9	349	164	2.9	10.5	103	49	0.3	1.1
2000	2,266	1,020	26.1	95.8	312	161	2.8	10.4	83	23	0.2	0.6
2001	1,113	469	13.8	50.6	44	40	0.7	2.6	56	30	0.2	0.8
2002	1,594	1,114	29.2	107.0	857	636	11.2	40.9	30	16	0.1	0.5
2003	1,453	792	20.4	74.7	234	157	2.8	10.1	19	13	0.1	0.3
2004	491	321	6.5	23.8	2,656	1,963	34.4	126.3	62	35	0.2	0.9
2005	1,730	601	11.7	42.9	1,964	1,254	22.0	80.7	107	62	0.3	1.3
2006	3,609	947	26.5	97.1	106	81	1.4	5.2	111	80	0.6	2.1
2007	3,208	1,488	40.3	147.9	239	81	1.4	5.2	158	97	0.6	2.2
2008	1,614	724	23.9	87.7	38	17	0.3	1.1	322	252	1.6	6.0
2009	1,488	493	9.6	35.0	1,143	683	12.0	44.0	412	318	2.1	7.8
2010	582	141	3.3	12.2	311	174	3.1	11.2	771	658	5.0	18.4
2011	3,166	1,226	20.2	73.9	96	55	1.0	3.5	998	245	1.6	5.9
2012	3,429	1,463	36.5	133.7	102	42	0.7	2.7	151	110	0.8	2.9

[109] Retrieved from <http://apps.fs.fed.us/fiadb-downloads/datamart.html> on June 2, 2015.

2013	1,091	637	17.6	64.7	498	347	6.1	22.3	277	267	1.5	5.3
2014[b]	1,091	637	17.6	64.7	498	347	6.1	22.3	277	267	1.5	5.3

[a] These emissions have already been accounted for in the estimates of net annual changes in C stocks, which accounts for the amount sequestered minus any emissions, including the assumption that combusted wood may continue to decay through time.
[b] The data for 2014 were incomplete when these estimates were summarized; therefore 2013, the most recent available estimate, is applied to 2014.

Table A-269: Emission Factors for Extra Tropical Forest Burning and 100-year GWP (AR4), or equivalence ratios, of CH_4 and N_2O to CO_2

Emission Factor (g per kg dry matter burned)[a]		Equivalence Ratios[b]	
CH_4	4.70	CH_4 to CO_2	25
N_2O	0.26	N_2O to CO_2	298
CO_2	1,569	CO_2 to CO_2	1

[a] IPCC (2006)
[b] IPCC (2007)

The set of fire emissions estimates using MODIS imagery and post-fire observations developed for Alaska by Veraverbeke et al. (2015a) is used here to provide a comparison with the estimates developed here (i.e., Table A-16). The spatial Alaskan Fire Emissions Database (AKFED, Veraverbeke et al. 2015b) was partitioned to forest land based on both Ruefenacht et al. (2008) and Homer et al. (2015) as well as managed/unmanaged (Ogle et al. in preparation). The estimates of annual C emitted from fire are in Table A-270, which also includes the estimates for managed forest land (both wildland and prescribed) that underlie the values provided in Table A-268. Note that the values in the six rightmost columns effectively partition the C emissions estimates provided in Veraverbeke et al. (2015a, see Table 2). That is, Table A-270, column 2 provides the estimates developed for this Inventory while each of columns 3-5 and 6-8 sum to the emissions estimates of Veraverbeke et al. (2015a); the differences between the two sets are how they are partitioned according to forest land.

Table A-270: Estimated C emissions (MMT/yr) for fire based on the AKFED, and partitioned to managed forest land in Alaska

		Forest land based on Ruefenacht et al. (2008)			Forest land based on Homer et al. (2015)		
Year[a]	Managed forest land (Table A-14)[b]	Managed forest land	Unmanaged forest land	Non-forest land	Managed forest land	Unmanaged forest land	Non-forest land
	C emitted (MMT/year)						
2001	0.7	0.8	0.3	0.0	0.1	0.0	1.1
2002	11.2	12.7	3.3	0.8	1.5	0.4	14.8
2003	2.8	4.0	1.4	0.0	0.6	0.2	4.7
2004	34.4	51.8	16.6	1.0	7.0	2.5	59.9
2005	22.0	29.8	14.1	1.7	4.1	1.9	39.6
2006	1.4	0.7	0.1	0.0	0.1	0.0	0.7
2007	1.5	1.4	1.0	2.9	0.3	0.1	4.9
2008	0.3	0.4	0.4	0.1	0.1	0.0	0.8
2009	12.0	16.3	9.8	0.2	1.5	0.7	24.1
2010	4.7	4.6	1.1	0.3	0.7	0.1	5.1
2011	1.0	1.5	0.3	0.1	0.8	0.2	0.9
2012	0.8	0.8	0.2	0.2	0.4	0.2	0.6
2013	6.1	7.4	2.5	0.3	4.7	1.7	3.7

[a] The AKFED data include the years 2001-2013 (Veraverbeke et al. 2015b).
[b] Values include both wildland and prescribed fires in Alaska.

