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.[84]

Step 1: Livestock Population Characterization Data

Annual animal population data for 1990 through 2015 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 2016a). 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, 2015a 2015b, 2016b, and 2016c). 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 2015 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 2015 were interpolated and 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 2015 were interpolated and 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 through 2006, 2008 through 2011, and 2013 through 2015 were interpolated and extrapolated based on the 1987, 1992, 1997, 2002, 2007, and 2012 Census data.

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[84] 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.

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 2015 were interpolated and 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, 2015a, 2015b, 2016b, and 2016c). 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-179.

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-180 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-181 (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 (ASABE), 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. Expert sources agreed interpolating the two data sources across the time series would be appropriate as each methodology reflect the best available for that time period and the more recent data may not appropriately reflect the historic time series (ERG 2010b). 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). Differing trends in VS and Nex values are due to the updated Nex calculation method from 2008 AWMFH. VS calculations did not follow the same procedure and were updated based on a fixed ratio of VS to total solids and past ASABE standards (ERG 2010b).
- *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 *2006 IPCC Guidelines* 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.

$$\text{N}_{\text{excreted}} = \text{N}_{\text{consumed}} - \left(\text{N}_{\text{growth}} + \text{N}_{\text{milk}}\right)$$

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:

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

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:

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

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-182 presents the state-specific VS and Nex production rates used for cattle in 2015.

Step 3: Waste Management System Usage Data

Table A-183 summarizes 2015 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. Note that the Inventory WMS estimates are based on state or regional WMS usage data and not built upon farm-level WMS estimates. 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-184.

Beef Cattle, Dairy Heifers and American Bison: The beef feedlot and dairy heifer WMS data were developed using regional 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 state and regional 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 and 2012 Census of Agriculture (USDA 2016d). It was assumed that the Census data provided for 1992 were the same as that for 1990 and 1991, and data provided for 2012 were the same as that for 2013 through 2015. Data for 1993 through 1996, 1998 through 2001, and 2003 through 2006, and 2008 through 2011 were interpolated using the 1992, 1997, 2002, 2007, and 2012 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 at the regional level 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, 2007, and 2012 (USDA 2016d) 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 2015, which were obtained from the USDA NASS (USDA 2016a).

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 at the state-level. AD system data were obtained from EPA's AgSTAR Program's project database (EPA 2016). This database includes basic information for AD systems in the United States, based on publicly available data and data submitted by farm operators, project developers, financiers, and others involved in the development of farm AD projects.

Swine: The regional 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, 2007, and 2012 Census of Agriculture (USDA 2016d) 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 2012 were the same as that for 2013 through 2015. Data for 1993 through 1996, 1998 through 2001, 2003 through 2006, and 2008 through 2011 were interpolated using the 1992, 1997, 2002, 2007, and 2012 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 state-level WMS distribution based on data from EPA's AgSTAR database (EPA 2016).

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 2015 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 2015 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 2016), 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 used to update the WMS distributions based on information from EPA's AgSTAR database (EPA 2016).

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-185. 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 2016) 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 interpolated based on 1992 and 1997 data; county population data for 1998 through 2001 were interpolated based on 1997 and 2002 data; county population data for 2003 through 2006 were interpolated based on 2002 and 2007 data; county population data for 2008 through 2015 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-186 by state, WMS, and animal group for 2015.

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-187.

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-188.

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:

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

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)
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° 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 (CH_4 m^3/kg VS)
0.662	= Density of CH_4 at 25° 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:

$$CH_4 \text{ Emissions AD} = \sum_{\text{State, Animal, AD Systems}} \left(\begin{array}{l} \left[CH_4 \text{ Production AD}_{\text{AD system}} \times CE_{\text{AD system}} \times (1 - DE) \right] \\ + \left[CH_4 \text{ Production AD}_{\text{AD system}} \times (1 - CE_{\text{AD system}}) \right] \end{array} \right)$$

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 $_{\text{State, Animal, WMS}}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
Population $_{\text{state}}$	= 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 $_{\text{State, Animal, WMS}}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
Population $_{\text{state}}$	= 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:

$$\text{Direct } N_2O = \sum_{\text{State, Animal, WMS}} \left(\text{N excreted}_{\text{State, Animal, WMS}} \times EF_{\text{WMS}} \times \frac{44}{28} \right)$$

where,

Direct N_2O	= Direct N_2O emissions (kg N_2O/yr)
N excreted $_{\text{State, Animal, WMS}}$	= 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 $_{\text{State, Animal, WMS}}$	= Amount of N excreted in manure managed in each WMS for each animal type (kg/yr)
$\text{Frac}_{\text{gas,WMS}}$	= Nitrogen lost through volatilization in each WMS
$\text{Frac}_{\text{runoff/leach,WMS}}$	= Nitrogen lost through runoff and leaching in each WMS (data were not available for leaching so the value reflects only runoff)
$EF_{\text{volatilization}}$	= Emission factor for volatilization (0.010 kg N_2O-N/kg N)
$EF_{\text{runoff/leach}}$	= 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-189 and Table A-190 respectively. Emission estimates for 2015 are presented by animal type and state in Table A-191 and Table A-192 respectively.

Table A-179: Livestock Population (1,000 Head)

Animal Type	1990	1995	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Dairy Cattle	19,512	18,681	18,142	17,927	17,833	17,919	17,642	17,793	18,078	18,190	18,422	18,560	18,297	18,442	18,587	18,505	18,527
Dairy Cows	*10,015*	*9,482*	*9,183*	*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*	*4,008*	*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*	*4,579*
Dairy Calves	*5,369*	*5,091*	*17,431*	*17,508*	*17,483*	*17,126*	*17,013*	*16,918*	*16,814*	*16,644*	*16,231*	*16,051*	*16,067*	*15,817*	*15,288*	*14,859*	*14,741*
Swine[a]	53,941	58,899	58,864	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	64,325
Market <50 lb.	*18,359*	*19,656*	*19,574*	*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*	*18,952*
Market 50-119 lb.	*11,734*	*12,836*	*12,926*	*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*	*16,576*
Market 120-179 lb.	*9,440*	*10,545*	*10,748*	*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*	*12,333*
Market >180 lb.	*7,510*	*8,937*	*9,385*	*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*	*10,572*
Breeding	*6,899*	*6,926*	*6,231*	*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*	*5,892*
Beef Cattle[b]	81,576	90,361	84,810	84,237	84,260	83,361	81,672	82,193	83,263	82,801	81,532	80,993	80,484	78,937	76,858	76,075	75,245
Feedlot Steers	*6,357*	*7,233*	*8,304*	*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*	*8,695*
Feedlot Heifers	*3,192*	*3,831*	*4,702*	*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*	*4,525*
NOF Bulls	*2,160*	*2,385*	*2,293*	*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*	*4,951*	*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*	*4,740*
NOF Heifers	*10,182*	*11,829*	*9,781*	*9,832*	*9,843*	*9,564*	*9,321*	*9,550*	*9,716*	*9,592*	*9,356*	*9,473*	*9,349*	*8,874*	*8,687*	*8,787*	*8,787*
NOF Steers	*10,321*	*11,716*	*8,724*	*8,724*	*8,883*	*8,347*	*8,067*	*8,185*	*8,248*	*8,302*	*8,244*	*8,560*	*8,234*	*7,568*	*7,173*	*7,457*	*7,374*
NOF Cows	*32,455*	*35,190*	*33,575*	*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	7,036	6,908	6,623	6,321	6,065	6,135	6,200	6,120	5,950	5,747	5,620	5,470	5,375	5,360	5,245
Sheep On Feed	*1,180*	*1,771*	*2,963*	*3,256*	*3,143*	*3,049*	*2,923*	*2,971*	*3,026*	*3,000*	*2,911*	*2,806*	*2,778*	*2,687*	*2,666*	*2,655*	*2,593*
Sheep NOF	*10,178*	*7,218*	*4,073*	*3,652*	*3,480*	*3,272*	*3,142*	*3,164*	*3,174*	*3,120*	*3,039*	*2,941*	*2,842*	*2,783*	*2,709*	*2,705*	*2,652*
Goats	2,516	2,357	2,419	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	2,033,123	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	2,116,333
Hens >1 yr.	*273,467*	*299,071*	*333,593*	*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*	*370,637*
Pullets	*73,167*	*81,369*	*95,159*	*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*	*106,490*
Chickens	*6,545*	*7,637*	*8,088*	*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*	*1,506,127*	*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*	*1,553,636*
Turkeys	*117,685*	*106,960*	*90,155*	*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	3,395	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	112	109	105	141	177	212	248	284	286	287	289	291	293	294	296
American Bison	47	104	194	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.
Source(s): See *Step 1: Livestock Population Characterization Data*

Table A-180: Waste Characteristics Data

Animal Group	Typical Animal Mass, TAM		Total Kjeldahl Nitrogen Excreted, Nex[a]		Maximum Methane Generation Potential, B_0		Volatile Solids Excreted, VS[a]	
	Value (kg)	Source	Value	Source	Value (m^3 CH_4/kg VS added)	Source	Value	Source
Dairy Cows	680	CEFM	Table A-182	CEFM	0.24	Morris 1976	Table A-182	CEFM
Dairy Heifers	406-408	CEFM	Table A-182	CEFM	0.17	Bryant et al. 1976	Table A-182	CEFM
Feedlot Steers	419-457	CEFM	Table A-182	CEFM	0.33	Hashimoto 1981	Table A-182	CEFM
Feedlot Heifers	384-430	CEFM	Table A-182	CEFM	0.33	Hashimoto 1981	Table A-182	CEFM
NOF Bulls	831-917	CEFM	Table A-182	CEFM	0.17	Hashimoto 1981	Table A-182	CEFM
NOF Calves	118	ERG 2003b	Table A-181	USDA 1996, 2008	0.17	Hashimoto 1981	Table A-181	USDA 1996, 2008
NOF Heifers	296-407	CEFM	Table A-182	CEFM	0.17	Hashimoto 1981	Table A-182	CEFM
NOF Steers	314-335	CEFM	Table A-182	CEFM	0.17	Hashimoto 1981	Table A-182	CEFM
NOF Cows	554-611	CEFM	Table A-182	CEFM	0.17	Hashimoto 1981	Table A-182	CEFM
American Bison	578.5	Meagher 1986	Table A-182	CEFM	0.17	Hashimoto 1981	Table A-182	CEFM
Market Swine <50 lbs.	13	ERG 2010a	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Market Swine <60 lbs.	16	Safley 2000	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Market Swine 50-119 lbs.	39	ERG 2010a	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Market Swine 60-119 lbs.	41	Safley 2000	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Market Swine 120-179 lbs.	68	Safley 2000	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Market Swine >180 lbs.	91	Safley 2000	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Breeding Swine	198	Safley 2000	Table A-181	USDA 1996, 2008	0.48	Hashimoto 1984	Table A-181	USDA 1996, 2008
Feedlot Sheep	25	EPA 1992	Table A-181	ASAE 1998, USDA 2008	0.36	EPA 1992	Table A-181	ASAE 1998, USDA 2008
NOF Sheep	80	EPA 1992	Table A-181	ASAE 1998, USDA 2008	0.19	EPA 1992	Table A-181	ASAE 1998, USDA 2008
Goats	64	ASAE 1998	Table A-181	ASAE 1998	0.17	EPA 1992	Table A-181	ASAE 1998
Horses	450	ASAE 1998	Table A-181	ASAE 1998, USDA 2008	0.33	EPA 1992	Table A-181	ASAE 1998, USDA 2008
Mules and Asses	130	IPCC 2006	Table A-181	IPCC 2006	0.33	EPA 1992	Table A-181	IPCC 2006
Hens >/= 1 yr	1.8	ASAE 1998	Table A-181	USDA 1996, 2008	0.39	Hill 1982	Table A-181	USDA 1996, 2008
Pullets	1.8	ASAE 1998	Table A-181	USDA 1996, 2008	0.39	Hill 1982	Table A-181	USDA 1996, 2008
Other Chickens	1.8	ASAE 1998	Table A-181	USDA 1996, 2008	0.39	Hill 1982	Table A-181	USDA 1996, 2008
Broilers	0.9	ASAE 1998	Table A-181	USDA 1996, 2008	0.36	Hill 1984	Table A-181	USDA 1996, 2008
Turkeys	6.8	ASAE 1998	Table A-181	USDA 1996, 2008	0.36	Hill 1984	Table A-181	USDA 1996, 2008

[a] Nex and VS values vary by year; Table A-182 shows state-level values for 2015 only.

Table A-181: 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	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
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
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
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
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
Swine, Breeding	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	2.7
NOF Cattle Calves	6.4	6.4	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	7.7
Sheep	9.2	9.2	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	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
Hens >1yr.	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	10.2
Pullets	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	10.2
Chickens	10.8	10.8	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	11.0
Broilers	15.0	15.0	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	17.0
Turkeys	9.7	9.7	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	8.5
Horses	10.0	10.0	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	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
Nex																		
Swine, Market <50 lbs.	0.60	0.60	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	0.92
Swine, Market 50-119 lbs.	0.42	0.42	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	0.54
Swine, Market 120-179 lbs.	0.42	0.42	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	0.54
Swine, Market >180 lbs.	0.42	0.42	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	0.54
Swine, Breeding	0.24	0.24	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	0.20
NOF Cattle Calves	0.30	0.30	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	0.45
Sheep	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	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
Hens >1yr.	0.70	0.70	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	0.79
Pullets	0.70	0.70	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	0.79
Chickens	0.83	0.83	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	1.10
Broilers	1.10	1.10	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	0.96
Turkeys	0.74	0.74	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	0.63
Horses	0.30	0.30	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	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

Source: USDA AWMFH

Table A-182: Estimated Volatile Solids (VS) and Total Kjeldahl Nitrogen Excreted (Nex) Production Rates by State for Cattle (other than Calves) and American Bison[a] for 2015 (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	2,097	1,251	1,664	1,101	972	690	669	1,721	1,721	128	69	73	51	42	56	57	83	83
Alaska	1,971	1,251	1,891	1,273	1,116	690	670	1,956	1,956	121	69	59	42	33	56	57	69	69
Arizona	2,928	1,251	1,891	1,247	1,116	691	669	1,956	1,956	162	69	59	40	33	56	57	69	69
Arkansas	2,075	1,251	1,664	1,097	972	690	669	1,721	1,721	126	69	73	50	42	56	57	83	83
California	2,799	1,251	1,891	1,232	1,116	690	669	1,956	1,956	156	69	59	40	33	56	57	69	69
Colorado	3,018	1,251	1,891	1,204	1,116	691	669	1,956	1,956	166	69	59	38	33	56	57	69	69
Connecticut	2,656	1,251	1,674	1,111	977	691	669	1,731	1,731	151	69	74	52	42	56	57	84	84
Delaware	2,571	1,251	1,674	1,081	977	691	668	1,731	1,731	147	69	74	50	42	56	57	84	84
Florida	2,697	1,251	1,664	1,103	972	691	669	1,721	1,721	154	69	73	51	42	56	57	83	83
Georgia	2,771	1,251	1,664	1,098	972	691	668	1,721	1,721	157	69	73	50	42	56	57	83	83
Hawaii	2,288	1,251	1,891	1,254	1,116	691	668	1,956	1,956	135	69	59	41	33	56	57	69	69
Idaho	2,902	1,251	1,891	1,224	1,116	691	669	1,956	1,956	161	69	59	39	33	56	57	69	69
Illinois	2,603	1,251	1,589	1,011	924	691	669	1,643	1,643	148	69	75	49	43	56	57	85	85
Indiana	2,753	1,251	1,589	1,025	924	691	669	1,643	1,643	155	69	75	50	43	56	57	85	85
Iowa	2,813	1,251	1,589	991	924	691	669	1,643	1,643	157	69	75	48	43	56	57	85	85
Kansas	2,760	1,251	1,589	985	924	691	669	1,643	1,643	155	69	75	48	43	56	57	85	85
Kentucky	2,469	1,251	1,664	1,082	972	690	669	1,721	1,721	144	69	73	49	42	56	57	83	83
Louisiana	2,107	1,251	1,664	1,099	972	691	669	1,721	1,721	127	69	73	50	42	56	57	83	83
Maine	2,578	1,251	1,674	1,095	977	691	669	1,731	1,731	147	69	74	51	42	56	57	84	84
Maryland	2,598	1,251	1,674	1,081	977	691	669	1,731	1,731	148	69	74	50	42	56	57	84	84
Massachusetts	2,450	1,251	1,674	1,097	977	691	668	1,731	1,731	142	69	74	51	42	56	57	84	84
Michigan	2,977	1,251	1,589	1,011	924	691	669	1,643	1,643	164	69	75	49	43	56	57	85	85
Minnesota	2,636	1,251	1,589	1,007	924	691	669	1,643	1,643	150	69	75	49	43	56	57	85	85
Mississippi	2,274	1,251	1,664	1,097	972	690	669	1,721	1,721	136	69	73	50	42	56	57	83	83
Missouri	2,258	1,251	1,589	1,032	924	691	669	1,643	1,643	134	69	75	51	43	56	57	85	85
Montana	2,695	1,251	1,891	1,254	1,116	690	670	1,956	1,956	152	69	59	41	33	56	58	69	69
Nebraska	2,812	1,251	1,589	994	924	691	669	1,643	1,643	157	69	75	48	43	56	57	85	85
Nevada	2,823	1,251	1,891	1,241	1,116	691	669	1,956	1,956	158	69	59	40	33	56	57	69	69
New Hampshire	2,604	1,251	1,674	1,097	977	691	669	1,731	1,731	148	69	74	51	42	56	57	84	84
New Jersey	2,454	1,251	1,674	1,090	977	691	669	1,731	1,731	142	69	74	50	42	56	57	84	84
New Mexico	2,910	1,251	1,891	1,239	1,116	691	669	1,956	1,956	162	69	59	40	33	56	57	69	69
New York	2,804	1,251	1,674	1,079	977	691	668	1,731	1,731	157	69	74	50	42	56	57	84	84
North Carolina	2,721	1,251	1,664	1,095	972	691	669	1,721	1,721	155	69	73	50	42	56	57	83	83
North Dakota	2,649	1,251	1,589	1,020	924	691	668	1,643	1,643	150	69	75	50	43	56	57	85	85
Ohio	2,636	1,251	1,589	1,022	924	691	669	1,643	1,643	150	69	75	50	43	56	57	85	85
Oklahoma	2,483	1,251	1,664	1,078	972	691	669	1,721	1,721	143	69	73	49	42	56	57	83	83
Oregon	2,624	1,251	1,891	1,235	1,116	691	668	1,956	1,956	149	69	59	40	33	56	57	69	69
Pennsylvania	2,622	1,251	1,674	1,081	977	690	669	1,731	1,731	149	69	74	50	42	56	57	84	84
Rhode Island	2,419	1,251	1,674	1,101	977	691	669	1,731	1,731	140	69	74	51	42	56	57	84	84
South Carolina	2,454	1,251	1,664	1,095	972	690	669	1,721	1,721	144	69	73	50	42	56	57	83	83
South Dakota	2,762	1,251	1,589	1,017	924	691	669	1,643	1,643	155	69	75	50	43	56	57	85	85

State	Volatile Solids									Nitrogen Excreted								
	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
Tennessee	2,385	1,251	1,664	1,092	972	692	666	1,721	1,721	141	69	73	50	42	55	56	83	83
Texas	2,765	1,251	1,664	1,058	972	691	669	1,721	1,721	155	69	73	48	42	56	57	83	83
Utah	2,828	1,251	1,891	1,240	1,116	691	669	1,956	1,956	158	69	59	40	33	56	57	69	69
Vermont	2,608	1,251	1,674	1,075	977	691	669	1,731	1,731	149	69	74	49	42	56	57	84	84
Virginia	2,608	1,251	1,664	1,095	972	691	669	1,721	1,721	150	69	73	50	42	56	57	83	83
Washington	2,881	1,251	1,891	1,207	1,116	691	668	1,956	1,956	160	69	59	38	33	56	57	69	69
West Virginia	2,269	1,251	1,674	1,093	977	690	669	1,731	1,731	134	69	74	51	42	56	57	84	84
Wisconsin	2,795	1,251	1,589	1,034	924	691	669	1,643	1,643	157	69	75	51	43	56	57	85	85
Wyoming	2,785	1,251	1,891	1,242	1,116	691	669	1,956	1,956	156	69	59	40	33	56	57	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-183: 2015 Manure Distribution Among Waste Management Systems by Operation (Percent)

State	Beef Feedlots		Beef Not on Feed Operations	Dairy Cow Farms[a]						Dairy Heifer Facilities				Swine Operations[a]					Layer Operations		Broiler and Turkey Operations	
	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	9	9	14	0	17	38	0	45	6	4	7	54	30	42	58	1	99
Alaska	100	1	100	4	7	34	19	25	10	6	90	1	4	66	1	9	7	16	25	75	1	99
Arizona	100	0	100	0	10	9	19	61	0	10	90	0	0	5	4	7	54	31	60	40	1	99
Arkansas	100	1	100	63	14	8	6	8	0	15	28	0	57	5	4	17	36	38	0	100	1	99
California	100	1	100	0	10	9	20	60	0	11	88	1	1	20	3	7	43	27	12	88	1	99
Colorado	100	0	100	0	1	11	22	66	0	1	98	0	1	1	6	26	17	50	60	40	1	99
Connecticut	100	1	100	6	43	15	22	13	2	43	51	0	6	83	1	5	4	8	5	95	1	99
Delaware	100	1	100	6	44	18	19	11	2	44	50	0	6	17	4	22	16	41	5	95	1	99
Florida	100	1	100	12	22	7	15	43	0	22	61	1	17	73	1	7	6	13	42	58	1	99
Georgia	100	1	100	28	20	10	13	29	0	18	42	0	40	8	3	6	53	30	42	58	1	99
Hawaii	100	1	100	1	0	11	21	67	0	0	99	1	1	47	2	15	11	25	25	75	1	99
Idaho	100	0	100	0	0	11	22	66	0	1	99	0	0	9	5	24	16	46	60	40	1	99
Illinois	100	1	100	3	6	35	33	19	4	8	87	0	5	1	5	29	13	53	2	98	1	99
Indiana	100	1	100	6	10	26	30	26	2	13	79	0	8	1	5	29	13	52	0	100	1	99
Iowa	100	1	100	3	5	30	34	25	3	10	83	0	6	0	4	8	56	32	0	100	1	99
Kansas	100	1	100	2	3	15	38	40	1	5	92	0	3	1	5	29	13	53	2	98	1	99
Kentucky	100	1	100	57	15	15	8	4	1	14	24	0	61	5	4	8	52	31	5	95	1	99
Louisiana	100	1	100	51	16	9	9	14	0	14	26	0	60	89	0	3	2	5	60	40	1	99
Maine	100	1	100	6	44	18	19	12	2	45	48	0	7	75	1	7	5	12	5	95	1	99
Maryland	100	1	100	6	44	20	17	10	3	44	49	0	7	19	4	22	15	40	5	95	1	99
Massachusetts	100	1	100	7	45	22	17	7	2	45	47	0	7	67	1	9	7	15	5	95	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
Michigan	100	1	100	2	3	20	39	33	2	6	91	0	3	2	5	26	17	49	2	98	1	99
Minnesota	100	1	100	4	7	35	30	20	4	10	84	0	6	0	5	26	17	50	0	100	1	99
Mississippi	100	1	100	55	15	10	8	11	1	15	28	0	57	1	4	6	59	31	60	40	1	99
Missouri	100	1	100	7	12	39	24	14	4	14	77	0	8	1	5	29	13	53	0	100	1	99
Montana	100	0	100	3	4	19	27	43	4	4	93	0	3	3	5	26	17	50	60	40	1	99
Nebraska	100	1	100	3	5	21	36	33	2	6	90	0	4	1	5	29	14	52	2	98	1	99
Nevada	100	0	100	0	0	10	23	66	0	0	99	0	0	100	0	0	0	0	0	100	1	99
New Hampshire	100	1	100	6	44	18	19	10	2	44	49	0	7	100	0	0	0	0	5	95	1	99
New Jersey	100	1	100	8	46	25	13	6	3	45	47	0	8	70	1	8	6	14	5	95	1	99
New Mexico	100	0	100	0	10	9	19	61	0	10	90	0	0	74	1	7	6	12	60	40	1	99
New York	100	1	100	6	44	16	18	14	2	45	48	0	7	30	4	19	13	35	5	95	1	99
North Carolina	100	1	100	41	18	10	17	13	1	15	31	0	54	0	4	6	59	31	42	58	1	99
North Dakota	100	1	100	5	9	27	31	25	2	11	83	0	6	2	5	26	17	50	2	98	1	99
Ohio	100	1	100	7	11	33	27	19	3	14	78	0	8	2	5	28	13	52	0	100	1	99
Oklahoma	100	0	100	0	8	17	22	50	3	6	94	0	0	1	4	6	59	31	60	40	1	99
Oregon	100	1	100	12	0	10	22	54	1	0	80	1	20	78	1	6	5	11	25	75	1	99
Pennsylvania	100	1	100	8	46	24	13	7	2	47	44	0	9	3	5	26	18	48	0	100	1	99
Rhode Island	100	1	100	7	45	24	15	6	3	47	44	0	9	77	1	6	5	11	5	95	1	99
South Carolina	100	1	100	44	17	7	12	20	0	15	31	0	54	5	4	7	54	31	60	40	1	99
South Dakota	100	1	100	2	4	17	39	38	1	8	87	0	5	1	5	26	17	50	2	98	1	99
Tennessee	100	1	100	55	15	12	10	5	2	15	26	0	59	11	3	7	50	29	5	95	1	99
Texas	100	0	100	0	9	11	21	59	1	8	92	0	0	6	4	6	56	30	12	88	1	99
Utah	100	0	100	1	1	13	24	60	1	1	98	0	1	1	6	26	17	51	60	40	1	99
Vermont	100	1	100	5	43	15	20	15	2	44	49	0	7	81	1	5	4	9	5	95	1	99
Virginia	100	1	100	52	16	12	12	7	2	15	28	0	57	7	3	7	53	30	5	95	1	99
Washington	100	1	100	8	0	10	22	59	1	0	83	1	17	33	3	18	13	33	12	88	1	99
West Virginia	100	1	100	8	46	24	14	5	3	45	48	0	7	93	0	2	1	3	5	95	1	99
Wisconsin	100	1	100	4	6	32	32	22	3	12	82	0	7	12	4	24	17	43	2	98	1	99
Wyoming	100	0	100	4	7	19	21	44	4	12	81	0	7	1	6	26	17	51	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.
Source(s): *See Step 3: Waste Management System Usage Data*

Table A-184: 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-185: 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
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

Waste Management System	Cool Climate MCF	Temperate Climate MCF	Warm Climate MCF
Poultry without bedding	1.5	1.5	1.5
Solid Storage	2	4	5

Source: IPCC 2006

Table A-186: Methane Conversion Factors by State for Liquid Systems for 2015 (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	78	42	78	41	43	78
Alaska	49	15	49	15	15	49
Arizona	79	58	78	49	54	75
Arkansas	77	37	78	40	37	77
California	73	34	73	33	43	74
Colorado	66	22	68	24	24	65
Connecticut	71	26	71	26	26	71
Delaware	76	33	76	33	33	76
Florida	82	60	81	58	58	81
Georgia	78	44	78	42	42	77
Hawaii	77	58	77	58	58	77
Idaho	68	25	65	22	22	67
Illinois	73	30	73	29	28	73
Indiana	71	27	72	28	28	72
Iowa	70	26	70	26	26	70
Kansas	76	34	76	33	34	76
Kentucky	75	33	75	33	32	76
Louisiana	80	50	80	50	50	79
Maine	65	21	65	21	21	65
Maryland	75	31	75	32	32	75
Massachusetts	69	24	70	25	25	70
Michigan	68	24	69	24	24	68
Minnesota	68	24	69	24	24	68
Mississippi	79	45	78	43	46	79
Missouri	75	32	74	32	32	75
Montana	60	19	63	21	21	63
Nebraska	72	27	72	28	27	72
Nevada	70	26	71	28	26	70
New Hampshire	66	22	66	23	22	66
New Jersey	74	30	75	31	29	74
New Mexico	74	32	72	29	30	71
New York	67	23	68	24	24	68
North Carolina	76	35	78	41	33	76
North Dakota	67	23	67	23	23	67
Ohio	71	27	72	28	28	72
Oklahoma	78	40	77	37	37	77
Oregon	65	23	65	23	23	65
Pennsylvania	71	27	72	28	28	72
Rhode Island	71	26	71	26	26	71
South Carolina	78	43	79	44	42	78
South Dakota	69	25	70	25	25	70
Tennessee	76	34	76	36	35	76
Texas	78	42	78	45	39	79
Utah	66	22	69	25	24	65
Vermont	64	21	64	21	21	65
Virginia	73	30	76	33	31	74
Washington	65	23	67	24	25	66
West Virginia	72	28	72	28	27	71
Wisconsin	67	23	68	24	24	68
Wyoming	62	20	63	21	22	62

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

Table A-187: Direct Nitrous Oxide Emission Factors for 2015 (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: *2006 IPCC Guidelines*

Table A-188: 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
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-189: Total Methane Emissions from Livestock Manure Management (kt)[a]

Animal Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Dairy Cattle	**590**	**685**	**889**	**951**	**985**	**1,036**	**988**	**1,057**	**1,091**	**1,212**	**1,243**	**1,243**	**1,256**	**1,297**	**1,373**	**1,338**	**1,361**	**1,391**
Dairy Cows	*581*	*676*	*880*	*942*	*977*	*1,027*	*980*	*1,049*	*1,083*	*1,202*	*1,233*	*1,233*	*1,247*	*1,288*	*1,363*	*1,328*	*1,350*	*1,380*
Dairy Heifer	*7*	*7*	*7*	*7*	*7*	*7*	*6*	*7*	*7*	*8*	*8*	*8*	*8*	*8*	*9*	*8*	*8*	*9*
Dairy Calves	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
Swine	**622**	**763**	**835**	**854**	**877**	**859**	**858**	**916**	**902**	**984**	**938**	**899**	**950**	**949**	**982**	**930**	**890**	**985**
Market Swine	483	608	681	697	719	705	707	755	742	816	780	751	794	795	823	779	739	826
Market <50 lbs.	*102*	*121*	*131*	*134*	*137*	*135*	*135*	*142*	*141*	*155*	*110*	*104*	*110*	*110*	*114*	*106*	*104*	*113*
Market 50-119 lbs.	*101*	*123*	*136*	*138*	*144*	*140*	*141*	*150*	*148*	*163*	*174*	*168*	*177*	*0*	*0*	*0*	*0*	*0*
Market 120-179 lbs.	*136*	*170*	*189*	*192*	*199*	*196*	*196*	*210*	*206*	*228*	*228*	*219*	*233*	*232*	*241*	*231*	*219*	*244*
Market >180 lbs.	*144*	*193*	*225*	*232*	*240*	*234*	*235*	*252*	*247*	*270*	*268*	*260*	*274*	*276*	*283*	*268*	*249*	*284*
Breeding Swine	139	155	155	158	158	154	151	161	160	168	158	149	156	155	159	151	151	160
Beef Cattle	**126**	**139**	**131**	**134**	**131**	**131**	**129**	**133**	**137**	**134**	**130**	**130**	**132**	**131**	**128**	**121**	**120**	**126**
Feedlot Steers	*14*	*14*	*15*	*15*	*15*	*16*	*15*	*15*	*16*	*16*	*16*	*16*	*16*	*17*	*16*	*16*	*16*	*16*
Feedlot Heifers	*7*	*8*	*9*	*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*
Beef Calves	*6*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*6*	*6*	*7*
NOF Heifers	*12*	*15*	*13*	*13*	*13*	*13*	*12*	*13*	*13*	*13*	*13*	*13*	*13*	*12*	*12*	*12*	*12*	*13*
NOF Steers	*12*	*14*	*11*	*11*	*11*	*10*	*10*	*10*	*11*	*10*	*10*	*11*	*10*	*10*	*9*	*9*	*9*	*9*
NOF Cows	*69*	*76*	*71*	*73*	*71*	*71*	*71*	*73*	*75*	*73*	*70*	*70*	*71*	*71*	*69*	*64*	*63*	*67*
Sheep	**7**	**5**	**4**	**4**	**4**	**4**	**3**	**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**
Poultry	**131**	**128**	**127**	**131**	**129**	**130**	**129**	**129**	**131**	**134**	**129**	**128**	**129**	**127**	**128**	**128**	**131**	**135**
Hens >1 yr.	*73*	*69*	*66*	*70*	*67*	*68*	*66*	*66*	*66*	*67*	*64*	*64*	*64*	*63*	*63*	*65*	*67*	*68*
Total Pullets	*25*	*22*	*22*	*22*	*22*	*22*	*23*	*22*	*23*	*25*	*23*	*23*	*24*	*23*	*23*	*24*	*24*	*26*
Chickens	*4*	*4*	*3*	*3*	*4*	*4*	*3*	*3*	*3*	*3*	*3*	*4*	*3*	*3*	*3*	*3*	*3*	*3*
Broilers	*19*	*23*	*28*	*28*	*29*	*29*	*30*	*31*	*32*	*32*	*33*	*31*	*31*	*31*	*32*	*31*	*31*	*32*
Turkeys	*10*	*9*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*6*	*6*	*6*	*6*	*6*	*6*	*6*
Horses	**9**	**11**	**13**	**13**	**13**	**13**	**12**	**12**	**12**	**11**	**10**	**10**	**10**	**10**	**10**	**9**	**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-190: Total (Direct and Indirect) Nitrous Oxide Emissions from Livestock Manure Management (kt)

Animal Type	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Dairy Cattle	**17.7**	**18.2**	**18.4**	**18.7**	**18.9**	**19.1**	**18.2**	**18.7**	**19.3**	**19.3**	**19.0**	**19.2**	**19.3**	**19.5**	**19.8**	**19.7**	**19.8**	**20.3**
Dairy Cows	*10.6*	*10.7*	*10.8*	*10.9*	*11.0*	*11.1*	*10.6*	*10.8*	*11.1*	*11.1*	*10.9*	*11.1*	*11.0*	*11.1*	*11.3*	*11.3*	*11.4*	*11.6*
Dairy Heifer	*7.1*	*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*	*8.4*	*8.7*
Dairy Calves	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Swine	**4.0**	**4.5**	**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**	**6.6**

Market Swine	*3.0*	*3.5*	*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*	*5.8*
Market <50 lbs.	*0.6*	*0.6*	*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*	*0.8*
Market 50-119 lbs.	*0.6*	*0.7*	*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*	*1.3*
Market 120-179 lbs.	*0.9*	*1.0*	*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*	*1.7*
Market >180 lbs.	*0.9*	*1.1*	*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*	*2.0*
Breeding Swine	*1.0*	*1.1*	*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*	*0.8*
Beef Cattle	**19.8**	**21.8**	**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**	**25.8**
Feedlot Steers	*13.4*	*14.4*	*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*	*17.3*
Feedlot Heifers	*6.4*	*7.4*	*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*	*8.5*
Sheep	**0.4**	**0.7**	**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**	**1.1**	**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**
Poultry	**4.7**	**5.1**	**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**	**5.2**
Hens >1 yr.	*1.0*	*1.0*	*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*	*1.3*
Total Pullets	*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*	*0.4*
Chickens	*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*
Broilers	*2.2*	*2.7*	*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*	*2.8*
Turkeys	*1.2*	*1.1*	*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*	*0.7*
Horses	**0.3**	**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**	**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**