Non-CO_2 Emissions from Forest Fires

Emissions of non-CO_2 gasses – specifically, methane (CH_4) and nitrous oxide (N_2O) – from forest fires are estimated using the same methodology described above (i.e., equation 2.27 of IPCC 2006, Volume 4, Chapter 2). The only difference in calculations is the gas-specific emission factors, which are listed in Table A-269. The summed annual estimates are provided in Table A-271. Conversion of the CH_4 and N_2O estimates to CO_2 equivalents (as provided in Chapter 6-2) is based on global warming potentials (GWPs) provided in the IPCC Fourth Assessment Report (AR4) (IPCC 2007), which are the equivalence ratios listed in Table A-269. An example application of these ratios for the current year's estimate of CH_4 emissions is: 7.34 MMT CO_2 equiv. = 293,836 MT CH_4 × (25 kg CO_2 / 1 kg CH_4) × 10^{-6}.

Uncertainty about the non-CO_2 estimates is based on assigning a probability distribution to represent the estimated precision of each factor in equation 2.27 (of IPCC 2006). These probability distributions are randomly sampled with each calculation, and this is repeated a large number of times to produce a histogram, or frequency distribution of values for the calculated emissions. That is, a simple Monte Carlo ("Approach 2") method was employed to propagate uncertainty in the equation (IPCC 2006). In general, probability densities are normal and also considered marginal distributions.

Estimates of burned forest area from the MTBS data (MTBS Data Summaries 2015; Ruefenacht et al. 2008; Ogle et al. in preparation) are assigned a normal distribution with relatively low uncertainty with a standard deviation of 4 percent, and these were sampled independently by year (Homer et al. 2015; Hao and Larkin 2014; Eidenshink et al. 2007). Fuel available is based on the distribution of plot level C densities (as metric tons dry matter per hectare) as defined within the current USDA Forest Service inventory data (USDA Forest Service 2015; US EPA 2015). We assume that current data adequately represent the general range of plot level C densities within a state's forest land, given the limitations of the older inventory data as discussed elsewhere in this report. The plot-level C densities are summarized as dry weight densities (metric tons per hectare) for each plot with all aboveground dry weight summed as potential fuel for wildfires and all non-living components of aboveground dry weight assigned as potential fuel for prescribed fires. Frequency distributions of the plot data indicate that densities are distributed approximately lognormally. Each state's data are fit to a lognormal distribution, and these were sampled independently by state and year. Note that each state has separate lognormal distributions for wild versus prescribed fire fuels, yet the same sampling sequence was used (i.e., jointly distributed within each state by year). Estimates for the Alaska fuel-by-combustion value as well as the combustion factor and emission factors are normal distributions with mean and standard deviations as defined in the tables (IPCC 2006 Tables 2.4, 2.5, and 2.6). These were sampled independently by year, and truncated to positive values where necessary. The equivalence ratios (Table A-269) to represent estimates as CO_2 equivalent were not considered uncertain values for these results.

Table A-271: Estimated C Released and Estimates of Non-CO_2 Emissions (MMT/yr) for U.S. forests

Year	C emitted (MMT/yr)	CH_4 emitted (MMT/yr)	N_2O (MMT/yr)
1990	11.2	0.13	0.007
1991	12.6	0.15	0.008
1992	5.7	0.07	0.004
1993	3.2	0.04	0.002
1994	20.4	0.23	0.013
1995	2.7	0.03	0.002
1996	13.2	0.15	0.008
1997	1.7	0.02	0.001
1998	7.4	0.09	0.005
1999	16.8	0.20	0.011
2000	29.1	0.33	0.018
2001	14.7	0.17	0.010
2002	40.5	0.48	0.026
2003	23.2	0.26	0.015
2004	41.2	0.48	0.027
2005	34.1	0.40	0.022
2006	28.5	0.33	0.018
2007	42.4	0.49	0.027
2008	25.8	0.32	0.018
2009	23.7	0.28	0.016
2010	11.4	0.13	0.007
2011	22.7	0.27	0.015
2012	38.0	0.44	0.024
2013	25.2	0.29	0.016

2014[a]	25.2	0.29	0.016

[a] The data for 2014 were incomplete when these estimates were summarized; therefore 2013, the most recent available estimate, is applied to 2014.

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3.14. Methodology for Estimating CH_4 Emissions from Landfills

Landfill gas is a mixture of substances generated when bacteria decompose the organic materials contained in solid waste. By volume, landfill gas is about half CH_4 and half CO_2.[110] The amount and rate of CH_4 generation depends upon the quantity and composition of the landfilled material, as well as the surrounding landfill environment.

Not all CH_4 generated within a landfill is emitted to the atmosphere. The CH_4 can be extracted and either flared or utilized for energy, thus oxidizing the CH_4 to CO_2 during combustion. Of the remaining CH_4, a portion oxidizes to CO_2 as it travels through the top layer of the landfill cover. In general, landfill-related CO_2 emissions are of biogenic origin and primarily result from the decomposition, either aerobic or anaerobic, of organic matter such as food or yard wastes.[111] To estimate the amount of CH_4 produced in a landfill in a given year, information is needed on the type and quantity of waste in the landfill, as well as the landfill characteristics (e.g., size, aridity, waste density). This information is not available for the majority of landfills in the United States. Consequently, to estimate CH_4 generation, a methodology was developed (i.e., the first order decay waste model) based on the quantity of waste placed in landfills nationwide each year and model parameters from the analysis of measured CH_4 generation rates for U.S. landfills with gas recovery systems.

From various studies, surveys, and regulatory reporting programs (i.e., the Greenhouse Gas Reporting Program [GHGRP]) of the generation and disposal of solid waste, estimates of the amount of waste placed in MSW and industrial waste landfills were developed for previous Inventory years. The current Inventory relied heavily on the GHGRP data for municipal solid waste (MSW) landfills for current and historical (since the year the landfill started accepting waste) reported waste disposal quantities. A database of measured CH_4 generation rates at MSW landfills with gas recovery systems was compiled and analyzed. The results of this analysis and other studies were used to develop an estimate of the CH_4 generation potential for use in the first order decay model. In addition, the analysis and other studies provided estimates of the CH_4 generation rate constant as a function of precipitation. The first order decay (FOD) model was applied to annual waste disposal estimates for each year and for three ranges of precipitation to estimate CH_4 generation rates nationwide for the years of interest. Based on the organic content of industrial wastes and the estimates of the fraction of these wastes sent to industrial waste landfills, CH_4 emissions from industrial waste landfills were also estimated using the first order decay model. Total CH_4 emissions were estimated by adding the CH_4 generation from MSW and industrial landfills and subtracting the amounts of CH_4 recovered for energy or flaring at MSW landfills[112] and the amount oxidized in the soil at MSW and industrial landfills. The steps taken to estimate CH_4 emissions from U.S. landfills for the years 1990 through the current inventory year are discussed in greater detail below.

Figure A-24 presents the CH_4 emissions process—from waste generation to emissions—in graphical format.

Step 1: Estimate Annual Quantities of Solid Waste Placed in Landfills

For 1989 to 2014, estimates of the annual quantity of waste placed in MSW landfills were developed from a survey of State agencies as reported in the State of Garbage (SOG) in America surveys (Shin 2014; BioCycle 2010), adjusted to include U.S. territories.[113] The SOG survey is the only continually updated nationwide survey of waste disposed in landfills in the United States. Table A-272 shows estimates of waste quantities contributing to CH_4 emissions. The table shows SOG estimates of total waste generated and total waste landfilled (adjusted for U.S. territories) for various years over the 1990 to 2013 timeframe.

State-specific landfill waste generation data and a national average disposal factor for 1989 through 2008 were obtained from the SOG survey for every two years (i.e., 2002, 2004, 2006, and 2008 as published in BioCycle 2006; 2008, and 2010). The most recent SOG survey was published in 2014 (Shin 2014) for the 2011 year. A linear interpolation was used for the amount of waste generated in 2001, 2003, 2005, 2007, 2009, 2010, 2012, 2013, and 2014 because no SOG surveys were published for those years. Upon publication of the next SOG survey, the waste landfilled for 2012 to 2014 will be updated. Estimates of the quantity of waste landfilled from 1989 to the current inventory year are determined by applying a waste disposal factor to the total amount of waste generated (i.e., the SOG data). A waste disposal factor is determined for each year a SOG survey is published and is the ratio of the total amount of waste landfilled to the total amount of waste

110 Typically, landfill gas also contains small amounts of nitrogen, oxygen, and hydrogen, less than 1 percent nonmethane volatile organic compounds (NMVOCs), and trace amounts of inorganic compounds.

111 See Box 7-1 "Biogenic Emissions and Sinks of Carbon" in the Waste chapter for additional background on how biogenic emissions of landfill CO_2 are addressed in the U.S. Inventory.

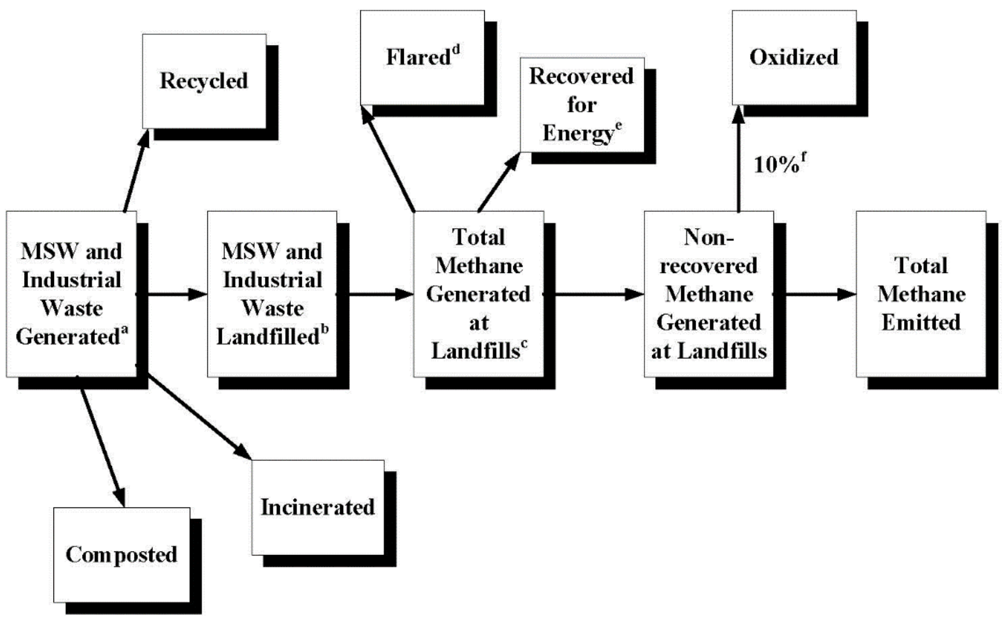
112 Landfill gas recovery is only estimated for MSW landfills due to a lack of national data on industrial waste landfills. Approximately 1 percent of the industrial waste landfills reporting under the GHGRP have active landfill gas collection systems.

113 Since the SOG survey does not include U.S. territories, waste landfilled in U.S. territories was estimated using population data for the U.S territories (U.S. Census Bureau 2013) and the per capita rate for waste landfilled from BioCycle (2010).

generated. The waste disposal factor is interpolated for the years in-between the SOG surveys and extrapolated for years after the last SOG survey. Methodological changes have occurred over the time that the SOG survey has been published, and this has affected the fluctuating trends observed in the data (RTI 2013).