+ 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-191: Methane Emissions by State from Livestock Manure Management for 2015 (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	0.0151	2.3891	0.4306	0.0081	1.6671	0.4671	9.3023	3.9333	0.0208	0.0085	0.0135	0.1632	0.0132	0.0005
Alaska	+	0.0166	0.0161	0.0002	0.0023	0.0015	0.2705	+	0.0207	0.0057	0.0002	0.0026	+	0.0040
Arizona	0.6429	1.0611	54.2481	0.1537	2.0060	0.6661	0.9310	+	0.0208	0.1057	0.0335	0.3502	0.0041	+
Arkansas	0.0336	3.2110	0.2329	0.0106	0.9678	1.8692	0.6232	3.4942	0.6877	0.0085	0.0136	0.1655	0.0095	0.0002
California	1.3318	3.6631	399.7726	1.9988	1.3906	0.1080	2.8400	0.2036	0.2876	0.4229	0.0546	0.3931	0.0072	0.0029
Colorado	1.5020	2.8195	33.5230	0.1506	4.5934	2.6309	3.9822	+	0.0207	0.1973	0.0066	0.2303	0.0049	0.0174
Connecticut	0.0003	0.0189	1.1524	0.0137	0.0044	0.0021	0.1012	+	0.0207	0.0034	0.0011	0.0459	0.0008	0.0002
Delaware	0.0003	0.0092	0.3293	0.0045	0.0194	0.0124	0.1061	0.8844	0.0207	0.0057	0.0003	0.0164	0.0001	0.0002
Florida	0.0111	3.2606	23.4736	0.1038	0.0609	0.0435	7.0412	0.2365	0.0208	0.0085	0.0182	0.3985	0.0113	+
Georgia	0.0133	1.7873	10.2297	0.0740	2.2700	0.8846	16.1855	4.8657	0.0208	0.0085	0.0241	0.2160	0.0099	0.0005
Hawaii	0.0027	0.2858	0.5184	0.0029	0.0615	0.0411	0.4163	+	0.0208	0.0085	0.0057	0.0140	0.0005	0.0002
Idaho	0.3871	1.6927	122.1684	0.4856	0.1477	0.0870	0.8315	+	0.0207	0.1222	0.0046	0.1180	0.0030	0.0100
Illinois	0.4035	1.0113	9.3806	0.0844	44.8221	10.5079	0.2696	0.2029	0.0207	0.0268	0.0076	0.1153	0.0026	0.0006
Indiana	0.1744	0.5910	15.9269	0.1285	36.1877	5.5922	1.0429	0.2029	0.4811	0.0235	0.0084	0.2346	0.0041	0.0018
Iowa	2.0667	3.1056	26.2279	0.2073	315.5249	31.8828	1.3261	0.2029	0.2268	0.0822	0.0141	0.1234	0.0033	0.0022
Kansas	3.8121	5.0002	27.4863	0.1485	21.7869	4.1020	0.0607	+	0.0207	0.0310	0.0095	0.1442	0.0027	0.0085
Kentucky	0.0302	2.5062	1.6651	0.0802	6.5611	1.4136	0.6808	1.1139	0.0207	0.0226	0.0109	0.2664	0.0099	0.0024
Louisiana	0.0089	1.6866	0.8189	0.0141	0.0125	0.0090	2.4196	0.2036	0.0208	0.0085	0.0064	0.1950	0.0086	0.0001
Maine	0.0008	0.0399	1.3959	0.0265	0.0092	0.0050	0.0951	+	0.0207	0.0034	0.0017	0.0260	0.0003	0.0004
Maryland	0.0193	0.1268	2.6337	0.0442	0.1577	0.0992	0.3375	1.0987	0.0207	0.0057	0.0018	0.0600	0.0009	0.0005
Massachusetts	0.0003	0.0194	0.3615	0.0118	0.0355	0.0145	0.0135	+	0.0207	0.0034	0.0022	0.0442	0.0004	0.0001
Michigan	0.2642	0.4435	60.3755	0.2640	10.0486	2.0626	0.8292	0.2029	0.1296	0.0357	0.0066	0.1755	0.0031	0.0016
Minnesota	0.6416	1.2525	37.3493	0.4428	67.6863	10.8214	0.3365	0.1680	1.0219	0.0611	0.0080	0.1142	0.0021	0.0022
Mississippi	0.0173	1.7844	0.4742	0.0166	8.6468	1.8000	8.2770	2.6243	0.0208	0.0085	0.0078	0.1798	0.0102	+
Missouri	0.1236	4.5447	6.6046	0.0985	23.2820	8.4510	0.4077	1.0665	0.4736	0.0399	0.0270	0.2150	0.0070	0.0019
Montana	0.0679	4.4400	1.7480	0.0105	1.1951	0.3948	0.3877	+	0.0207	0.1010	0.0023	0.2049	0.0036	0.0324
Nebraska	4.2658	5.9518	8.3449	0.0321	27.8275	8.3543	0.4730	0.2029	0.0207	0.0381	0.0051	0.1392	0.0030	0.0487
Nevada	0.0064	0.6131	6.6164	0.0137	0.0002	0.0002	0.0305	+	0.0207	0.0324	0.0068	0.0545	0.0005	0.0001
New Hampshire	0.0002	0.0117	0.6768	0.0092	0.0011	0.0005	0.0961	+	0.0207	0.0034	0.0014	0.0189	0.0001	0.0006
New Jersey	0.0003	0.0218	0.2701	0.0067	0.0477	0.0117	0.1047	+	0.0207	0.0057	0.0017	0.0573	0.0006	0.0004
New Mexico	0.0164	1.2871	77.4625	0.1702	0.0033	0.0033	0.8774	+	0.0207	0.0423	0.0070	0.1073	0.0014	0.0118
New York	0.0459	0.4512	34.6877	0.5859	0.4460	0.1100	0.6165	0.2029	0.0207	0.0376	0.0086	0.2043	0.0029	0.0009
North Carolina	0.0076	0.9251	3.4750	0.0453	138.7190	33.7077	13.0670	2.9882	0.7753	0.0211	0.0177	0.1970	0.0106	0.0002
North Dakota	0.0711	2.2401	1.6826	0.0094	0.8179	0.5490	0.0571	+	0.0207	0.0301	0.0013	0.0998	0.0010	0.0107
Ohio	0.2862	0.8297	22.4935	0.2006	22.0331	3.6934	1.0647	0.2911	0.1296	0.0569	0.0102	0.2433	0.0053	0.0010
Oklahoma	0.6394	7.8899	7.8296	0.0572	29.2451	16.8565	3.3746	0.7882	0.0208	0.0374	0.0252	0.5090	0.0153	0.0270
Oregon	0.1582	1.6292	20.1686	0.1044	0.0176	0.0096	0.8733	0.2029	0.0207	0.0916	0.0076	0.1293	0.0023	0.0033
Pennsylvania	0.1757	0.6268	18.5185	0.5243	11.1041	2.0637	0.8124	0.6893	0.1620	0.0404	0.0112	0.2673	0.0071	0.0009
Rhode Island	0.0001	0.0044	0.0325	0.0009	0.0028	0.0022	0.1017	+	0.0207	0.0034	0.0002	0.0039	0.0001	+
South Carolina	0.0039	0.6349	1.2822	0.0136	4.4947	0.4184	5.0005	0.8812	0.0208	0.0085	0.0134	0.1901	0.0067	0.0003
South Dakota	0.6453	4.3993	15.3640	0.1034	11.0760	3.3747	0.1014	+	0.1072	0.1198	0.0050	0.1493	0.0011	0.0566

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
Tennessee	0.0259	3.2529	1.5998	0.0449	3.6006	0.6394	0.2260	0.6727	0.0208	0.0310	0.0256	0.2276	0.0155	+
Texas	6.0470	18.2179	113.7558	0.5747	13.4191	3.4142	4.9055	2.2109	0.0208	0.5075	0.2708	1.2156	0.0715	0.0101
Utah	0.0391	0.9999	19.2656	0.0724	5.7015	1.2942	4.0254	+	0.0897	0.1363	0.0033	0.1281	0.0025	0.0021
Vermont	0.0010	0.0651	6.6809	0.0927	0.0063	0.0041	0.0102	+	0.0207	0.0034	0.0032	0.0234	0.0010	0.0001
Virginia	0.0383	1.6286	3.5346	0.0753	4.8657	0.1645	0.3717	0.9514	0.4237	0.0352	0.0109	0.1856	0.0053	0.0019
Washington	0.4006	0.8123	52.7571	0.2355	0.1193	0.0689	1.4902	0.2029	0.0207	0.0244	0.0059	0.1085	0.0026	0.0014
West Virginia	0.0078	0.4799	0.2976	0.0069	0.0038	0.0031	0.1820	0.3392	0.0748	0.0155	0.0033	0.0432	0.0022	+
Wisconsin	0.4347	1.1380	123.7352	1.1506	2.4610	0.7450	0.3117	0.1951	0.0207	0.0362	0.0160	0.2049	0.0043	0.0058
Wyoming	0.1192	2.1020	0.8642	0.0075	0.3552	0.4711	0.7751	+	0.0207	0.1621	0.0024	0.1482	0.0021	0.0171

+ 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-192: Nitrous Oxide Emissions by State from Livestock Manure Management for 2015 (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	0.0033	0.0067	0.0036	0.0027	0.0081	0.0017	0.0650	0.3480	0.0024	0.0046	0.0011	0.0056	0.0005
Alaska	+	+	0.0003	0.0002	+	+	0.0045	+	0.0024	0.0015	+	0.0001	+
Arizona	0.1684	0.3396	0.2457	0.1379	0.0094	0.0023	0.0048	+	0.0024	0.0165	0.0026	0.0120	0.0001
Arkansas	0.0077	0.0155	0.0023	0.0027	0.0059	0.0082	0.0882	0.3091	0.0797	0.0040	0.0011	0.0057	0.0003
California	0.2950	0.5935	2.1651	1.6122	0.0078	0.0004	0.0596	0.0180	0.0333	0.0747	0.0043	0.0135	0.0003
Colorado	0.6137	1.2390	0.2039	0.2301	0.0485	0.0205	0.0239	+	0.0024	0.0463	0.0008	0.0119	0.0003
Connecticut	0.0001	0.0002	0.0174	0.0100	+	+	0.0043	+	0.0024	0.0027	0.0001	0.0024	+
Delaware	0.0001	0.0002	0.0045	0.0031	0.0002	0.0001	0.0043	0.0785	0.0024	0.0046	+	0.0008	+
Florida	0.0022	0.0045	0.1143	0.0514	0.0003	0.0002	0.0463	0.0209	0.0024	0.0046	0.0015	0.0137	0.0004
Georgia	0.0029	0.0060	0.0648	0.0273	0.0110	0.0032	0.1128	0.4305	0.0024	0.0046	0.0019	0.0074	0.0004
Hawaii	0.0005	0.0011	0.0025	0.0023	0.0003	0.0002	0.0045	+	0.0024	0.0015	0.0005	0.0005	+
Idaho	0.1589	0.3214	0.7943	0.7418	0.0016	0.0007	0.0048	+	0.0024	0.0287	0.0005	0.0061	0.0002
Illinois	0.1558	0.3138	0.1370	0.1066	0.4147	0.0709	0.0192	0.0180	0.0024	0.0187	0.0009	0.0059	0.0001
Indiana	0.0673	0.1356	0.2458	0.1488	0.3485	0.0395	0.1449	0.0180	0.0559	0.0164	0.0010	0.0121	0.0002
Iowa	0.8033	1.6226	0.3207	0.2555	1.8775	0.1390	0.1842	0.0180	0.0264	0.0574	0.0017	0.0064	0.0002
Kansas	1.4249	2.8802	0.2062	0.1944	0.1831	0.0255	0.0043	+	0.0024	0.0217	0.0011	0.0074	0.0001
Kentucky	0.0104	0.0209	0.0301	0.0266	0.0353	0.0056	0.0277	0.0989	0.0024	0.0183	0.0013	0.0137	0.0005
Louisiana	0.0019	0.0038	0.0062	0.0031	0.0001	+	0.0121	0.0180	0.0024	0.0040	0.0005	0.0067	0.0003
Maine	0.0003	0.0006	0.0265	0.0189	0.0001	+	0.0043	+	0.0024	0.0027	0.0002	0.0013	+
Maryland	0.0066	0.0134	0.0444	0.0301	0.0013	0.0006	0.0137	0.0975	0.0024	0.0046	0.0002	0.0031	+
Massachusetts	0.0001	0.0002	0.0106	0.0082	0.0003	0.0001	0.0006	+	0.0024	0.0027	0.0003	0.0023	+
Michigan	0.1036	0.2096	0.6380	0.3560	0.1016	0.0155	0.0612	0.0180	0.0151	0.0249	0.0008	0.0090	0.0002
Minnesota	0.2515	0.5083	0.6572	0.5547	0.6848	0.0807	0.0468	0.0149	0.1188	0.0426	0.0009	0.0059	0.0001
Mississippi	0.0038	0.0076	0.0053	0.0041	0.0415	0.0062	0.0423	0.2322	0.0024	0.0046	0.0006	0.0062	0.0004
Missouri	0.0468	0.0943	0.1073	0.1095	0.2157	0.0569	0.0568	0.0947	0.0551	0.0279	0.0032	0.0111	0.0004

Montana	0.0283	0.0569	0.0188	0.0153	0.0140	0.0034	0.0024	+	0.0024	0.0237	0.0003	0.0106	0.0002
Nebraska	1.6457	3.3280	0.0799	0.0425	0.2698	0.0596	0.0341	0.0180	0.0024	0.0266	0.0006	0.0072	0.0002
Nevada	0.0026	0.0053	0.0376	0.0209	+	+	0.0042	+	0.0024	0.0076	0.0008	0.0028	+
New Hampshire	0.0001	0.0001	0.0125	0.0066	+	+	0.0043	+	0.0024	0.0027	0.0002	0.0010	+
New Jersey	0.0001	0.0002	0.0058	0.0044	0.0004	0.0001	0.0043	+	0.0024	0.0046	0.0002	0.0030	+
New Mexico	0.0065	0.0132	0.4053	0.2332	+	+	0.0048	+	0.0024	0.0099	0.0008	0.0055	0.0001
New York	0.0167	0.0339	0.5709	0.4138	0.0045	0.0008	0.0269	0.0180	0.0024	0.0305	0.0010	0.0105	0.0002
North Carolina	0.0026	0.0052	0.0331	0.0132	0.6712	0.1203	0.0923	0.2644	0.0898	0.0114	0.0014	0.0068	0.0004
North Dakota	0.0280	0.0567	0.0218	0.0117	0.0088	0.0044	0.0043	+	0.0024	0.0210	0.0001	0.0051	0.0001
Ohio	0.1102	0.2229	0.3582	0.2316	0.2128	0.0262	0.1466	0.0258	0.0151	0.0459	0.0012	0.0125	0.0003
Oklahoma	0.1736	0.3507	0.0481	0.0549	0.1469	0.0616	0.0172	0.0697	0.0024	0.0173	0.0020	0.0175	0.0005
Oregon	0.0548	0.1110	0.1444	0.1130	0.0002	0.0001	0.0111	0.0180	0.0024	0.0243	0.0009	0.0067	0.0001
Pennsylvania	0.0627	0.1260	0.4561	0.3336	0.1024	0.0142	0.1130	0.0612	0.0188	0.0328	0.0013	0.0138	0.0004
Rhode Island	+	0.0001	0.0008	0.0005	+	+	0.0043	+	0.0024	0.0027	+	0.0002	+
South Carolina	0.0009	0.0018	0.0084	0.0037	0.0227	0.0016	0.0252	0.0780	0.0024	0.0046	0.0011	0.0065	0.0002
South Dakota	0.2515	0.5083	0.1437	0.1336	0.1087	0.0244	0.0074	+	0.0125	0.0837	0.0006	0.0077	0.0001
Tennessee	0.0062	0.0127	0.0226	0.0159	0.0187	0.0025	0.0093	0.0595	0.0024	0.0168	0.0020	0.0078	0.0005
Texas	1.6347	3.3045	0.5806	0.5408	0.0713	0.0133	0.0977	0.1956	0.0024	0.0794	0.0214	0.0418	0.0025
Utah	0.0160	0.0323	0.1305	0.1100	0.0573	0.0107	0.0240	+	0.0104	0.0320	0.0004	0.0066	0.0001
Vermont	0.0004	0.0007	0.1181	0.0673	0.0001	+	0.0005	+	0.0024	0.0027	0.0004	0.0012	0.0001
Virginia	0.0132	0.0267	0.0512	0.0288	0.0256	0.0006	0.0154	0.0844	0.0493	0.0286	0.0013	0.0096	0.0003
Washington	0.1369	0.2771	0.3563	0.2674	0.0012	0.0005	0.0347	0.0180	0.0024	0.0065	0.0007	0.0056	0.0001
West Virginia	0.0028	0.0056	0.0071	0.0047	+	+	0.0078	0.0301	0.0087	0.0126	0.0004	0.0022	0.0001
Wisconsin	0.1709	0.3452	1.9134	1.4068	0.0245	0.0055	0.0230	0.0173	0.0024	0.0253	0.0019	0.0106	0.0002
Wyoming	0.0491	0.0992	0.0077	0.0095	0.0049	0.0047	0.0048	+	0.0024	0.0380	0.0003	0.0076	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[85] 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*[86], 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[87] 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 DAYCENT Pasture/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_4 emissions 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.

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

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[85] 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).

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

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

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 biosolids (i.e., 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 biosolids (i.e., 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.[88] 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

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

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 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

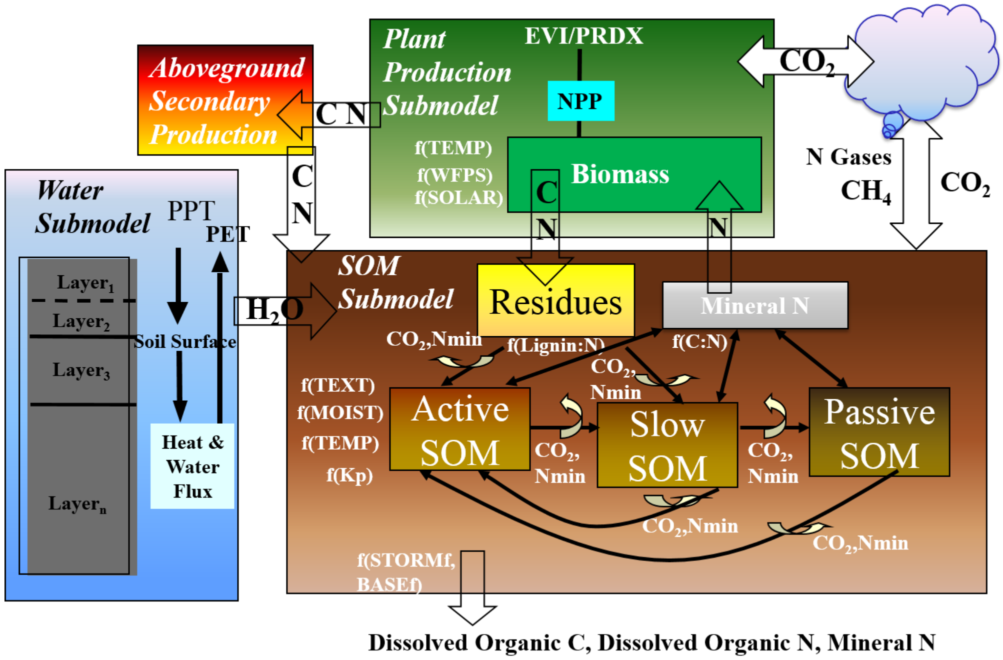
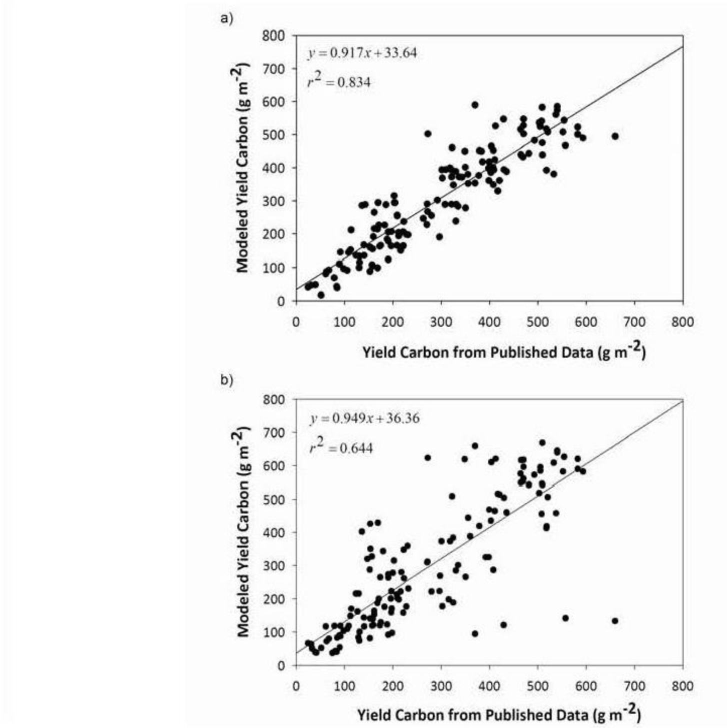


Figure A-8: Modeled versus measured net primary production (g C m^{-2})



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]

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

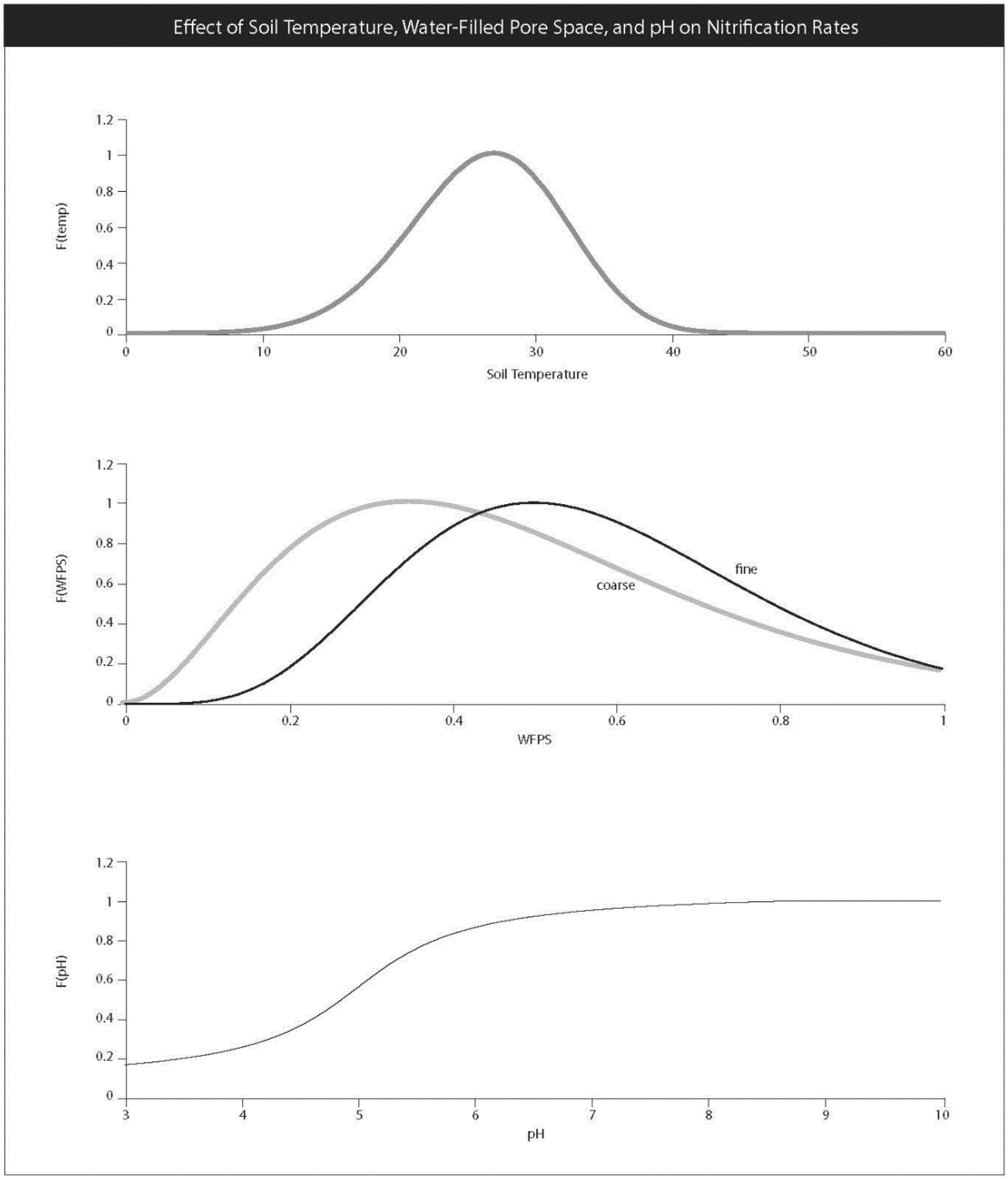
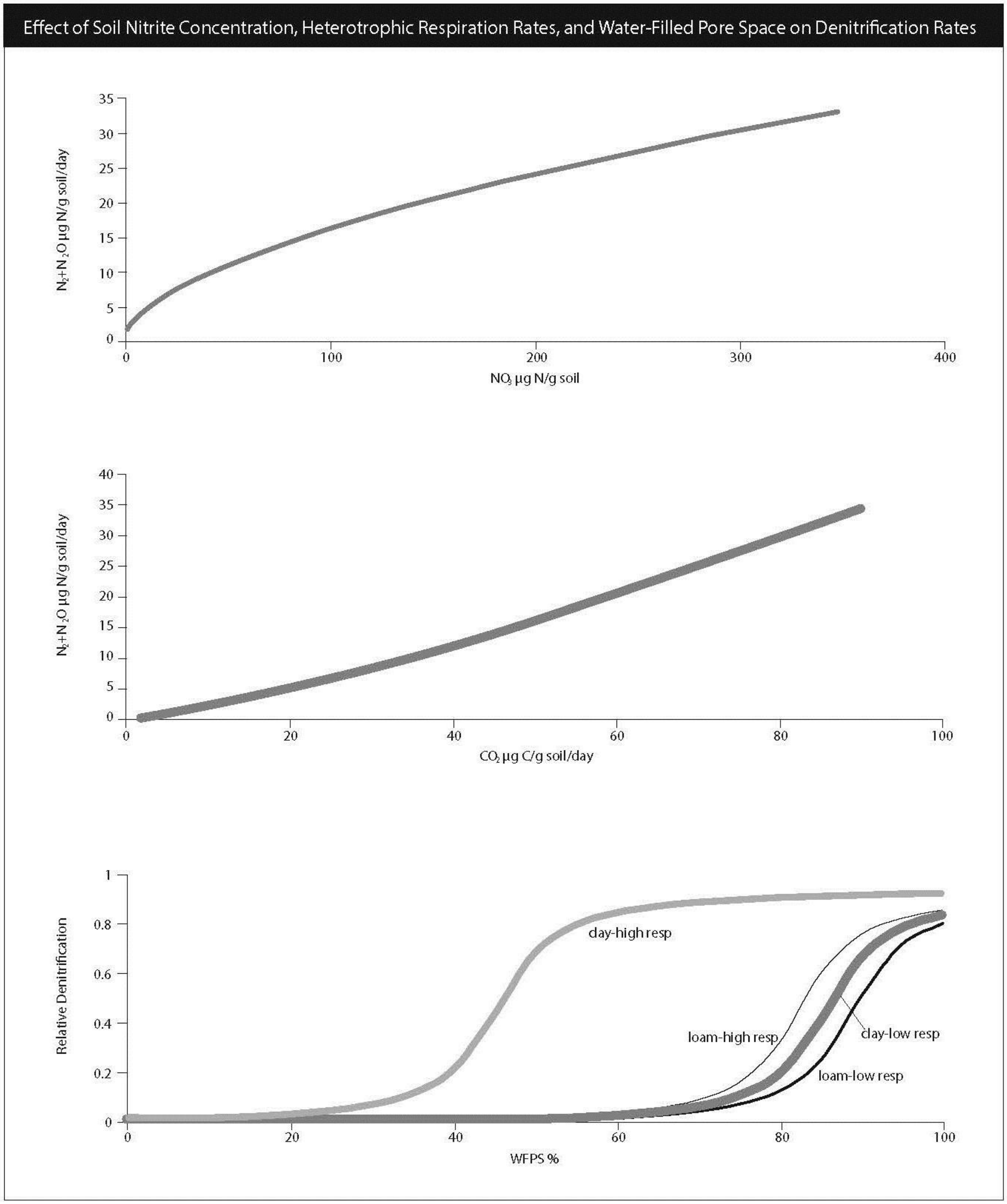


Figure A-10: Effect of Soil Nitrite Concentration (a), Heterotrophic Respiration Rates (b), and Water-Filled Pore Space (c) on Denitrification Rates



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 92 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,

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

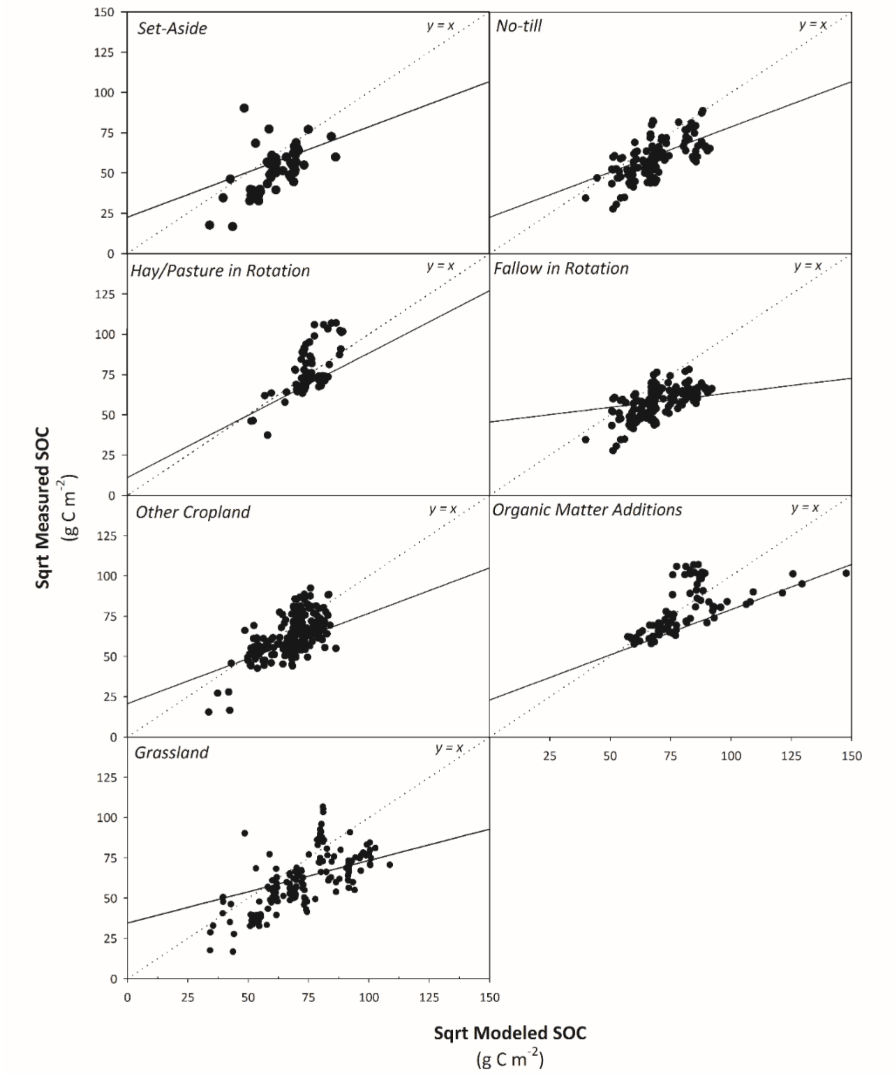
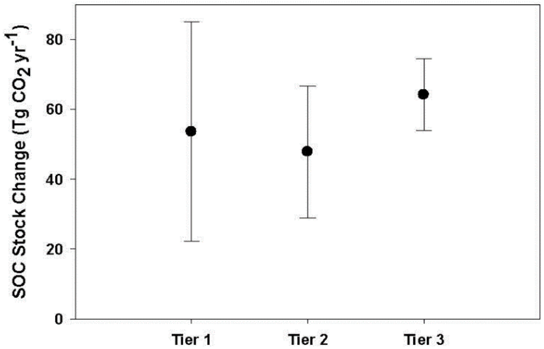
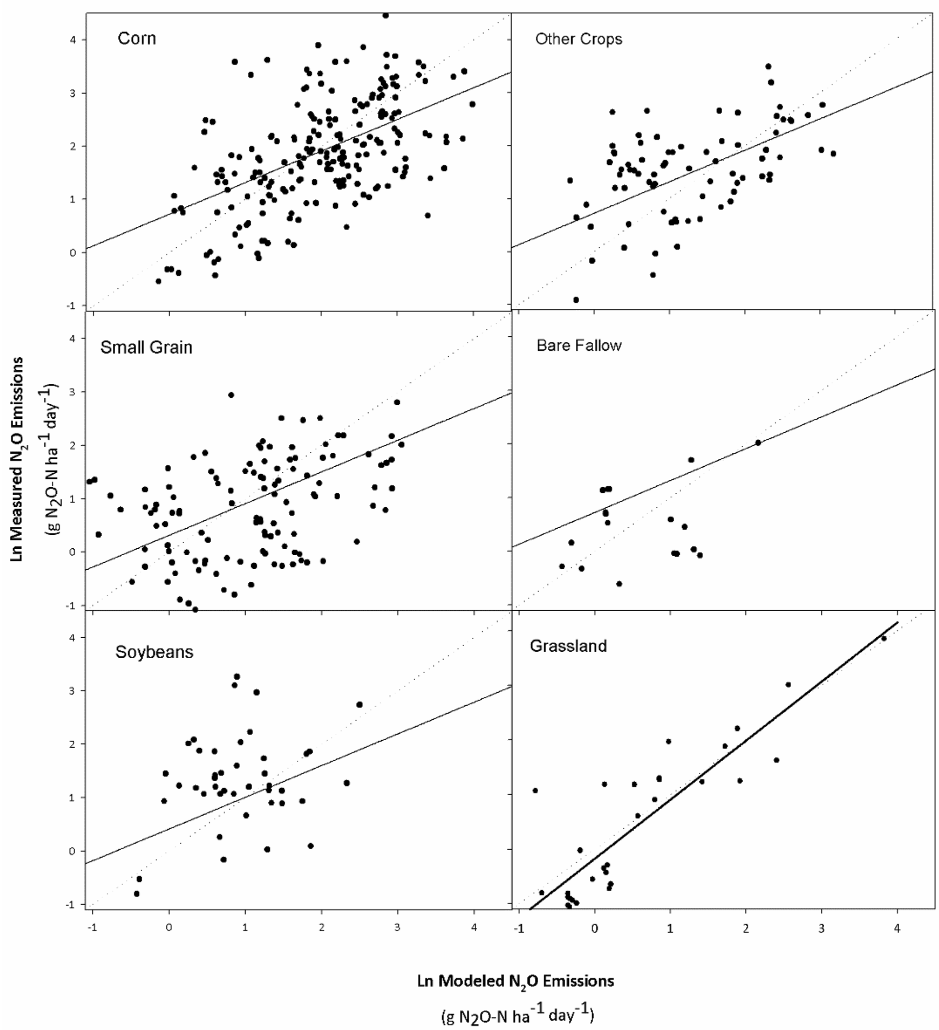


Figure A-12: Comparison of Estimated Soil Organic C Stock Changes and Uncertainties using Tier 1 (IPCC 2006), Tier 2 (Ogle et al. 2003, 2006) and Tier 3 Methods



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 =

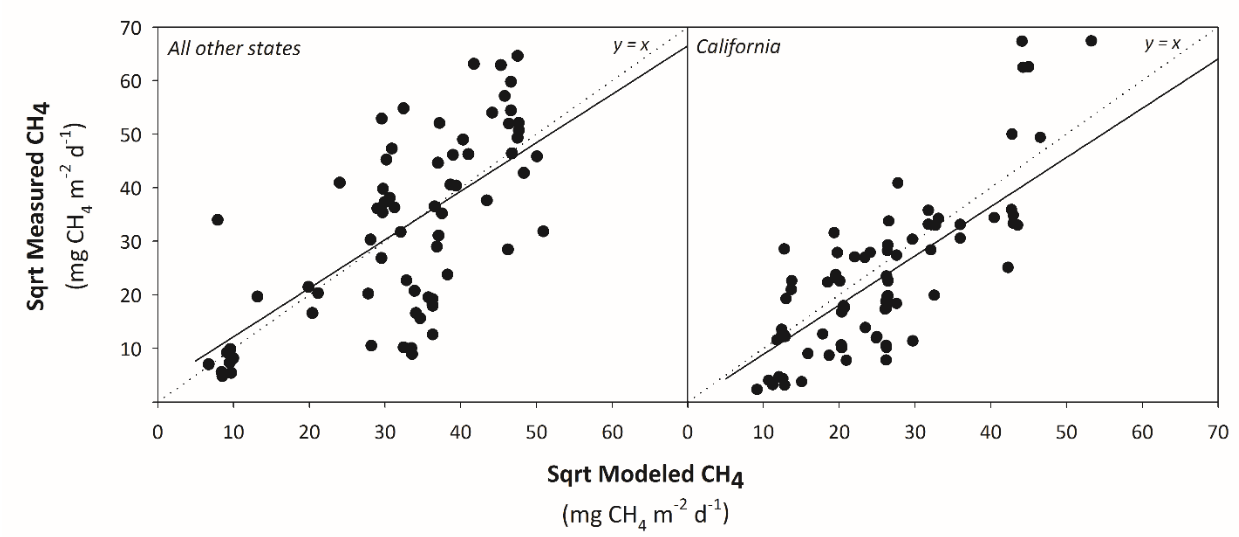
Figure A-13: Comparisons of Results from DAYCENT Model and Measurements of Soil Nitrous Oxide Emissions



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 (Table 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-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,[89] (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.[90]

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

The U.S. Department of Agriculture's 2012 National Resources Inventory (NRI) (USDA-NRCS 2015) 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). The time series will be extended as new data are released by the USDA NRI program. 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

[89] 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.
[90] Edaphic characteristics include such factors as water content, acidity, aeration, and the availability of nutrients.

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).[91] 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 2012, 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[92] between 1990 and 2012 (Table A-193).[93] NRI does not provide land use data on federal 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[94]. 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-193: 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**	**2002**
Mineral Soils	**421.74**	**421.03**	**420.41**	**419.74**	**419.11**	**418.34**	**417.45**	**416.61**	**415.72**	**414.93**	**414.32**	**413.79**	**413.29**
Croplands	**172.92**	**172.82**	**172.61**	**172.13**	**171.76**	**171.34**	**171.02**	**170.59**	**168.14**	**167.71**	**167.42**	**166.85**	**166.54**
Cropland Remaining Cropland	160.44	159.99	159.52	157.78	156.20	155.62	155.01	154.46	150.61	149.80	149.71	149.34	149.15
Grassland Converted to Cropland	11.79	12.13	12.39	13.62	14.77	14.95	15.22	15.36	16.75	17.13	16.92	16.75	16.66
Forest Converted to Cropland	0.28	0.27	0.26	0.24	0.24	0.23	0.23	0.22	0.21	0.19	0.17	0.14	0.13
Other Lands Converted to Cropland	0.20	0.21	0.22	0.23	0.26	0.26	0.27	0.27	0.27	0.27	0.32	0.31	0.29
Settlements Converted to Croplands	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11
Wetlands Converted to Croplands	0.14	0.14	0.14	0.16	0.19	0.19	0.20	0.19	0.20	0.20	0.20	0.20	0.20
Grasslands	**248.82**	**248.21**	**247.80**	**247.61**	**247.35**	**247.00**	**246.44**	**246.02**	**247.58**	**247.22**	**246.90**	**246.94**	**246.75**
Grasslands Remaining Grasslands	238.89	238.06	237.34	235.76	234.27	233.70	232.99	232.40	230.08	229.24	228.31	227.57	226.99
Croplands Converted to Grasslands	8.65	8.77	8.95	10.24	11.38	11.58	11.69	11.84	15.43	15.83	16.29	16.98	17.32
Forest Converted to Grasslands	0.57	0.58	0.61	0.60	0.58	0.58	0.59	0.59	0.80	0.80	0.81	0.80	0.81
Other Lands Converted to Grasslands	0.41	0.43	0.47	0.54	0.63	0.66	0.67	0.71	0.77	0.82	0.95	1.03	1.05
Settlements Converted to Grasslands	0.06	0.07	0.07	0.08	0.09	0.09	0.09	0.09	0.10	0.11	0.11	0.12	0.13
Wetlands Converted to Grasslands	0.24	0.30	0.37	0.39	0.40	0.40	0.40	0.39	0.41	0.42	0.43	0.44	0.45
Organic Soils	**1.43**	**1.42**	**1.41**	**1.42**	**1.43**	**1.43**	**1.42**	**1.42**	**1.42**	**1.33**	**1.32**	**1.41**	**1.42**
Croplands	**0.73**	**0.72**	**0.72**	**0.72**	**0.72**	**0.73**	**0.73**	**0.73**	**0.73**	**0.64**	**0.63**	**0.74**	**0.74**
Cropland Remaining Cropland	0.66	0.64	0.65	0.64	0.64	0.64	0.63	0.63	0.62	0.54	0.54	0.62	0.63
Grassland Converted to Cropland	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.07	0.09	0.09

[91] 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.