Historical waste data, preferably since 1940, are required for the FOD model to estimate CH_4 generation for the Inventory time series. Estimates of waste placed in landfills in the 1940s and 1950s were developed based on U.S. population for each year and the per capital disposal rates from the 1960s. Estimates of the annual quantity of waste placed in landfills from 1960 through 1983 were developed from EPA's 1993 Report to Congress (EPA 1993) and a 1986 survey of MSW landfills (EPA 1988).

Figure A-24: Methane Emissions Resulting from Landfilling Municipal and Industrial Waste



[a] MSW waste generation is not calculated because annual quantities of waste disposal are available through EPA 2015c; annual production data used for industrial waste (Lockwood Post's Directory and the USDA).
[b] 1940 through 1988 based on EPA 1988 and EPA 1993; 1989 through 2008 based on *BioCycle* 2010; 2009 through 2014 based on Shin 2014.
[c] *2006 IPCC Guidelines* – First Order Decay Model.
[d] EIA 2007, flare vendor database, EPA (GHGRP) 2015b.
[e] EIA 2007, EPA (LMOP) 2015a, and EPA (GHGRP) 2015b.
[f] *2006 IPCC Guidelines*; Mancinelli and McKay 1985; Czepiel et al 1996.

Table A-272: Solid Waste in MSW Landfills Contributing to CH_4 Emissions (MMT unless otherwise noted)

	1990	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total MSW Generated[a]	270	458	454	429	403	405	406	408	411	414	418
Percent of MSW Landfilled[a]	77%	64%	65%	67%	69%	66%	66%	63%	63%	63%	63%
Total MSW Landfilled	205	290	289	283	275	265	266	256	258	259	262
MSW last 30 years[b]	4,876	6,281	6,415	6,539	6,653	6,753	6,851	6,935	7,018	7,099	7,180
MSW since 1940[c]	6,808	10,214	10,503	10,786	11,061	11,326	11,591	11,847	12,104	12,364	12,625
Total Industrial Waste Landfilled	10	11	11	11	11	10	11	11	11	11	11

[a] This estimate represents the waste that has been in place for 30 years or less, which contributes about 90 percent of the CH_4 generation. Values are based on EPA (1993) for years 1940 to years 1988 (not presented in table), *BioCycle* 2010 and Shin 2014 for years 1989 to 2014 (years prior to 1990 and 1991 to 2004 are not presented in table).
[b] Source: Data for years 1990 through 2014 are from the GHGRP for MSW landfills EPA (GHGRP) 2015, EPA (LMOP) 2015, and state agencies (EPA 2015c).
[c] This estimate represents the cumulative amount of waste that has been placed in landfills since 1940 to the year indicated and is the sum of the annual disposal rates used in the first order decay model. Values are based on EPA 1993, *BioCycle* 2010 and Shin 2014.

Step 2: Estimate CH_4 Generation at Municipal Solid Waste Landfills

The CH_4 generation was estimated from the integrated form of the FOD model using the procedures and spreadsheets from IPCC (2006) for estimating CH_4 emissions from solid waste disposal. The form of the FOD model that was applied incorporates a time delay of 6 months after waste disposal before the generation of CH_4 begins.

The input parameters needed for the FOD model equations are the mass of waste disposed each year, which was discussed in the previous section, degradable organic carbon (DOC), and the decay rate constant (k). The DOC is determined from the CH_4 generation potential (L_0 in m^3 CH_4/Mg waste), which is discussed in more detail in subsequent paragraphs, and the following equation:

$$DOC = [L_0 \times 6.74 \times 10^{-4}] \div [F \times 16/12 \times DOC_f \times MCF]$$

where,

DOC	=	degradable organic carbon (fraction, kt C/kt waste),
L_0	=	CH_4 generation potential (m^3 CH_4/Mg waste),
6.74×10^{-4}	=	CH_4 density (Mg/m^3),
F	=	fraction of CH_4 by volume in generated landfill gas (equal to 0.5)
16/12	=	molecular weight ratio CH_4/C,
DOC_f	=	fraction of DOC that can decompose in the anaerobic conditions in the landfill (fraction equal to 0.5 for MSW), and
MCF	=	methane correction factor for year of disposal (fraction equal to 1 for anaerobic managed sites).

The DOC value used in the CH_4 generation estimates from MSW landfills is 0.203 based on the CH_4 generation potential of 100 m^3 CH_4/Mg waste as described below. Data from a set of 52 representative landfills across the U.S. in different precipitation ranges were chosen to evaluate L_o, and ultimately the country-specific DOC value. The 2004 Chartwell Municipal Solid Waste Facility Directory confirmed that each of the 52 landfills chosen accepted or accepts both MSW and construction and demolition (C&D) waste (Chartwell 2004; RTI 2009).

The methane generation potential (L_o) varies with the amount of organic content of the waste material. A higher L_o occurrs with a higher content of organic waste. Waste composition data are not collected for all landfills nationwide; thus a default value must be used. Values for L_o were evaluated from landfill gas recovery data for this set of 52 landfills, which resulted in a best fit value for L_o of 99 m^3/Mg of waste (RTI 2004). This value compares favorably with a range of 50 to 162 (midrange of 106) m^3/Mg presented by Peer, Thorneloe, and Epperson (1993); a range of 87 to 91 m^3/Mg from a detailed analysis of 18 landfills sponsored by the Solid Waste Association of North America (SWANA 1998); and a value of 100 m^3/Mg recommended in EPA's compilation of emission factors (EPA 1998; EPA 2008) based on data from 21 landfills. Based on the results from these studies, a value of 100 m^3/Mg appears to be a reasonable best estimate to use in the FOD model for the national inventory.