[92] 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).

[93] 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).

[94] 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.

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	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Grasslands	**0.70**	**0.70**	**0.69**	**0.70**	**0.71**	**0.70**	**0.69**	**0.69**	**0.70**	**0.69**	**0.69**	**0.68**	**0.68**
Grasslands Remaining Grasslands	0.64	0.63	0.63	0.62	0.62	0.61	0.61	0.60	0.59	0.59	0.58	0.55	0.55
Croplands Converted to Grasslands	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.08	0.08	0.08	0.09	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	0.01
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	0.02	0.02	0.02	0.03	0.03	0.02
Total	**423.18**	**422.45**	**421.82**	**421.16**	**420.54**	**419.77**	**418.88**	**418.02**	**417.15**	**416.26**	**415.64**	**415.20**	**414.71**

Category	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Mineral Soils	**412.44**	**411.78**	**410.79**	**410.09**	**409.44**	**408.83**	**408.29**	**407.70**	**407.18**	**406.59**	**406.36**	**406.13**	**405.89**
Croplands	**165.89**	**164.76**	**164.42**	**164.02**	**163.70**	**163.22**	**162.81**	**162.37**	**162.08**	**161.86**	**161.86**	**161.86**	**161.86**
Cropland Remaining Cropland	149.81	149.73	149.40	149.09	149.32	149.46	149.68	149.28	148.86	148.59	148.59	148.59	148.59
Grassland Converted to Cropland	15.42	14.42	14.43	14.33	13.82	13.25	12.66	12.63	12.75	12.80	12.80	12.80	12.80
Forest Converted to Cropland	0.11	0.10	0.10	0.09	0.09	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Other Lands Converted to Cropland	0.27	0.26	0.25	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.21	0.21	0.21
Settlements Converted to Croplands	0.09	0.08	0.09	0.09	0.09	0.08	0.07	0.08	0.08	0.09	0.09	0.09	0.09
Wetlands Converted to Croplands	0.19	0.17	0.17	0.17	0.15	0.13	0.11	0.11	0.12	0.12	0.12	0.12	0.12
Grasslands	**246.55**	**247.01**	**246.37**	**246.08**	**245.74**	**245.61**	**245.48**	**245.33**	**245.10**	**244.74**	**244.50**	**244.27**	**244.03**
Grasslands Remaining Grasslands	227.28	227.37	226.83	226.48	226.44	226.74	226.93	226.62	226.26	226.03	225.80	225.56	225.33
Croplands Converted to Grasslands	16.89	17.31	17.14	17.21	16.92	16.61	16.36	16.57	16.76	16.72	16.72	16.72	16.72
Forest Converted to Grasslands	0.77	0.73	0.76	0.72	0.68	0.63	0.62	0.60	0.59	0.57	0.57	0.57	0.57
Other Lands Converted to Grasslands	1.05	1.05	1.07	1.09	1.12	1.14	1.13	1.14	1.14	1.12	1.12	1.12	1.12
Settlements Converted to Grasslands	0.12	0.12	0.12	0.13	0.13	0.13	0.12	0.12	0.12	0.13	0.13	0.13	0.13
Wetlands Converted to Grasslands	0.44	0.44	0.44	0.44	0.44	0.37	0.31	0.27	0.23	0.17	0.17	0.17	0.17
Organic Soils	**1.41**	**1.41**	**1.40**	**1.38**	**1.37**	**1.36**	**1.37**	**1.36**	**1.33**	**1.33**	**1.32**	**1.33**	**1.33**
Croplands	**0.74**	**0.74**	**0.73**	**0.73**	**0.72**	**0.71**	**0.72**	**0.71**	**0.68**	**0.69**	**0.69**	**0.69**	**0.69**
Cropland Remaining Cropland	0.64	0.64	0.64	0.64	0.64	0.63	0.64	0.64	0.61	0.61	0.61	0.61	0.61
Grassland Converted to Cropland	0.09	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	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	0.01	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	**0.66**	**0.67**	**0.67**	**0.65**	**0.65**	**0.65**	**0.65**	**0.65**	**0.65**	**0.64**	**0.64**	**0.64**	**0.64**
Grasslands Remaining Grasslands	0.54	0.54	0.53	0.52	0.51	0.51	0.51	0.50	0.50	0.49	0.49	0.49	0.49
Croplands Converted to Grasslands	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Forest Converted to Grasslands	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
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	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Total	**413.85**	**413.18**	**412.19**	**411.48**	**410.81**	**410.19**	**409.66**	**409.06**	**408.51**	**407.92**	**407.69**	**407.45**	**407.22**

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-194) (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-194: 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	106.49	315.25	421.74	1.43	**423.18**
1991	105.49	315.54	421.03	1.42	**422.45**
1992	104.55	315.86	420.41	1.41	**421.82**
1993	103.40	316.34	419.74	1.42	**421.16**
1994	102.30	316.81	419.11	1.43	**420.54**
1995	101.02	317.33	418.34	1.43	**419.77**
1996	99.68	317.78	417.45	1.42	**418.88**
1997	98.34	318.26	416.61	1.42	**418.02**
1998	96.96	318.77	415.72	1.42	**417.15**
1999	95.63	319.30	414.93	1.33	**416.26**
2000	94.65	319.66	414.32	1.32	**415.64**
2001	93.80	320.00	413.79	1.41	**415.20**
2002	92.97	320.32	413.29	1.42	**414.71**
2003	92.14	320.30	412.44	1.41	**413.85**
2004	91.47	320.31	411.78	1.41	**413.18**
2005	90.53	320.27	410.79	1.40	**412.19**
2006	89.87	320.23	410.09	1.38	**411.48**
2007	89.24	320.20	409.44	1.37	**410.81**
2008	88.83	320.00	408.83	1.36	**410.19**
2009	88.45	319.84	408.29	1.37	**409.66**
2010	88.05	319.65	407.70	1.36	**409.06**
2011	87.60	319.57	407.18	1.33	**408.51**
2012	87.26	319.34	406.59	1.33	**407.92**
2013	87.14	319.22	406.36	1.32	**407.69**
2014	87.03	319.09	406.13	1.33	**407.45**
2015	86.92	318.97	405.89	1.33	**407.22**

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-195). 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-195: 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**	**2002**
Cropland Systems	**22.42**	**22.14**	**21.80**	**21.33**	**20.90**	**20.48**	**20.07**	**19.62**	**18.83**	**18.33**	**17.93**	**17.67**	**17.43**
Conservation Reserve Program	1.98	2.25	2.30	2.16	1.97	1.90	1.77	1.73	1.32	1.25	1.14	1.12	1.07
High Input Cropping Systems, Full Tillage	1.42	1.24	1.12	0.98	0.91	0.88	0.91	0.59	0.57	0.63	0.69	0.66	0.60
High Input Cropping Systems, Reduced Tillage	1.00	1.08	1.15	1.18	1.24	1.27	1.27	1.38	1.32	1.22	1.12	1.09	1.01
High Input Cropping Systems, No Tillage	0.10	0.11	0.05	0.07	0.08	0.10	0.10	0.17	0.17	0.18	0.18	0.19	0.18
High Input Cropping Systems with Manure, Full Tillage	0.10	0.09	0.09	0.08	0.07	0.07	0.08	0.05	0.05	0.05	0.06	0.06	0.05
High Input Cropping Systems with Manure, Reduced Tillage	0.08	0.09	0.08	0.09	0.09	0.10	0.10	0.11	0.11	0.09	0.09	0.08	0.07
High Input Cropping Systems with Manure, No Tillage	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Medium Input Cropping Systems, Full Tillage	5.31	4.95	4.34	3.80	3.47	3.47	3.35	1.80	1.76	1.89	2.01	2.09	2.15

Medium Input Cropping Systems, Reduced Tillage	4.32	4.38	4.85	5.10	5.19	4.83	4.80	5.87	5.59	5.29	4.97	4.79	4.64
Medium Input Cropping Systems, No Tillage	0.34	0.37	0.23	0.31	0.36	0.43	0.42	0.74	0.74	0.76	0.79	0.79	0.79
Low Input Cropping Systems, Full Tillage	2.91	2.84	2.76	2.68	2.60	2.63	2.64	2.49	2.35	2.20	2.18	2.08	1.99
Low Input Cropping Systems, Reduced Tillage	0.07	0.05	0.18	0.19	0.25	0.27	0.26	0.32	0.37	0.37	0.38	0.39	0.40
Low Input Cropping Systems, No Tillage	0.02	0.02	0.01	0.02	0.03	0.04	0.04	0.06	0.07	0.07	0.08	0.11	0.13
Hay with Legumes or Irrigation	1.23	1.18	1.09	1.16	1.12	1.07	0.95	0.88	0.94	0.88	0.76	0.73	0.82
Hay with Legumes or Irrigation and Manure	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Hay, Unimproved	0.71	0.72	0.76	0.70	0.67	0.62	0.62	0.67	0.62	0.56	0.53	0.49	0.53
Pasture with Legumes or Irrigation in Rotation	2.42	2.41	2.41	2.43	2.45	2.43	2.41	2.38	2.48	2.51	2.55	2.61	2.60
Pasture with Legumes or Irrigation and Manure, in Rotation	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16
Rice	0.17	0.15	0.17	0.16	0.16	0.16	0.16	0.16	0.17	0.14	0.19	0.18	0.18
Grassland Systems	**84.07**	**83.35**	**82.75**	**82.07**	**81.40**	**80.54**	**79.60**	**78.73**	**78.13**	**77.30**	**76.72**	**76.13**	**75.54**
Pasture with Legumes or Irrigation	5.59	5.39	5.11	5.03	5.01	4.82	4.46	3.98	4.00	3.88	3.64	3.52	3.40
Pasture with Legumes or Irrigation and Manure	0.17	0.17	0.15	0.15	0.15	0.15	0.13	0.11	0.11	0.11	0.10	0.09	0.09
Rangelands and Unimproved Pasture	47.71	47.17	47.00	46.75	46.26	45.56	44.53	44.27	43.47	42.77	43.10	42.64	43.43
Rangelands and Unimproved Pasture, Moderately Degraded	22.07	22.19	22.26	22.10	22.09	22.16	22.49	22.36	23.01	22.95	22.29	22.34	21.31
Rangelands and Unimproved Pasture, Severely Degraded	8.52	8.43	8.23	8.04	7.89	7.85	7.99	8.00	7.54	7.59	7.60	7.54	7.31
Total	**106.49**	**105.49**	**104.55**	**103.40**	**102.30**	**101.02**	**99.68**	**98.34**	**96.96**	**95.63**	**94.65**	**93.80**	**92.97**

	Land Areas (million hectares)												
Land-Use/Management System	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Cropland Systems	**17.13**	**16.76**	**16.57**	**16.40**	**16.22**	**16.13**	**16.00**	**15.90**	**15.78**	**15.73**	**15.73**	**15.73**	**15.73**
Conservation Reserve Program	0.92	0.68	0.76	0.75	0.73	0.69	0.68	0.66	0.61	0.55	0.55	0.55	0.55
High Input Cropping Systems, Full Tillage	0.60	0.59	0.57	0.55	0.53	0.54	0.55	0.53	0.53	0.51	0.51	0.51	0.51
High Input Cropping Systems, Reduced Tillage	1.00	0.96	0.93	0.91	0.88	0.90	0.91	0.88	0.88	0.86	0.86	0.86	0.86
High Input Cropping Systems, No Tillage	0.20	0.21	0.21	0.20	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.18
High Input Cropping Systems with Manure, Full Tillage	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
High Input Cropping Systems with Manure, Reduced Tillage	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
High Input Cropping Systems with Manure, No Tillage	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Medium Input Cropping Systems, Full Tillage	2.08	2.03	2.00	1.98	1.98	1.98	1.98	1.97	1.97	1.97	1.97	1.97	1.97
Medium Input Cropping Systems, Reduced Tillage	4.55	4.50	4.42	4.38	4.39	4.39	4.39	4.38	4.38	4.39	4.39	4.39	4.39
Medium Input Cropping Systems, No Tillage	0.88	0.98	0.96	0.95	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Low Input Cropping Systems, Full Tillage	1.90	1.77	1.74	1.74	1.69	1.66	1.56	1.55	1.51	1.55	1.55	1.55	1.55
Low Input Cropping Systems, Reduced Tillage	0.42	0.45	0.44	0.43	0.42	0.41	0.38	0.38	0.37	0.39	0.39	0.39	0.39
Low Input Cropping Systems, No Tillage	0.20	0.25	0.25	0.25	0.24	0.24	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Hay with Legumes or Irrigation	0.77	0.77	0.75	0.73	0.73	0.72	0.68	0.70	0.66	0.66	0.66	0.66	0.66
Hay with Legumes or Irrigation and Manure	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Hay, Unimproved	0.53	0.50	0.50	0.49	0.50	0.48	0.47	0.46	0.46	0.46	0.46	0.46	0.46
Pasture with Legumes or Irrigation in Rotation	2.58	2.57	2.56	2.56	2.52	2.51	2.57	2.56	2.58	2.57	2.57	2.57	2.57
Pasture with Legumes or Irrigation and Manure, in Rotation	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Rice	0.16	0.17	0.16	0.14	0.13	0.14	0.12	0.14	0.14	0.13	0.13	0.13	0.13
Grassland Systems	**75.01**	**74.71**	**73.96**	**73.47**	**73.02**	**72.70**	**72.45**	**72.16**	**71.82**	**71.53**	**71.41**	**71.30**	**71.19**

Pasture with Legumes or Irrigation	3.28	3.25	3.17	3.09	2.98	2.90	2.90	2.81	2.76	2.73	2.72	2.72	2.72
Pasture with Legumes or Irrigation and Manure	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06
Rangelands and Unimproved Pasture	43.43	42.65	42.19	41.96	41.66	41.52	41.32	41.29	41.07	40.87	40.83	40.78	40.74
Rangelands and Unimproved Pasture, Moderately Degraded	20.86	20.84	20.76	20.64	20.69	20.63	20.62	20.52	20.48	20.43	20.39	20.34	20.30
Rangelands and Unimproved Pasture, Severely Degraded	7.36	7.89	7.77	7.70	7.62	7.58	7.54	7.47	7.45	7.43	7.41	7.39	7.37
Total	**92.14**	**91.47**	**90.53**	**89.87**	**89.24**	**88.83**	**88.45**	**88.05**	**87.60**	**87.26**	**87.14**	**87.03**	**86.92**

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-196).

Table A-196: Total Land Areas for Drained Organic Soils By Land Management Category and Climate Region (Million Hectares)

IPCC Land-Use Category for Organic Soils	Land Areas (million ha) 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Cold Temperate														
Cultivated Cropland (high drainage)	0.43	0.42	0.42	0.43	0.42	0.42	0.42	0.43	0.43	0.42	0.41	0.41	0.41	0.41
Managed Pasture (low drainage)	0.47	0.47	0.47	0.47	0.48	0.48	0.47	0.47	0.47	0.46	0.46	0.47	0.47	0.46
Undrained	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03
Total	**0.95**	**0.95**	**0.94**	**0.94**	**0.94**	**0.94**	**0.93**	**0.92**	**0.92**	**0.91**	**0.92**	**0.91**	**0.90**	**0.90**
Warm Temperate														
Cultivated Cropland (high drainage)	0.10	0.10	0.09	0.09	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10
Managed Pasture (low drainage)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.11
Undrained	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	0.00
Total	**0.21**	**0.20**	**0.19**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.21**
Sub-Tropical														
Cultivated Cropland (high drainage)	0.20	0.20	0.20	0.20	0.21	0.21	0.21	0.21	0.21	0.13	0.13	0.24	0.24	0.23
Managed Pasture (low drainage)	0.14	0.14	0.13	0.13	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.11	0.11	0.10
Undrained	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.09	0.00	0.00	0.00
Total	**0.34**	**0.34**	**0.34**	**0.34**	**0.34**	**0.34**	**0.35**	**0.34**	**0.35**	**0.35**	**0.34**	**0.35**	**0.35**	**0.33**

IPCC Land-Use Category for Organic Soils	Land Areas (million ha) 2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cold Temperate												
Cultivated Cropland (high drainage)	0.41	0.41	0.40	0.41	0.40	0.40	0.40	0.40	0.41	0.41	0.41	0.41
Managed Pasture (low drainage)	0.47	0.47	0.47	0.46	0.46	0.46	0.46	0.45	0.44	0.44	0.44	0.45
Undrained	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Total	**0.90**	**0.90**	**0.90**	**0.89**	**0.89**	**0.88**	**0.88**	**0.88**	**0.87**	**0.87**	**0.87**	**0.87**
Warm Temperate												
Cultivated Cropland (high drainage)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Managed Pasture (low drainage)	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Undrained	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.21**	**0.21**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**
Sub-Tropical												
Cultivated Cropland (high drainage)	0.23	0.22	0.22	0.21	0.21	0.22	0.22	0.18	0.18	0.18	0.18	0.18

Managed Pasture (low drainage)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Undrained	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.03	0.03	0.03	0.03	0.03
Total	**0.33**	**0.33**	**0.33**	**0.33**	**0.32**	**0.32**	**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-197). 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-197: 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	0.16	1.54	1.70
1991	0.16	1.60	1.76
1992	0.17	1.67	1.84
1993	0.17	1.63	1.80
1994	0.17	1.53	1.70
1995	0.15	1.56	1.71
1996	0.15	1.56	1.72
1997	0.15	1.52	1.67
1998	0.17	1.43	1.60
1999	0.31	1.49	1.80
2000	0.33	1.51	1.84
2001	0.18	1.44	1.62
2002	0.18	1.60	1.79
2003	0.15	1.47	1.62
2004	0.17	1.53	1.69
2005	0.18	1.65	1.83
2006	0.14	1.33	1.48
2007	0.12	1.45	1.57
2008	0.14	1.27	1.41
2009	0.14	1.57	1.71
2010	0.15	1.61	1.76
2011	0.13	1.32	1.45
2012	0.11	1.18	1.29
2013	0.11	1.18	1.29
2014	0.11	1.18	1.29
2015	0.11	1.18	1.29

Note: Land use data for 2013 through 2015 are based on the 2012 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)[95]. 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 2015 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.