The FOD model was applied to the gas recovery data for the 52 landfills to calculate the decay rate constant (k) directly for L_0 = 100 m^3/Mg. The rate constant was found to increase with annual average precipitation; consequently, average values of k were developed for three ranges of precipitation, shown in Table A-273 and recommended in EPA's compilation of emission factors (EPA 2008).

Table A-273: Average Values for Rate Constant (k) by Precipitation Range (yr^{-1})

Precipitation range (inches/year)	k (yr^{-1})
<20	0.020
20-40	0.038
>40	0.057

These values for k show reasonable agreement with the results of other studies. For example, EPA's compilation of emission factors (EPA 1998; EPA 2008) recommends a value of 0.02 yr^{-1} for arid areas (less than 20 inches/year of precipitation) and 0.04 yr^{-1} for non-arid areas. The SWANA (1998) study of 18 landfills reported a range in values of k from 0.03 to 0.06 yr^{-1} based on CH_4 recovery data collected generally in the time frame of 1986 to 1995.

Using data collected primarily for the year 2000, the distribution of waste in place versus precipitation was developed from over 400 landfills (RTI 2004). A distribution was also developed for population vs. precipitation for comparison. The two distributions were very similar and indicated that population in areas or regions with a given precipitation range was a reasonable proxy for waste landfilled in regions with the same range of precipitation. Using U.S. Census data and rainfall data, the distributions of population versus rainfall were developed for each Census decade from

1950 through 2000. The distributions showed that the U.S. population has shifted to more arid areas over the past several decades. Consequently, the population distribution was used to apportion the waste landfilled in each decade according to the precipitation ranges developed for k, as shown in Table A-274.

Table A-274: Percent of U.S. Population within Precipitation Ranges (%)

Precipitation Range (inches/year)	1950	1960	1970	1980	1990	2000	2010
<20	10	13	14	16	19	19	18
20-40	40	39	37	36	34	33	44
>40	50	48	48	48	48	48	38

Source: Years 1950 through 2000 are from RTI (2004) using population data from the U.S. Census Bureau and precipitation data from the National Climatic Data Center's National Oceanic and Atmospheric Administration. Year 2010 is based on the methodology from RTI (2004) and the U.S. Bureau of Census and precipitation data from the National Climatic Data Center's National Oceanic and Atmospheric Administration where available.

In developing the Inventory, the proportion of waste disposed of in managed landfills versus open dumps prior to 1980 was re-evaluated. Based on the historical data presented by Mintz et al. (2003), a timeline was developed for the transition from the use of open dumps for solid waste disposed to the use of managed landfills. Based on this timeline, it was estimated that 6 percent of the waste that was land disposed in 1940 was disposed of in managed landfills and 94 percent was managed in open dumps. Between 1940 and 1980, the fraction of waste that was land disposed transitioned towards managed landfills until 100 percent of the waste was disposed of in managed landfills in 1980. For wastes disposed of in dumps, a methane correction factor (MCF) of 0.6 was used based on the recommended IPCC default value for uncharacterized land disposal (IPCC 2006); this MCF is equivalent to assuming 50 percent of the open dumps are deep and 50 percent are shallow. The recommended IPCC default value for the MCF for managed landfills of 1 was used for the managed landfills (IPCC 2006).

Step 3: Estimate CH_4 Generation at Industrial Landfills

Industrial waste landfills receive waste from factories, processing plants, and other manufacturing activities. In national inventories prior to the 1990 through 2005 inventory, CH_4 generation at industrial landfills was estimated as seven percent of the total CH_4 generation from MSW landfills, based on a study conducted by EPA (1993). For the 1990 through current inventories, the methodology was updated and improved by using activity factors (industrial production levels) to estimate the amount of industrial waste landfilled each year and by applying the FOD model to estimate CH_4 generation. A nationwide survey of industrial waste landfills found that over 99 percent of the organic waste placed in industrial landfills originated from two sectors: food processing (meat, vegetables, fruits) and pulp and paper (EPA 1993). Data for annual nationwide production for the food processing and pulp and paper sectors were taken from industry and government sources for recent years; estimates were developed for production for the earlier years for which data were not available. For the pulp and paper sector, production data published by the Lockwood-Post's Directory were used for years 1990 to 2001 and production data published by the U.S. Department of Agriculture were used for years 2002 through 2013. An extrapolation based on U.S. real gross domestic product was used for years 1940 through 1964. For the food processing sector, production levels were obtained or developed from the U.S. Department of Agriculture for the years 1990 through 2013 (ERG 2014). An extrapolation based on U.S. population was used for the years 1940 through 1989, and for the year 2014.

In addition to production data for the pulp and paper and food processing sectors, the following inputs are needed to use the FOD model for estimating CH_4 generation from industrial landfills: 1) quantity of waste that is disposed in industrial waste landfills (as a function of production), 2) CH_4 generation potential (L_0) or DOC, and 3) the decay rate constant (k). Research into waste generation and disposal in landfills for the pulp and paper sector indicated that the quantity of waste landfilled was about 0.050 MT/MT of product compared to 0.046 MT/MT product for the food processing sector (RTI 2006). These factors were applied to estimates of annual production to estimate annual waste disposal in industrial waste landfills. Estimates for DOC were derived from available data (EPA, 2015b; Heath et al., 2010; NCASI, 2005; Kraft and Orender, 1993; NCASI 2008; Flores et al. 1999 as documented in RTI 2015b). The DOC value for industrial pulp and paper waste is estimated at 0.15 (L_o of 49 m^3/MT); the DOC value for industrial food waste is estimated as 0.26 (L_o of 128 m^3/MT) (RTI 2015b; RTI 2014). Estimates for k were taken from the default values in the *2006 IPCC Guidelines*; the value of k given for food waste with disposal in a wet temperate climate is 0.19 yr^{-1}, and the value given for paper waste is 0.06 yr^{-1}.

A literature review was conducted for the 1990 to 2010 and 1990 to 2014 inventory years with the intent of updating values for L_o (specifically DOC) and k in the pulp and paper sector. Where pulp and paper mill wastewater treatment residuals or sludge are the primary constituents of pulp and paper waste landfilled, values for k available in the literature range from 0.01/yr to 0.1/yr, while values for L_o range from 50 m^3/Mt to 200 m^3/Mt.[114] Values for these factors are highly variable and are dependent on the soil moisture content, which is generally related to rainfall amounts. At this time, sufficient data were available through the GHGRP to warrant a change to the L_o (DOC) from 99 to 49 m^3/MT, but sufficient data were not obtained to warrant a change to k for the current inventory year. EPA will consider an update to the k values for the pulp and paper sector as new data arises and will work with stakeholders to gather data and other feedback on potential changes to these values.

As with MSW landfills, a similar trend in disposal practices from open dumps to managed landfills was expected for industrial waste landfills; therefore, the same time line that was developed for MSW landfills was applied to the industrial landfills to estimate the average MCF. That is, between 1940 and 1980, the fraction of waste that was land disposed transitioned from 6 percent managed landfills in 1940 and 94 percent open dumps to 100 percent managed landfills in 1980 and on. For wastes disposed of in dumps, an MCF of 0.6 was used and for wastes disposed of in managed landfills, an MCF of 1 was used, based on the recommended IPCC default values (IPCC 2006).

The parameters discussed above were used in the integrated form of the FOD model to estimate CH_4 generation from industrial waste landfills.

Step 4: Estimate CH_4 Emissions Avoided

The estimated landfill gas recovered per year (R) at MSW landfills was based on a combination of four databases and including recovery from flares and/or landfill gas-to-energy projects:

- EPA's GHGRP dataset for MSW landfills (EPA 2015b)
- a database developed by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases (EIA 2007)
- a database of LFGTE projects that is primarily based on information compiled by EPA LMOP (EPA 2015a), and
- the flare vendor database (contains updated sales data collected from vendors of flaring equipment).

EPA's GHGRP MSW landfills database was first introduced as a data source for the 1990 to 2013 Inventory. The GHGRP MSW landfills database contains facility-reported data that undergoes rigorous verification and is considered to contain the least uncertain data of the four databases. However, this database is unique in that it only contains a portion of the landfills in the U.S. (although, presumably the highest emitters since only those landfills that meet the methane generation threshold must report) and only contains data from 2010 and later.

The destruction efficiencies reported through EPA's GHGRP were applied to the landfills in the GHGRP MSW landfills database. The median value of the reported destruction efficiencies was 99 percent for all reporting years (2010 through 2014, EPA 2015b). A destruction efficiency of 99 percent was applied to CH_4 recovered to estimate CH_4 emissions avoided for the other three databases. This value for destruction efficiency was selected based on the range of efficiencies (86 to 99+ percent) recommended for flares in EPA's *AP-42 Compilation of Air Pollutant Emission Factors*, Draft Chapter 2.4, Table 2.4-3 (EPA 2008). A typical value of 97.7 percent was presented for the non-methane components (i.e., volatile organic compounds and non-methane organic compounds) in test results (EPA 2008). An arithmetic average of 98.3 percent and a median value of 99 percent are derived from the test results presented in EPA 2008. Thus, a value of 99 percent for the destruction efficiency of flares has been used in Inventory methodology. Other data sources supporting a 99 percent destruction efficiency include those used to establish New Source Performance Standards (NSPS) for landfills and in recommendations for closed flares used in the EPA's LMOP.

Step 4a: Estimate CH_4 Emissions Avoided Through Landfill Gas-to-Energy (LFGTE) and Flaring Projects

The quantity of CH_4 avoided due to LFGTE systems was estimated based on information from three sources: (1) a database developed by the EIA for the voluntary reporting of greenhouse gases (EIA 2007); (2) a database compiled by LMOP and referred to as the LFGTE database for the purposes of this inventory (EPA 2015a); and (3) the GHGRP MSW landfills dataset (EPA 2015b). The EIA database included location information for landfills with LFGTE projects, estimates of CH_4 reductions, descriptions of the projects, and information on the methodology used to determine the CH_4 reductions. In general, the CH_4 reductions for each reporting year were based on the measured amount of landfill gas collected and the percent CH_4 in the gas. For the LFGTE database, data on landfill gas flow and energy generation (i.e., MW capacity) were used to estimate the total direct CH_4 emissions avoided due to the LFGTE project. The GHGRP MSW landfills database contains the most detailed data on landfills that reported under the GHGRP for years 2010 through 2014, however the amount of CH_4 recovered is not specifically allocated to a flare versus a LFGTE project. The allocation into flares or LFGTE was

[114] Sources reviewed included Heath et al. 2010; Miner 2008; Skog 2008; Upton et al. 2008; Barlaz 2006; Sonne 2006; NCASI 2005; Barlaz 1998; and Skog and Nicholson 2000.

performed by matching landfills to the EIA and LMOP databases for LFGTE projects and to the flare database for flares. Detailed information on the landfill name, owner or operator, city, and state are available for both the EIA and LFGTE databases; consequently, it was straightforward to identify landfills that were in both databases against those in EPA's GHGRP MSW landfills database. EPA's GHGRP MSW landfills database was given priority because CH_4 recovery and other supporting information were reported for each year and were based on direct measurements. The EIA database was given second priority (for landfills not in the GHGRP MSW landfills database) for years 1990 through 2005 because CH_4 recovery based on direct measurements was reported by landfill during this period. Landfills in the LMOP database that were also in EPA's GHGRP MSW landfills database and/or EIA database were not included in the total recovery values to avoid double or triple counting across the databases.