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

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

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-198.

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:[96] 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-199.

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 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

[96] 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.

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-199.

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)[97] are provided in Table A-200.

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-200.

Tillage Practices: Tillage practices are estimated for each cropping system based on data from the Conservation Technology Information Center[98] (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).

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.,

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

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

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 2015. 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 2015) 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 2012 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.[99]

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 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

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

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 .[100] 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).[101] 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 2015, county-level fertilizer used on-farms is adjusted based on annual fluctuations in total U.S. fertilizer sales (AAPFCO 1995 through 2007; AAPFCO 2008 through 2016). 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 years 2013 through 2015 so a "least squares line" statistical extrapolation using the previous 5 years of data is used to arrive at an approximate value for 2013 through 2015. 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-201.

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 2016). Commercial organic fertilizers include dried blood, tankage, compost, and other; dried manure and biosolids (i.e., 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 biosolids is assumed to be applied only to grasslands. The organic fertilizer data, which are recorded in mass units of fertilizer, had to

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

101 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.

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). Similar to the data for synthetic fertilizers described above, the organic 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 through 2015 so a "least squares line" statistical extrapolation using the previous 5 years of data is used to arrive at an approximate value for 2013 through 2015. 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-202. The fate of manure N is summarized in Table A-199.

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-199.

Biosolids (i.e., Sewage Sludge) Amendments: Biosolids 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 biosolids that are amended to agricultural soils are assumed to be applied to grasslands. Estimates of the amounts of biosolids N applied to agricultural lands are derived from national data on biosolids generation, disposition, and N content. Total biosolids generation data for 1990 through 2004, in dry mass units, are obtained from AAPFCO (1995 through 2004). Values for 2005 through 2015 were not available so a "least squares line" statistical extrapolation using the previous 16 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 biosolids N applied to agricultural land are used to estimate N_2O emissions from agricultural soil management; the estimates of biosolids 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). Biosolids disposal data are provided in Table A-203.

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-204. 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-205.

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).

Biosolids (i.e., Sewage Sludge) Amendments: Biosolids are generated from the treatment of raw sewage in public or private wastewater treatment facilities and are typically used as a soil amendment or is sent for waste disposal to landfills. In this Inventory, all biosolids that are amended to agricultural soils are assumed to be applied to grasslands. See section on biosolids in Step 1c for more information about the methods used to derive biosolids N estimates. The total amount of biosolids N is given in Table A-203. Biosolids 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 biosolids N available for application is divided by the assimilative capacity to estimate the total land area over which biosolids had been applied. The resulting estimates are used for the estimation of soil C stock change.

CRP Enrollment after 2012: The change in enrollment for the Conservation Reserve Program after 2012 is based on the amount of land under active contracts from 2013 through 2015 relative to 2012 (USDA-FSA 2015).

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-198: Synthetic Fertilizer N Added to Tier 3 Crops (kt N)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fertilizer N	9,681	9,571	9,831	9,896	9,678	9,435	9,750	9,742	9,620	9,343	9,697	9,532	9,546	9,570	9,565	9,689	9,465	10,263	9,850	9,755	9,912

	2011	2012	2013	2014	2015
Fertilizer N	9,935	10,101	10,101	10,101	10,101

Table A-199: Fate of Livestock Manure Nitrogen (kt N)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Managed Manure N Applied to Tier 3 Cropland and Non-federal Grasslands[a,b]	819	812	834	857	789	739	773	784	794	965	977	953	972	956	917	929
Managed Manure N Applied to Tier 1 Cropland[c]	1,311	1,350	1,341	1,288	1,402	1,484	1,446	1,467	1,429	1,302	1,330	1,335	1,358	1,382	1,327	1,359
Managed Manure N Applied to Grasslands	404	400	396	411	435	428	424	423	482	463	467	478	480	484	506	502
Pasture, Range, & Paddock Manure N	4,097	4,104	4,265	4,354	4,427	4,529	4,493	4,382	4,327	4,255	4,150	4,137	4,134	4,132	4,081	4,124
Total	**6,631**	**6,666**	**6,836**	**6,911**	**7,054**	**7,180**	**7,136**	**7,055**	**7,032**	**6,985**	**6,924**	**6,903**	**6,943**	**6,954**	**6,830**	**6,914**

[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.

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Managed Manure N Applied to Tier 3 Cropland and Non-federal Grasslands[a,b]	917	979	937	988	1,015	1,015	1,026	1,026	1,026	1,026
Managed Manure N Applied to Tier 1 Cropland[c]	1,449	1,420	1,421	1,338	1,298	1,319	1,320	1,320	1,319	1,360
Managed Manure N Applied to Grasslands	502	497	497	497	494	490	482	481	481	481
Pasture, Range, & Paddock Manure N	4,168	4,051	4,036	4,025	3,998	3,924	3,862	3,824	3,771	3,832
Total	**7,036**	**6,946**	**6,891**	**6,849**	**6,806**	**6,748**	**6,690**	**6,651**	**6,597**	**6,699**

[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-200: Crop Residue N and Other N Inputs to Tier 3 Crops as Simulated by DAYCENT (kt N)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Residue N[a]	3,880	4,105	3,722	4,051	3,741	4,183	3,934	3,967	3,891	4,604	4,222	4,199	4,204	4,303	3,954	4,218
Mineralization & Asymbiotic Fixation	11,962	11,401	11,469	12,313	11,470	12,122	11,767	11,892	13,247	11,891	12,151	12,752	12,151	12,834	13,909	12,738

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

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Residue N[a]	4,082	4,171	3,969	4,072	4,484	4,426	4,369	4,369	4,369	4,369
Mineralization & Asymbiotic Fixation	12,627	13,111	13,175	13,789	14,334	12,752	11,646	11,646	11,646	11,646

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

Table A-201: Synthetic Fertilizer N Added to Tier 1 Crops (kt N)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fertilizer N	1,291	1,308	1,232	1,137	2,007	1,496	1,865	1,699	1,807	2,042	1,734	1,271	1,438	1,716	1,872	1,489	1,755	1,584	1,453	1,212	1,433

Activity	2011	2012	2013	2014	2015	2011	2012	2013	2014	2015
Fertilizer N	1,815	2,017	1,653	1,647	1,658	1,815	2,017	1,653	1,647	1,658

Table A-202: Other Organic Commercial Fertilizer Consumption on Agricultural Lands (kt N)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Other Commercial Organic Fertilizer N[a]	4	8	6	5	8	10	13	14	12	11	9	7	8	8	9	10

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

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Other Commercial Organic Fertilizer N[a]	12	15	12	10	10	12	13	12	12	12

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

Table A-203: Biosolids (i.e., Sewage Sludge) Nitrogen by Disposal Practice (kt N)

Disposal Practice	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Applied to Agricultural Soils	52	55	58	62	65	68	72	75	78	81	84	86	89	91	94	98
Other Land Application	25	26	26	27	27	28	29	29	29	30	30	30	30	30	30	31
Surface Disposal	20	19	19	18	17	16	15	14	13	12	10	9	8	6	5	5
Total	**97**	**100**	**104**	**107**	**109**	**111**	**116**	**118**	**121**	**122**	**124**	**125**	**127**	**128**	**130**	**134**

Note: Totals may not sum due to independent rounding.

Disposal Practice	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Applied to Agricultural Soils	101	104	107	110	113	116	119	122	124	127
Other Land Application	31	32	32	32	32	33	33	33	33	33
Surface Disposal	4	4	3	3	3	2	2	2	2	1
Total	**137**	**140**	**142**	**145**	**148**	**151**	**153**	**156**	**159**	**162**

Note: Totals may not sum due to independent rounding.

Table A-204: Key Assumptions for Crop Production in the Tier 1 Method

	Dry Matter Fraction of Harvested	Above-ground Residue		Ratio of Below-ground Residue to Above-	Residue N Fraction	
Crop	Product	Slope	Intercept	ground Biomass	Above-ground	Below-ground
Alfalfa	0.9	0.29	0	0.4	0.027	0.019
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 and Lentils	0.9	0.36	0.68	0.19	0.01	0.01
Broccoli	0.09	0.1	0	0.11	0.006	0.009
Cabbage	0.08	0.1	0	0.11	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
Corn	0.87	1.03	0.61	0.22	0.006	0.007
Corn for 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
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
Greens	0.08	0.1	0	0.11	0.006	0.009
Hay Grass	0.9	0.18	0	0.54	0.015	0.012
Hay legume	0.9	0.235	0	0.47	0.021	0.0155
Lettuce Head	0.04	0.1	0	0.11	0.006	0.009
Lettuce Leaf	0.04	0.1	0	0.11	0.006	0.009
Melons Cantaloup	0.06	1.77	0	0.04	0.006	0.009
Melons Honeydew	0.06	1.77	0	0.04	0.006	0.009
Melons Watermelon	0.085	1.77	0	0.04	0.006	0.009
Millet	0.88	1.09	0.88	0.22	0.006	0.009
Oats	0.89	0.91	0.89	0.25	0.007	0.008
Onions	0.12	0.23	0	0.14	0.019	0.014
Other Vegetables	0.05	0.59	0.57	0.19	0.006	0.009
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
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
Rice	0.89	0.95	2.46	0.16	0.007	0.009
Sorghum Grain	0.89	0.88	1.33	0.22	0.007	0.006
Sorghum for 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
Squash	0.05	1.57	0	0.04	0.006	0.009
Sugar beets	0.22	0.1	1.06	0.2	0.019	0.014
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
Wheat	0.89	1.51	0.52	0.24	0.006	0.009

Table A-205: Nitrogen in Crop Residues Retained on Soils Producing Crops not Simulated by DAYCENT (kt N)

Crop Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Alfalfa	83,273	71,670	62,572	68,216	72,375	72,238	62,135	58,522	72,454	67,821	62,386
Asparagus	7	15	5	5	7	6	5	16	13	8	11
Barley	7,202	6,493	8,095	6,897	5,438	7,046	4,574	5,699	4,060	3,817	3,745
Beans and Lentils	1,988	2,087	1,905	1,941	2,086	2,157	2,217	2,169	2,383	2,083	1,795
Broccoli	6	3	3	3	3	5	5	5	1	1	36
Cabbage	76	89	73	71	48	59	77	91	70	72	28
Carrots	1,653	1,406	1,354	1,505	1,734	1,767	1,610	1,859	1,322	1,853	1,376
Cauliflower	6	1	0	1	2	3	3	3	1	4	9
Celery	164	164	160	171	172	175	169	167	152	150	208
Corn	157,085	140,273	163,074	116,107	152,485	120,853	132,009	129,618	128,842	119,312	117,803
Corn for silage	6,044	6,040	6,065	5,686	5,680	5,169	5,207	5,810	5,152	5,366	5,241
Cotton	44,527	44,892	42,250	45,751	48,029	54,878	55,629	52,605	40,598	44,643	38,834
Cucumbers	108	107	77	132	90	104	89	82	96	41	17
Flaxseed	9,109	10,390	11,706	8,780	10,272	9,141	9,346	9,263	10,024	8,286	8,895
Garlic	260	367	310	265	249	226	259	191	493	617	475
Greens	0	0	0	0	0	0	0	0	0	0	9
Hay Grass	47,058	46,868	47,621	46,389	49,742	47,119	42,954	42,977	41,591	39,399	37,948

Hay legume	49,609	46,763	45,714	47,095	47,296	45,540	39,727	39,074	39,119	35,655	32,621
Lettuce Head	26	26	36	37	34	30	22	17	11	12	11
Lettuce Leaf	25	32	26	22	22	20	17	26	26	33	21
Melons Cantaloup	498	427	436	397	422	518	472	391	346	461	333
Melons Honeydew	293	273	278	287	275	204	254	166	170	263	181
Melons Watermelon	2,100	2,026	1,976	2,082	2,126	2,009	2,093	2,050	2,195	2,492	2,768
Millet	159,271	166,193	168,344	160,264	157,997	157,691	154,741	155,367	145,258	144,807	101,557
Oats	3,804	2,827	2,522	2,831	2,690	2,431	1,911	2,352	1,933	1,183	2,022
Onions	607	708	615	739	661	735	821	650	661	926	608
Other Vegetables	3,450	3,231	3,284	3,181	2,805	2,637	3,038	2,603	2,295	2,185	2,926
Peanuts	13,828	15,423	14,802	12,379	15,090	12,005	10,851	13,080	11,464	10,669	9,060
Peas	3,066	3,333	3,466	3,705	3,233	4,523	2,825	3,859	3,498	3,244	3,168
Peppers	214	284	257	276	311	291	399	384	440	364	606
Potatoes	4,907	5,921	5,233	4,945	5,392	5,051	5,620	4,266	4,348	4,317	4,045
Pumpkins	238	254	244	265	246	290	293	267	130	95	168
Radishes	0	0	0	0	0	0	0	0	0	0	34
Rice	9,659	9,199	9,170	9,214	10,496	8,712	9,712	9,028	10,687	17,999	20,037
Sorghum Grain	5,348	4,588	5,361	3,883	3,553	2,936	3,462	2,503	2,698	2,311	2,272
Sorghum for silage	218	236	282	252	179	211	225	187	168	167	121
Soybeans	70,073	67,980	63,414	57,642	66,042	52,916	56,572	51,691	55,228	50,664	50,411
Squash	97	56	56	70	87	103	105	111	92	70	149
Sugar beets	6,277	6,482	7,213	6,166	7,228	6,084	4,504	4,486	3,420	3,934	4,749
Sugarcane	19,061	18,530	17,444	16,158	14,347	12,147	13,280	12,690	12,663	14,968	15,376
Sunflower	654	434	713	649	680	523	465	429	733	1,243	750
Sweet Potatoes	2,432	2,739	3,102	3,085	2,891	2,860	3,410	3,540	1,695	1,459	3,079
Tobacco	3,450	2,546	2,174	2,051	2,332	1,941	1,903	2,216	1,753	1,365	1,257
Tomatoes	2,567	2,623	2,840	2,856	3,010	3,016	3,004	2,127	3,039	4,321	2,982
Wheat	42,145	32,638	40,295	38,640	33,911	31,264	33,943	33,578	31,322	25,797	29,723
Total	**762,484**	**726,638**	**744,564**	**681,091**	**731,766**	**677,633**	**669,956**	**656,211**	**642,645**	**624,478**	**569,854**

Crop Type	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Alfalfa	62,642	62,504	57,362	56,258	52,225	53,611	53,721	49,848	49,151	48,496	45,641
Asparagus	14	15	8	23	18	13	20	9	6	7	12
Barley	2,152	2,931	2,119	3,561	1,634	1,928	1,814	2,353	3,387	3,464	3,183
Beans and Lentils	1,788	2,389	1,967	1,421	2,204	2,234	2,224	2,130	2,245	2,499	3,086
Broccoli	8	1	6	0	3	2	1	10	0	2	8
Cabbage	55	60	40	26	24	38	55	79	36	53	41
Carrots	2,053	3,012	2,011	1,640	654	1,330	450	1,145	919	1,207	2,530
Cauliflower	2	4	4	0	5	0	0	5	1	0	5
Celery	287	445	403	693	632	630	731	718	640	43	47
Corn	114,825	101,695	110,754	125,805	112,545	113,901	129,388	123,378	131,972	118,018	119,829
Corn for silage	4,943	4,644	4,747	4,595	4,016	3,862	4,874	4,136	3,148	3,369	3,682
Cotton	47,280	42,225	46,101	39,763	45,836	44,746	34,876	31,812	29,707	34,049	40,214
Cucumbers	5	36	52	76	30	29	17	15	0	0	23
Flaxseed	7,615	6,205	6,483	4,995	5,662	4,742	4,537	4,019	5,333	4,880	3,771
Garlic	592	296	338	367	407	497	331	351	338	66	101
Greens	14	0	0	0	0	0	0	0	0	0	0
Hay Grass	35,074	33,468	35,766	35,552	31,241	28,897	30,394	29,387	28,696	27,765	26,698
Hay legume	31,120	29,950	30,343	28,541	26,310	24,668	24,915	24,415	24,724	23,527	22,687
Lettuce Head	7	9	34	16	23	43	68	55	58	206	79
Lettuce Leaf	23	46	8	17	21	4	12	20	3	0	9
Melons Cantaloup	661	419	442	448	406	263	419	322	281	1,006	616

Melons Honeydew	87	143	113	141	73	64	50	18	0	6	37
Melons Watermelon	3,666	3,345	3,642	4,521	3,676	3,733	4,176	4,835	4,479	2,593	4,891
Millet	139,408	79,101	92,480	104,170	109,375	95,290	124,607	122,910	126,667	121,519	108,278
Oats	1,716	1,667	1,658	1,721	2,019	1,540	1,584	1,732	2,073	1,868	1,305
Onions	573	621	711	1,067	771	808	860	985	1,013	1,046	1,579
Other Vegetables	2,552	2,748	2,622	2,767	2,993	2,574	3,052	2,453	2,512	952	1,022
Peanuts	12,198	10,447	11,961	14,464	13,977	10,533	12,173	12,259	10,775	12,284	11,419
Peas	5,793	4,706	4,646	6,401	5,336	4,253	4,981	4,137	5,594	4,779	3,523
Peppers	677	665	688	660	504	569	564	673	665	641	550
Potatoes	3,857	5,357	4,765	4,557	4,874	6,515	4,524	4,918	4,982	4,279	5,589
Pumpkins	131	194	206	259	219	196	200	291	188	974	877
Radishes	89	0	0	0	0	0	0	0	0	0	0
Rice	12,505	12,280	10,362	11,660	11,741	10,078	8,815	9,487	10,804	10,807	9,220
Sorghum Grain	1,810	1,357	1,633	1,727	1,324	946	2,017	1,508	688	1,019	1,032
Sorghum for silage	76	130	193	133	195	175	205	115	220	173	76
Soybeans	49,766	49,052	43,170	52,790	51,285	50,506	44,114	47,300	52,562	51,685	44,491
Squash	156	132	119	178	159	144	147	120	120	356	165
Sugar beets	3,555	2,955	2,560	2,999	2,560	3,373	1,630	1,887	1,796	3,799	2,223
Sugarcane	15,019	15,472	15,441	17,283	16,033	18,923	16,296	13,743	13,828	11,800	12,669
Sunflower	842	344	451	374	388	718	741	793	753	411	663
Sweet Potatoes	2,346	2,420	1,954	1,417	2,140	1,237	1,630	1,091	1,829	2,608	2,377
Tobacco	923	824	914	1,172	775	1,044	851	1,105	801	817	459
Tomatoes	3,270	3,382	3,206	4,005	2,812	3,513	3,795	3,297	3,445	5,366	3,795
Wheat	23,357	20,961	27,902	26,404	24,732	20,419	22,511	29,263	25,360	26,126	24,705
Total	**595,531**	**508,657**	**530,385**	**564,667**	**541,856**	**518,590**	**548,369**	**539,128**	**551,800**	**534,564**	**513,209**

Crop Type	**2012**	**2013**	**2014**	**2015**
Alfalfa	40,879	44,003	45,225	45,089
Asparagus	6	6	6	6
Barley	3,932	4,158	4,230	4,045
Beans and Lentils	2,522	2,505	2,415	2,420
Broccoli	4	4	4	4
Cabbage	47	50	48	49
Carrots	1,375	1,429	1,522	1,442
Cauliflower	4	4	4	3
Celery	81	75	76	71
Corn	107,230	135,630	146,097	143,988
Corn for silage	2,642	3,164	3,383	4,039
Cotton	38,179	37,426	37,606	36,843
Cucumbers	92	85	79	76
Flaxseed	3,658	3,941	4,147	4,276
Garlic	92	90	90	90
Greens	0	0	0	13
Hay Grass	24,077	26,215	27,565	27,790
Hay legume	20,211	22,006	23,139	35,039
Lettuce Head	31	30	32	31
Lettuce Leaf	5	5	5	6
Melons Cantaloup	591	596	530	584
Melons Honeydew	71	73	76	76
Melons Watermelon	4,332	4,415	4,068	4,207
Millet	74,845	111,564	118,168	124,772
Oats	1,286	1,330	1,387	1,421

Onions	1,513	1,510	1,625	1,575
Other Vegetables	833	794	825	839
Peanuts	16,557	15,914	15,675	15,437
Peas	4,009	4,315	4,230	3,875
Peppers	864	807	827	942
Potatoes	6,080	6,141	6,213	6,182
Pumpkins	898	842	1,004	694
Radishes	0	0	0	0
Rice	8,640	8,847	8,738	8,646
Sorghum Grain	824	938	1,028	1,124
Sorghum for silage	147	177	162	180
Soybeans	44,875	47,855	50,462	50,834
Squash	302	264	256	266
Sugar beets	2,658	2,596	2,528	2,768
Sugarcane	13,471	12,754	13,207	13,735
Sunflower	761	723	754	810
Sweet Potatoes	2,743	2,827	2,827	2,693
Tobacco	1,065	955	1,087	1,023
Tomatoes	4,305	4,138	4,315	4,289
Wheat	24,343	24,772	23,152	23,104
Total	**461,080**	**535,968**	**558,814**	**575,397**

Step 1e: Additional Activity Data for Indirect N_2O Emissions

A portion of the N that is applied as synthetic fertilizer, livestock manure, biosolids (i.e., 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, biosolids 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-198 through Table A-203, and Table A-205.

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, biosolids applications, and PRP manure on federal grasslands, which is simulated by DAYCENT. To estimate volatilized losses, synthetic fertilizers, manure, biosolids, 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, biosolids, and above- and belowground 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 2012 (USDA-NRCS 2015).

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 2012.[102] 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 92 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 41 experimental sites available with over200 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 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

[102] The estimated soil C stock change in 2012 is currently assumed to represent the changes between 2013 and 2015. More recent data will be incorporated in the future to extend the time series of land use and management data.

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-206, soil N_2O emissions are provided in Table A-207, and rice cultivation CH_4 emissions in Table A-208.

Table A-206: 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	(65.75)	(98.30) to (33.20)	20.62	11.32 to 29.93	(10.20)	(47.18) to 26.77	(5.11)	(9.71) to (.51)
1991	(71.64)	(103.66) to (39.63)	21.41	11.46 to 31.37	(12.53)	(50.86) to 25.80	(5.19)	(9.27) to (1.12)
1992	(63.04)	(91.32) to (34.76)	23.61	13.62 to 33.60	(6.81)	(37.06) to 23.44	(4.92)	(10.03) to .18
1993	(43.64)	(73.09) to (14.20)	17.95	7.22 to 28.69	1.66	(33.17) to 36.50	(5.53)	(10.31) to (.74)
1994	(55.49)	(86.59) to (24.40)	14.40	3.88 to 24.92	(24.13)	(58.06) to 9.80	(7.36)	(12.99) to (1.73)
1995	(49.18)	(80.21) to (18.15)	20.04	8.90 to 31.17	(0.96)	(33.43) to 31.50	(6.37)	(12.27) to (.48)
1996	(57.70)	(87.89) to (27.50)	16.93	7.08 to 26.79	(22.31)	(53.52) to 8.90	(7.59)	(14.10) to (1.08)
1997	(55.46)	(89.14) to (21.79)	18.98	8.58 to 29.37	(9.10)	(47.05) to 28.84	(7.46)	(13.49) to (1.43)
1998	(44.19)	(76.62) to (11.76)	12.57	1.18 to 23.95	(16.03)	(53.16) to 21.10	(8.12)	(15.15) to (1.10)
1999	(59.68)	(88.69) to (30.67)	12.78	2.58 to 22.98	(3.96)	(36.93) to 29.02	(8.55)	(15.40) to (1.69)
2000	(65.43)	(100.61) to (30.26)	12.95	1.93 to 23.98	(33.13)	(72.27) to 6.01	(10.51)	(17.58) to (3.44)
2001	(58.29)	(91.06) to (25.51)	11.21	.34 to 22.09	(8.82)	(40.46) to 22.82	(9.81)	(17.37) to (2.26)
2002	(54.71)	(83.13) to (26.29)	11.21	.07 to 22.34	(9.63)	(45.47) to 26.20	(10.51)	(17.31) to (3.70)
2003	(47.63)	(78.33) to (16.94)	13.08	2.53 to 23.63	(6.34)	(39.14) to 26.46	(10.52)	(17.46) to (3.59)
2004	(47.56)	(79.85) to (15.27)	12.63	3.60 to 21.66	0.42	(34.25) to 35.09	(9.91)	(17.96) to (1.86)
2005	(50.81)	(84.26) to (17.36)	12.40	1.10 to 23.71	1.97	(34.50) to 38.43	(10.22)	(17.93) to (2.52)
2006	(47.47)	(76.01) to (18.92)	13.21	3.03 to 23.39	(14.85)	(48.99) to 19.29	(12.24)	(20.62) to (3.86)
2007	(45.56)	(76.20) to (14.92)	11.83	1.45 to 22.21	1.80	(31.07) to 34.67	(10.92)	(19.03) to (2.81)
2008	(34.45)	(67.84) to (1.06)	12.68	2.46 to 22.89	(10.05)	(43.50) to 23.39	(10.84)	(18.52) to (3.17)
2009	(29.33)	(58.63) to (.04)	12.56	3.13 to 21.99	(5.66)	(43.85) to 32.53	(10.64)	(17.89) to (3.38)
2010	(29.43)	(62.67) to 3.80	14.53	5.38 to 23.68	1.34	(30.62) to 33.30	(10.76)	(19.24) to (2.29)
2011	(43.60)	(76.77) to (10.44)	14.27	4.15 to 24.40	(15.97)	(54.46) to 22.52	(10.97)	(18.96) to (2.98)
2012	(46.60)	(83.06) to (10.14)	13.38	2.10 to 24.66	(24.56)	(60.90) to 11.78	(11.21)	(19.48) to (2.94)
2013	(46.60)	(83.06) to (10.14)	13.38	2.10 to 24.66	(24.48)	(60.81) to 11.85	(11.21)	(19.48) to (2.94)
2014	(46.60)	(83.06) to (10.14)	13.38	2.10 to 24.66	(24.37)	(60.69) to 11.95	(11.21)	(19.48) to (2.94)
2015	(46.60)	(83.06) to (10.14)	13.38	2.10 to 24.66	(24.25)	(60.56) to 12.06	(11.21)	(19.48) to (2.94)

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-207: 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	128.5	121.74 to 137.33	51.2	48.03 to 55.26
1991	128.4	121.69 to 137.19	52.4	49.16 to 56.50
1992	128.5	121.81 to 137.26	51.4	48.61 to 55.10
1993	128.5	121.73 to 137.53	53.0	50.04 to 56.74
1994	127.8	121.29 to 136.23	49.4	46.52 to 53.03
1995	129.1	122.46 to 137.81	50.8	47.92 to 54.42

1996	129.6	122.94 to 138.48	53.9	50.62 to 58.21
1997	129.2	122.48 to 138.03	54.0	50.91 to 57.96
1998	136.2	128.94 to 145.71	58.6	55.19 to 62.99
1999	129.6	122.95 to 138.19	49.2	46.60 to 52.59
2000	132.2	125.41 to 141.24	49.7	46.63 to 53.68
2001	134.0	127.0 to 143.26	51.8	48.89 to 55.69
2002	132.5	125.60 to 141.66	53.8	50.52 to 58.06
2003	135.4	128.41 to 144.74	52.3	49.40 to 56.13
2004	142.0	134.79 to 151.32	62.7	58.77 to 67.99
2005	134.7	127.87 to 143.71	53.4	50.55 to 56.97
2006	135.7	128.82 to 144.66	55.9	52.77 to 60.04
2007	140.8	133.4 to 150.41	57.7	54.19 to 62.42
2008	137.3	130.17 to 146.68	54.7	51.81 to 58.49
2009	139.6	132.41 to 148.95	58.2	54.74 to 62.67
2010	144.2	136.70 to 154.10	57.4	54.31 to 61.52
2011	138.0	130.98 to 147.26	50.9	48.40 to 54.24
2012	135.7	128.72 to 144.87	47.7	44.84 to 51.4
2013	134.6	127.68 to 143.76	47.6	44.77 to 51.33
2014	134.6	127.68 to 143.76	47.6	44.73 to 51.28
2015	134.6	127.67 to 143.75	47.5	44.68 to 51.23

Table A-208: 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	14.39	10.22 to 18.57
1991	15.18	10.86 to 19.49
1992	15.17	10.58 to 19.76
1993	15.24	11.05 to 19.44
1994	13.10	9.20 to 16.99
1995	14.23	10.22 to 18.23
1996	14.40	10.32 to 18.48
1997	14.22	10.16 to 18.27
1998	14.35	9.96 to 18.73
1999	14.82	10.13 to 19.52
2000	14.98	10.45 to 19.51
2001	13.62	9.32 to 17.93
2002	14.62	10.23 to 19.01
2003	12.58	8.76 to 16.41
2004	12.26	8.40 to 16.12
2005	14.93	10.35 to 19.52
2006	11.38	7.96 to 14.80
2007	12.54	8.82 to 16.27
2008	9.92	6.85 to 12.99
2009	12.76	8.80 to 16.71
2010	14.09	9.85 to 18.33
2011	12.59	8.92 to 16.26
2012	9.96	6.70 to 13.22
2013	9.95	6.75 to 13.14
2014	9.90	6.76 to 13.04
2015	9.92	6.78 to 13.06

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.[103] For example, if 70 percent of the mineral N made available in the soil

[103] 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

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-209 and Table A-210.

Table A-209: Direct N_2O Emissions from Cropland Soils (MMT CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Mineral Soils	**144.1**	**144.2**	**143.9**	**143.0**	**147.1**	**146.2**	**148.2**	**147.0**	**154.3**	**148.1**	**149.2**	**148.9**	**148.0**	**152.4**	**159.5**	**150.6**
Tier 3	**128.5**	**128.4**	**128.5**	**128.5**	**127.8**	**129.1**	**129.6**	**129.2**	**136.2**	**129.6**	**132.2**	**134.0**	**132.5**	**135.4**	**142.0**	**134.7**
Synthetic Fertilizer	47.5	47.8	49.3	47.1	48.6	46.2	48.7	48.0	47.9	45.4	47.8	46.8	47.5	47.3	48.3	47.6
Managed Manure	3.9	3.8	4.0	4.0	3.8	3.5	3.7	3.7	3.9	4.6	4.7	4.6	4.7	4.6	4.5	4.4
Residue N[a]	18.6	20.1	18.3	18.9	18.4	20.2	19.2	19.2	18.9	22.1	20.5	20.2	20.5	20.9	19.6	20.5
Mineralization and Asymbiotic Fixation	58.4	56.7	56.9	58.5	56.9	59.2	58.1	58.3	65.5	57.5	59.2	62.4	59.8	62.6	69.6	62.2
Tier 1	**15.7**	**15.8**	**15.5**	**14.5**	**19.3**	**17.1**	**18.6**	**17.9**	**18.1**	**18.5**	**17.0**	**14.9**	**15.4**	**17.0**	**17.6**	**15.8**
Synthetic Fertilizer	6.0	6.1	5.8	5.3	9.4	7.0	8.7	8.0	8.5	9.6	8.1	6.0	6.7	8.0	8.8	7.0
Managed Manure and Other Organic Commercial Fertilizer	6.2	6.4	6.3	6.1	6.6	7.0	6.8	6.9	6.7	6.1	6.3	6.3	6.4	6.5	6.3	6.4
Residue N[a]	3.5	3.3	3.4	3.1	3.3	3.1	3.0	3.0	2.9	2.8	2.6	2.7	2.3	2.4	2.6	2.5
Organic Soils	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.4**	**3.4**	**3.3**	**3.3**	**3.3**
Total[a]	**147.5**	**147.5**	**147.2**	**146.3**	**150.3**	**149.5**	**151.5**	**150.3**	**157.5**	**151.4**	**152.5**	**152.3**	**151.3**	**155.7**	**162.9**	**153.9**

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

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Mineral Soils	**153.1**	**157.4**	**153.3**	**154.1**	**159.5**	**155.1**	**153.5**	**151.0**	**151.1**	**151.4**
Tier 3	**135.7**	**140.8**	**137.3**	**139.6**	**144.2**	**138.0**	**135.7**	**134.6**	**134.6**	**134.6**
Synthetic Fertilizer	47.9	50.8	48.9	48.0	48.3	49.5	51.0	50.5	50.5	50.5
Managed Manure	4.5	4.7	4.5	4.8	4.9	4.9	5.0	5.0	5.0	5.0
Residue N[a]	20.3	20.4	19.3	19.6	21.5	21.5	21.4	21.3	21.3	21.2
Mineralization and Asymbiotic Fixation	63.0	64.9	64.7	67.2	69.6	62.1	58.2	57.8	57.8	57.8
Tier 1	**17.4**	**16.6**	**16.0**	**14.5**	**15.3**	**17.1**	**17.8**	**16.4**	**16.5**	**16.8**
Synthetic Fertilizer	8.2	7.4	6.8	5.7	6.7	8.5	9.4	7.7	7.7	7.8
Managed Manure and Other Organic Commercial Fertilizer	6.8	6.7	6.7	6.3	6.1	6.2	6.2	6.2	6.2	6.4
Residue N[a]	2.4	2.5	2.4	2.5	2.4	2.3	2.1	2.4	2.5	2.6
Organic Soils	**3.3**	**3.3**	**3.3**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**
Total[a]	**156.4**	**160.7**	**156.5**	**157.3**	**162.7**	**158.3**	**156.7**	**154.2**	**154.3**	**154.6**

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

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-210: Direct N_2O Emissions from Grasslands (MMT CO_2 Eq.)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Mineral Soils	**61.3**	**62.3**	**61.6**	**63.2**	**59.6**	**61.0**	**63.9**	**63.4**	**67.6**	**58.0**	**58.2**	**60.0**	**61.8**	**60.1**	**70.4**	**61.1**
Tier 3	**51.2**	**52.4**	**51.4**	**53.0**	**49.4**	**50.8**	**53.9**	**54.0**	**58.6**	**49.2**	**49.7**	**51.8**	**53.8**	**52.3**	**62.7**	**53.4**
Synthetic Fertilizer	0.9	0.9	0.9	0.8	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.8	0.8
PRP Manure	6.3	6.2	6.3	6.5	6.6	6.6	7.2	6.7	7.5	6.2	6.5	6.6	7.0	6.6	7.5	6.5
Managed Manure	0.9	0.8	0.8	0.9	0.9	0.9	0.9	0.9	1.1	0.9	1.0	1.0	1.1	1.0	1.2	1.1
Residue N[a]	14.5	14.6	14.7	15.3	13.4	15.0	14.6	15.2	15.1	15.3	13.9	15.0	14.9	14.9	15.8	15.8
Mineralization and Asymbiotic Fixation	28.5	29.9	28.6	29.5	27.5	27.5	30.3	30.4	33.9	26.0	27.5	28.5	30.0	29.0	37.5	29.2
Tier 1	**10.1**	**9.9**	**10.2**	**10.3**	**10.3**	**10.2**	**10.0**	**9.4**	**9.1**	**8.7**	**8.5**	**8.2**	**8.0**	**7.8**	**7.7**	**7.8**
PRP Manure	9.9	9.7	9.9	10.0	10.0	9.9	9.6	9.1	8.7	8.4	8.1	7.8	7.6	7.3	7.2	7.3
Biosolids (i.e.,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
Organic Soils	**3.3**	**3.2**	**3.2**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.4**	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**
Total	**64.5**	**65.6**	**64.8**	**66.5**	**63.0**	**64.3**	**67.2**	**66.7**	**71.0**	**61.3**	**61.5**	**63.5**	**65.3**	**63.6**	**73.9**	**64.6**

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

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Mineral Soils	**63.7**	**65.1**	**62.2**	**65.8**	**65.1**	**58.8**	**55.7**	**55.3**	**54.9**	**55.4**
Tier 3	**55.9**	**57.7**	**54.7**	**58.2**	**57.4**	**50.9**	**47.7**	**47.6**	**47.6**	**47.5**
Synthetic Fertilizer	0.8	0.8	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.7
PRP Manure	7.1	6.9	6.6	7.0	6.6	6.3	5.9	5.8	5.8	5.8
Managed Manure	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Residue N[a]	15.6	16.5	15.5	15.4	16.5	14.8	14.2	14.2	14.2	14.2
Mineralization and Asymbiotic Fixation	31.3	32.6	30.9	33.8	32.4	28.1	25.8	25.8	25.8	25.7
Tier 1	**7.8**	**7.4**	**7.5**	**7.6**	**7.7**	**7.8**	**8.0**	**7.7**	**7.3**	**7.9**
PRP Manure	7.3	6.9	7.0	7.1	7.1	7.3	7.4	7.1	6.7	7.3
Biosolids (i.e., Sewage Sludge)	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Organic Soils	**3.5**	**3.4**	**3.4**	**3.4**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
Total	**67.2**	**68.5**	**65.6**	**69.1**	**68.5**	**62.1**	**59.0**	**58.6**	**58.1**	**58.7**

[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-209). 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).[104] 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 biosolids (i.e., 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-210). 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.

104 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 biosolids (i.e., sewage sludge) amendments to soils are currently treated as certain; these sources of uncertainty will be included in future Inventories.

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 1990-2012, 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.

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-211). Seven of these climate zones occur in the conterminous United States and Hawaii (Eve et al. 2001).