If a landfill in EPA's GHGRP MSW landfills database was also in the EIA, LFGTE, and/or flare vendor database, the avoided emissions were only based on EPA's GHGRP MSW landfills database to avoid double or triple counting the recovery amounts. In other words, the recovery from the same landfill was not included in the total recovery from the EIA, LFGTE, or flare vendor databases.

If a landfill in the EIA database was also in the LFGTE and/or the flare vendor database, the CH_4 recovery was based on the EIA data because landfill owners or operators directly reported the amount of CH_4 recovered using gas flow concentration and measurements, and because the reporting accounted for changes over time. However, as the EIA database only includes facility-reported data through 2006, the amount of CH_4 recovered for years 2007 and later were assumed to be the same as in 2006 for landfills that are in the EIA database, but not in the GHGRP or LFGTE databases. This quantity likely underestimates flaring because the EIA database does not have information on all flares in operation for the years after 2006. However, nearly all (93 percent) of landfills in the EIA database also report to the GHGRP, which means that only seven percent of landfills in the EIA database are counted in the total recovery.

If both the flare data and LFGTE recovery data were available for any of the remaining landfills (i.e., not in the EIA or GHGRP databases), then the avoided emissions were based on the LFGTE data, which provides reported landfill-specific data on gas flow for direct use projects and project capacity (i.e., megawatts) for electricity projects. The LFGTE database is based on the most EPA LMOP database (published annually).The remaining portion of avoided emissions is calculated by the flare vendor database, which estimates CH_4 combusted by flares using the midpoint of a flare's reported capacity. New flare vendor sales data were unable to be obtained for the current Inventory year. Given that each LFGTE project is likely to also have a flare, double counting reductions from flares and LFGTE projects in the LFGTE database was avoided by subtracting emission reductions associated with LFGTE projects for which a flare had not been identified from the emission reductions associated with flares (referred to as the flare correction factor).

Step 4b: Estimate CH_4 Emissions Avoided Through Flaring for the Flare Database

To avoid double counting, flares associated with landfills in EPA's GHGRP, EIA and LFGTE databases were not included in the total quantity of CH_4 recovery from the flare vendor database. As with the LFGTE projects, reductions from flaring landfill gas in the EIA database were based on measuring the volume of gas collected and the percent of CH_4 in the gas. The information provided by the flare vendors included information on the number of flares, flare design flow rates or flare dimensions, year of installation, and generally the city and state location of the landfill. When a range of design flare flow rates was provided by the flare vendor, the median landfill gas flow rate was used to estimate CH_4 recovered from each remaining flare (i.e., for each flare not associated with a landfill in the EIA, GHGRP, or LFGTE databases). Several vendors provided information on the size of the flare rather than the flare design gas flow rate. To estimate a median flare gas flow rate for flares associated with these vendors, the size of the flare was matched with the size and corresponding flow rates provided by other vendors. Some flare vendors reported the maximum capacity of the flare. An analysis of flare capacity versus measured CH_4 flow rates from the EIA database showed that the flares operated at 51 percent of capacity when averaged over the time series and at 72 percent of capacity for the highest flow rate for a given year. For those cases when the flare vendor supplied maximum capacity, the actual flow was estimated as 50 percent of capacity. Total CH_4 avoided through flaring from the flare vendor database was estimated by summing the estimates of CH_4 recovered by each flare for each year. Flare sales data were not provided to the EPA for the previous and current Inventory year.

Step 4c: Reduce CH_4 Emissions Avoided Through Flaring

As mentioned in Step 4b, flares in the flare vendor database associated with landfills in the GHGRP MSW landfills, EIA, and LMOP databases were not accounted for in the flare reduction estimates in the flare vendor database. If comprehensive data on flares were available, each LFGTE project in EPA's GHGRP, EIA, and LFGTE databases would have an identified flare because it is assumed that most LFGTE projects have flares. However, given that the flare vendor database only covers approximately 50 to 75 percent of the flare population, an associated flare was not identified for all LFGTE projects. These LFGTE projects likely have flares, yet flares were unable to be identified for one of two reasons: 1) inadequate identifier information in the flare vendor data, or 2) a lack of the flare in the flare vendor database. For those projects for which a flare was not identified due to inadequate information, CH_4 avoided would be overestimated, as both the CH_4 avoided from flaring and the LFGTE project would be counted. To avoid overestimating emissions avoided from flaring, the CH_4 avoided from LFGTE projects with no identified flares was determined and the flaring estimate from the flare vendor database was reduced by this quantity (referred to as a flare correction factor) on a state-by-state basis. This step likely underestimates CH_4 avoided due to flaring, but was applied to be conservative in the estimates of CH_4 emissions avoided.

Additional effort was undertaken to improve the methodology behind the flare correction factor for the 1990 to 2009 and 1990 to 2014 inventory years to reduce the total number of flares in the flare vendor database that were not matched to landfills and/or LFGTE projects in the EIA and LFGTE databases. Each flare in the flare vendor database not associated with a LFGTE project in the EIA, LFGTE, or GHGRP databases was investigated to determine if it could be matched. For some unmatched flares, the location information was missing or incorrectly transferred to the flare vendor database and was corrected during the review. In other instances, the landfill names were slightly different between what the flare vendor provided and the actual landfill name as listed in the EIA, LFGTE and GHGRP databases. The remaining flares did not have adequate information through the name, location, or owner to identify it to a landfill in any of the recovery databases or through an Internet search; it is these flares that are included in the flare correction factor for the current inventory year.

A large majority of the unmatched flares are associated with landfills in the LFGTE database that are currently flaring, but are also considering LFGTE. These landfills projects considering a LFGTE project are labeled as candidate, potential, or construction in the LFGTE database. The flare vendor database was improved in the 1990 to 2009 inventory year to match flares with operational, shutdown as well as candidate, potential, and construction LFGTE projects, thereby reducing the total number of unidentified flares in the flare vendor database, all of which are used in the flare correction factor. The results of this effort significantly decreased the number of flares used in the flare correction factor, and consequently, increased recovered flare emissions, and decreased net emissions from landfills for the 1990 through 2009 Inventory. The revised state-by-state flare correction factors were applied to the entire Inventory time series.

Step 5: Estimate CH_4 Oxidation

A portion of the CH_4 escaping from a landfill oxidizes to CO_2 in the top layer of the soil. The amount of oxidation depends upon the characteristics of the soil and the environment. For purposes of this analysis, it was assumed that of the CH_4 generated, minus the amount of gas recovered for flaring or LFGTE projects, 10 percent was oxidized in the soil (Jensen and Pipatti 2002; Mancinelli and McKay 1985; Czepiel et al 1996). The factor of 10 percent is consistent with the value recommended in the 2006 IPCC revised guidelines for managed and covered landfills, and was therefore applied to the estimates of CH_4 generation minus recovery for both MSW and industrial landfills

A literature review was conducted in 2011 (RTI 2011) to provide recommendations for the most appropriate oxidation rate assumptions. It was found that oxidation values are highly variable and range from zero to over 100 percent (i.e., the landfill is considered to be an atmospheric sink by virtue of the landfill gas extraction system pulling atmospheric methane down through the cover). There is considerable uncertainty and variability surrounding estimates of the rate of oxidation because oxidation is difficult to measure and varies considerably with the presence of a gas collection system, thickness and type of the cover material, size and area of the landfill, climate, and the presence of cracks and/or fissures in the cover material through which methane can escape. IPCC (2006) notes that test results from field and laboratory studies may lead to over-estimations of oxidation in landfill cover soils because they largely determine oxidation using uniform and homogeneous soil layers. In addition, a number of studies note that gas escapes more readily through the side slopes of a landfill as compared to moving through the cover thus complicating the correlation between oxidation and cover type or gas recovery.

Sites with landfill gas collection systems are generally designed and managed better to improve gas recovery. More recent research (2006 to 2012) on landfill cover methane oxidation has relied on stable isotope techniques that may provide a more reliable measure of oxidation. Results from this recent research consistently point to higher cover soil methane oxidation rates than the IPCC (2006) default of 10 percent. A continued effort will be made to review the peer-reviewed literature to better understand how climate, cover type, and gas recovery influence the rate of oxidation at active and closed landfills. At this time, the IPCC recommended oxidation factor of 10 percent will continue to be used for all landfills.

Step 6: Estimate Total CH_4 Emissions

Total CH_4 emissions were calculated by adding emissions from MSW and industrial landfills, and subtracting CH_4 recovered and oxidized, as shown in Table A-275.

Table A-275: CH_4 Emissions from Landfills (kt)

	1990	1995	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
MSW CH_4 Generation	8,214	9,140	10,084	10,383	10,769	11,135	11,482	11,809	12,118	12,395	12,638	12,839	13,008	13,144	13,280	13,418
Industrial CH_4 Generation	484	537	612	618	625	629	636	639	643	648	653	656	657	659	661	665
Potential Emissions	**8,698**	**9,676**	**10,696**	**11,001**	**11,394**	**11,765**	**12,117**	**12,448**	**12,760**	**13,043**	**13,291**	**13,495**	**13,665**	**13,803**	**13,942**	**14,083**
Emissions Avoided	**(718)**	**(1,935)**	**(4,616)**	**(4,894)**	**(4,995)**	**(5,304)**	**(5,272)**	**(5,707)**	**(5,954)**	**(6,176)**	**(6,424)**	**(7,178)**	**(7,249)**	**(7,480)**	**(7,529)**	**(7,507)**
Oxidation at MSW Landfills	(750)	(720)	(547)	(549)	(577)	(583)	(621)	(610)	(616)	(622)	(621)	(566)	(576)	(566)	(575)	(591)
Oxidation at Industrial Landfills	(48)	(54)	(61)	(62)	(63)	(63)	(64)	(64)	(64)	(65)	(65)	(66)	(66)	(66)	(66)	(67)
Net Emissions	**7,182**	**6,967**	**5,472**	**5,496**	**5,759**	**5,815**	**6,161**	**6,066**	**6,126**	**6,180**	**6,180**	**5,685**	**5,774**	**5,691**	**5,772**	**5,919**

Notes: MSW generation in Table A-248 represents emissions before oxidation. In other tables throughout the text, MSW generation estimates account for oxidation. Totals may not sum exactly to the last significant figure due to rounding. Parentheses denote negative values.

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