Table A-211: 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-212). 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

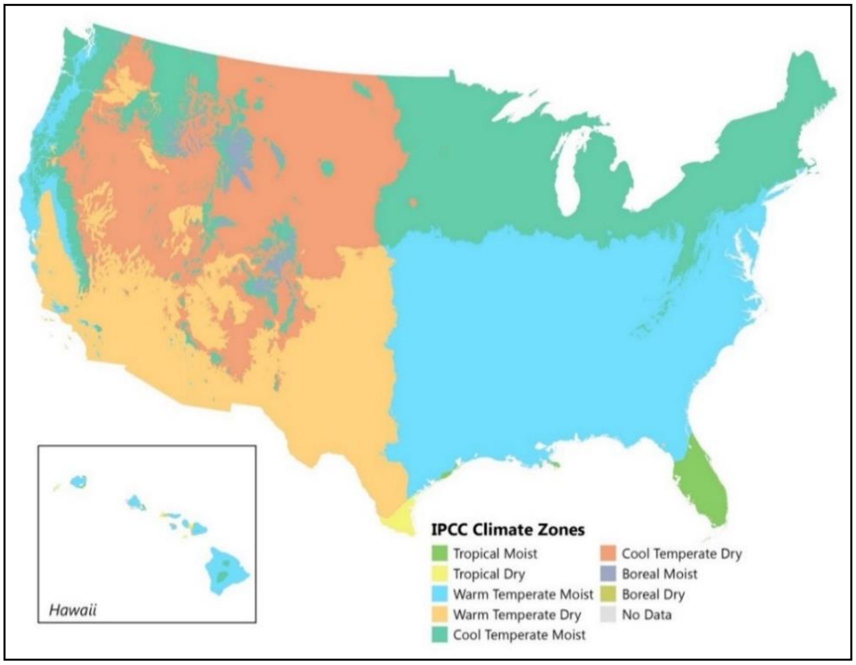

Table A-212: U.S. Soil Groupings Based on the IPCC Categories and Dominant Taxonomic Soil, and Reference Carbon Stocks (Metric Tons C/ha)

		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-213). 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.[105] 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.

Table A-213: 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-214). 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-214).

Table A-214: 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.[106]

[105] Improved grasslands are identified in the 2012 *National Resources Inventory* as grasslands that are irrigated or seeded with legumes, in addition to those reclassified as improved with manure amendments.
[106] The difference in C stocks is divided by 20 because the stock change factors represent change over a 20-year time period.

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-215 through Table A-220.

Step 2e: Estimate Additional Changes in Soil Organic C Stocks Due to CRP Enrollment after 2012 and Biosolids (i.e., 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 biosolids to agricultural lands. Minimal data exist on where and how much biosolids are applied to U.S. agricultural soils, but national estimates of mineral soil land area receiving biosolids can be approximated based on biosolids N production data, and the assumption that amendments are applied at a rate equivalent to the assimilative capacity from Kellogg et al. (2000). In this Inventory, it is assumed that biosolids for agricultural land application is only applied to grassland. 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-213), 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,[107] 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., $[50 \times 1.4 \times 1.11 - 50 \times 1.4] / 20 = 0.38$). 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 biosolids amendments. The influence of biosolids on soil organic C stocks are provided in

Table A-221.

The second activity is the change in enrollment for the Conservation Reserve Program after 2012 for mineral soils. Relative to the enrollment in 2012, the total area in the Conservation Reserve Program has decreased from 2013 to 2015 (USDA-FSA 2015). 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-213) 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., $[50 \times 1.2 - 50] / 20 = 0.5$). 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-230.

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

Table A-215: 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	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990	-5.44	(7.97) to (2.99)	1.32	(0.72) to 2.26	0.22	(0.12) to .38	0.16	(0.09) to 0.28
1991	-6.19	(8.94) to (3.53)	1.26	(0.84) to 2.25	0.20	(0.13) to .36	0.15	(0.10) to 0.27
1992	-6.19	(9.77) to (3.63)	1.29	(1.07) to 2.32	0.19	(0.16) to .35	0.16	(0.13) to 0.29
1993	-6.95	(10.16) to (3.79)	1.35	(0.75) to 2.45	0.18	(0.10) to .32	0.17	(0.09) to 0.31
1994	-6.70	(9.93) to (3.52)	1.48	(0.37) to 2.63	0.18	(0.05) to .33	0.19	(0.05) to 0.35
1995	-6.46	(9.52) to (3.48)	1.59	(0.35) to 2.76	0.19	(0.04) to .32	0.21	(0.05) to 0.36
1996	-6.10	(9.09) to (3.14)	1.65	(0.35) to 2.86	0.19	(0.04) to .33	0.22	(0.05) to 0.37
1997	-7.63	(11.37) to (3.99)	1.41	(0.47) to 2.63	0.15	(0.05) to .29	0.19	(0.06) to 0.35
1998	-7.33	(11.0) to (3.79)	1.63	(0.38) to 3.01	0.15	(0.04) to .28	0.20	(0.05) to 0.36
1999	-7.06	(10.56) to (3.71)	1.49	(0.33) to 2.79	0.13	(0.03) to .24	0.19	(0.04) to 0.35
2000	-6.75	(10.09) to (3.56)	1.48	(0.39) to 2.78	0.12	(0.03) to .22	0.22	(0.06) to 0.42
2001	-6.71	(9.94) to (3.62)	1.54	(0.36) to 2.85	0.10	(0.02) to .18	0.23	(0.05) to 0.42
2002	-6.72	(9.79) to (3.79)	1.45	(0.30) to 2.66	0.09	(0.02) to .16	0.20	(0.04) to 0.36
2003	-6.05	(8.97) to (3.30)	1.42	(0.24) to 2.59	0.08	(0.01) to .15	0.19	(0.03) to 0.34
2004	-5.42	(8.24) to (2.74)	1.60	(0.18) to 2.79	0.08	(0.01) to .15	0.21	(0.02) to 0.37
2005	-5.39	(7.97) to (2.97)	1.53	(0.18) to 2.70	0.08	(0.01) to .13	0.19	(0.02) to 0.34
2006	-4.36	(6.67) to (2.21)	1.77	(0.19) to 2.89	0.09	(0.01) to .14	0.23	(0.02) to 0.37
2007	-3.96	(6.14) to (1.97)	1.83	(0.13) to 2.92	0.08	(0.01) to .13	0.23	(0.02) to 0.36
2008	-3.37	(5.37) to (1.53)	1.86	(0.06) to 2.98	0.06	0 to 0.10	0.24	(0.01) to 0.38
2009	-3.52	(5.32) to (1.88)	1.70	(0.02) to 2.72	0.06	0 to 0.09	0.22	0 to 0.36
2010	-3.58	(5.45) to (1.91)	1.68	0.02 to 2.68	0.06	0 to 0.09	0.22	0 to 0.35
2011	-3.49	(5.17) to (1.99)	1.70	0.01 to 2.68	0.06	0 to 0.09	0.22	0 to 0.35
2012	-2.88	(4.40) to (1.55)	1.69	(0.01) to 2.64	0.06	0 to 0.10	0.22	0 to 0.34
2013	-2.69	(4.17) to (1.39)	1.70	0 to 2.64	0.06	0 to 0.10	0.22	0 to 0.34
2014	-2.74	(4.24) to (1.42)	1.70	0 to 2.65	0.06	0 to 0.10	0.22	0 to 0.34
2015	-2.70	(4.20) to (1.40)	1.70	0.01 to 2.65	0.06	0 to 0.10	0.22	0 to 0.34

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Non-Federal Croplands:	Settlements Converted to Cropland		Wetlands Converted to Cropland	
Year	Estimate	95% CI	Estimate	95% CI
Mineral Soils				
1990	0.06	(0.04) to 0.11	0.11	(0.06) to 0.19
1991	0.06	(0.04) to 0.11	0.10	(0.07) to 0.18
1992	0.06	(0.05) to 0.11	0.10	(0.08) to 0.18
1993	0.06	(0.04) to 0.12	0.12	(0.07) to 0.22
1994	0.07	(0.02) to 0.12	0.15	(0.04) to 0.26
1995	0.07	(0.02) to 0.13	0.15	(0.03) to 0.27
1996	0.07	(0.02) to 0.13	0.16	(0.03) to 0.28
1997	0.06	(0.02) to 0.12	0.14	(0.05) to 0.25
1998	0.08	(0.02) to 0.14	0.15	(0.03) to 0.27
1999	0.07	(0.02) to 0.13	0.14	(0.03) to 0.25
2000	0.07	(0.02) to 0.14	0.14	(0.04) to 0.26
2001	0.08	(0.02) to 0.14	0.14	(0.03) to 0.26
2002	0.07	(0.02) to 0.14	0.13	(0.03) to 0.25
2003	0.07	(0.01) to 0.12	0.13	(0.02) to 0.23
2004	0.07	(0.01) to 0.12	0.14	(0.02) to 0.25
2005	0.07	(0.01) to 0.12	0.13	(0.02) to 0.23
2006	0.08	(0.01) to 0.13	0.15	(0.02) to 0.25

2007	0.09	(0.01) to 0.14	0.14	(0.01) to 0.23
2008	0.08	0 to 0.13	0.14	0 to 0.22
2009	0.07	0 to 0.12	0.11	0 to 0.18
2010	0.08	0 to 0.12	0.11	0 to 0.18
2011	0.09	0 to 0.14	0.12	0 to 0.19
2012	0.09	0 to 0.15	0.12	0 to 0.19
2013	0.09	0 to 0.15	0.12	0 to 0.19
2014	0.09	0 to 0.15	0.12	0 to 0.19
2015	0.09	0 to 0.15	0.12	0 to 0.19

Table A-216: 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	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990	0.00	(0.01) to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1991	0.00	(0.01) to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1992	0.00	(0.02) to 0.02	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1993	0.00	(0.02) to 0.02	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1994	0.00	(0.03) to 0.02	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1995	0.00	(0.03) to 0.03	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1996	0.00	(0.03) to 0.02	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1997	-0.01	(0.05) to 0.02	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1998	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1999	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2000	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2001	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2002	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2003	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2004	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2005	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2006	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2007	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2008	0.00	(0.01) to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2009	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2010	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2011	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2012	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2013	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2014	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0
2015	0.00	0.0 to 0.0	0.00	0.0 to 0.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Federal Croplands:	Settlements Converted to Cropland		Wetlands Converted to Cropland	
Year	Estimate	95% CI	Estimate	95% CI
Mineral Soils				
1990	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1991	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1992	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1993	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1994	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1995	0.00	0.0 to 0.0	0.00	0.0 to 0.0

1996	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1997	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1998	0.00	0.0 to 0.0	0.00	0.0 to 0.01
1999	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2000	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2001	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2002	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2003	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2004	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2005	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2006	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2007	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2008	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2009	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2010	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2011	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2012	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2013	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2014	0.00	0.0 to 0.0	0.00	0.0 to 0.01
2015	0.00	0.0 to 0.0	0.00	0.0 to 0.01

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-217: 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	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990	-5.44	(7.97) to (3.0)	1.32	(.72) to 2.26	0.22	(.12) to .38	0.16	(.09) to .28
1991	-6.19	(8.94) to (3.53)	1.26	(.84) to 2.25	0.20	(.13) to .36	0.15	(.10) to .27
1992	-6.19	(9.77) to (3.63)	1.29	(1.07) to 2.32	0.19	(.16) to .35	0.16	(.13) to .29
1993	-6.95	(10.17) to (3.79)	1.35	(.75) to 2.45	0.18	(.10) to .32	0.17	(.09) to .31
1994	-6.71	(9.94) to (3.52)	1.48	(.37) to 2.63	0.18	(.05) to .33	0.19	(.05) to .35
1995	-6.46	(9.52) to (3.48)	1.59	(.35) to 2.76	0.19	(.04) to .32	0.21	(.05) to .36
1996	-6.10	(9.10) to (3.15)	1.65	(.35) to 2.86	0.19	(.04) to .33	0.22	(.05) to .37
1997	-7.64	(11.38) to (4.0)	1.41	(.47) to 2.63	0.15	(.05) to .29	0.19	(.06) to .35
1998	-7.33	(11.0) to (3.79)	1.63	(.37) to 3.01	0.15	(.04) to .28	0.20	(.05) to .36
1999	-7.07	(10.57) to (3.71)	1.49	(.33) to 2.79	0.13	(.03) to .24	0.19	(.04) to .35
2000	-6.75	(10.09) to (3.56)	1.48	(.39) to 2.78	0.12	(.03) to .22	0.22	(.06) to .42
2001	-6.71	(9.94) to (3.62)	1.54	(.35) to 2.85	0.10	(.02) to .18	0.23	(.05) to .42
2002	-6.72	(9.79) to (3.80)	1.45	(.30) to 2.66	0.09	(.02) to .16	0.20	(.04) to .36
2003	-6.05	(8.97) to (3.30)	1.42	(.24) to 2.59	0.08	(.01) to .15	0.19	(.03) to .34
2004	-5.43	(8.24) to (2.75)	1.60	(.17) to 2.79	0.08	(.01) to .15	0.21	(.02) to .37
2005	-5.40	(7.97) to (2.98)	1.53	(.18) to 2.70	0.08	(.01) to .13	0.19	(.02) to .34
2006	-4.36	(6.67) to (2.22)	1.77	(.19) to 2.89	0.09	(.01) to .14	0.23	(.02) to .37
2007	-3.96	(6.14) to (1.98)	1.83	(.13) to 2.92	0.08	(.01) to .13	0.23	(.02) to .36
2008	-3.37	(5.38) to (1.53)	1.86	(.06) to 2.98	0.06	.0 to .10	0.24	(.01) to .38
2009	-3.52	(5.33) to (1.88)	1.70	(.02) to 2.72	0.06	.0 to .09	0.22	.0 to .36
2010	-3.58	(5.45) to (1.91)	1.68	.02 to 2.68	0.06	.0 to .09	0.22	.0 to .35
2011	-3.49	(5.17) to (1.99)	1.70	.01 to 2.68	0.06	.0 to .09	0.22	.0 to .35
2012	-2.88	(4.41) to (1.55)	1.70	(.01) to 2.64	0.06	.0 to .10	0.22	.0 to .34
2013	-2.69	(4.17) to (1.39)	1.70	.0 to 2.65	0.06	.0 to .10	0.22	.0 to .34
2014	-2.74	(4.24) to (1.42)	1.71	.0 to 2.65	0.06	.0 to .10	0.22	.0 to .34
2015	-2.71	(4.20) to (1.40)	1.71	.01 to 2.65	0.06	.0 to .10	0.22	.0 to .34
Organic Soils								
1990	30.25	20.02 to 43.38	2.52	1.46 to 3.95	0.11	.06 to .18	0.10	.0 to .22
1991	29.75	19.76 to 42.59	2.55	1.53 to 3.87	0.11	.06 to .18	0.10	.0 to .24
1992	29.71	19.60 to 42.96	2.58	1.50 to 4.0	0.10	.05 to .17	0.04	.0 to .14
1993	29.54	19.53 to 42.63	2.71	1.60 to 4.16	0.10	.06 to .17	0.10	.0 to .24
1994	29.37	19.32 to 42.42	2.71	1.62 to 4.14	0.10	.05 to .17	0.10	.0 to .23
1995	29.34	19.27 to 42.49	2.93	1.71 to 4.50	0.09	.05 to .16	0.10	.0 to .24
1996	29.27	19.18 to 42.44	3.02	1.76 to 4.66	0.10	.05 to .17	0.10	.0 to .24
1997	29.26	19.19 to 42.51	3.00	1.79 to 4.61	0.10	.05 to .17	0.10	.0 to .24
1998	28.83	18.80 to 42.07	3.51	1.82 to 5.76	0.09	.04 to .17	0.06	.0 to .20

1999	24.45	15.81 to 35.47	3.53	1.82 to 5.80	0.09	.04 to .16	0.06	.0 to .20
2000	24.53	15.85 to 35.55	3.25	1.76 to 5.24	0.09	.04 to .16	0.06	.0 to .20
2001	28.99	18.76 to 42.52	4.18	1.92 to 7.59	0.08	.04 to .15	0.06	.0 to .20
2002	29.32	19.09 to 42.88	4.18	1.91 to 7.52	0.06	.02 to .12	0.06	.0 to .20
2003	29.65	19.33 to 43.45	3.99	1.78 to 7.27	0.08	.03 to .15	0.06	.0 to .20
2004	29.95	19.52 to 43.88	3.39	1.51 to 6.05	0.05	.01 to .10	0.06	.0 to .20
2005	29.66	19.26 to 43.32	3.33	1.47 to 5.93	0.04	.01 to .10	0.06	.0 to .20
2006	29.59	19.24 to 43.36	3.26	1.49 to 5.77	0.04	.01 to .09	0.06	.0 to .20
2007	29.46	19.33 to 42.90	3.23	1.39 to 5.83	0.02	.01 to .05	0.06	.0 to .20
2008	29.35	19.18 to 42.70	3.00	1.25 to 5.54	0.03	.01 to .07	0.06	.0 to .20
2009	29.70	19.31 to 43.44	2.94	1.20 to 5.41	0.03	.01 to .07	0.06	.0 to .20
2010	29.65	19.31 to 43.32	2.87	1.23 to 5.30	0.03	.01 to .07	0.00	.0 to .0
2011	27.95	18.31 to 40.44	2.98	1.09 to 5.61	0.02	.0 to .05	0.00	.0 to .0
2012	28.10	18.47 to 40.58	3.03	1.18 to 5.65	0.02	.0 to .03	0.00	.0 to .0
2013	28.07	18.47 to 40.43	3.03	1.27 to 5.54	0.02	.0 to .03	0.00	.0 to .0
2014	28.09	18.50 to 40.61	3.03	1.27 to 5.59	0.02	.0 to .03	0.00	.0 to .0
2015	28.05	18.44 to 40.35	3.02	1.26 to 5.55	0.02	.0 to .03	0.00	.0 to .0

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Total Croplands:	Settlements Converted to Cropland		Wetlands Converted to Cropland	
Year	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Mineral Soils				
1990	0.06	(0.04) to 0.11	0.11	(0.06) to 0.19
1991	0.06	(0.04) to 0.11	0.10	(0.07) to 0.18
1992	0.06	(0.05) to 0.11	0.10	(0.08) to 0.18
1993	0.06	(0.04) to 0.12	0.12	(0.07) to 0.22
1994	0.07	(0.02) to 0.12	0.15	(0.04) to 0.26
1995	0.07	(0.02) to 0.13	0.15	(0.03) to 0.27
1996	0.07	(0.02) to 0.13	0.16	(0.03) to 0.28
1997	0.06	(0.02) to 0.12	0.14	(0.05) to 0.25
1998	0.08	(0.02) to 0.14	0.15	(0.03) to 0.28
1999	0.07	(0.02) to 0.13	0.14	(0.03) to 0.26
2000	0.07	(0.02) to 0.14	0.14	(0.04) to 0.26
2001	0.08	(0.02) to 0.14	0.14	(0.03) to 0.26
2002	0.07	(0.02) to 0.14	0.14	(0.03) to 0.25
2003	0.07	(0.01) to 0.12	0.13	(0.02) to 0.24
2004	0.07	(0.01) to 0.12	0.14	(0.01) to 0.25
2005	0.07	(0.01) to 0.12	0.13	(0.01) to 0.23
2006	0.08	(0.01) to 0.13	0.15	(0.01) to 0.25
2007	0.09	(0.01) to 0.14	0.15	(0.01) to 0.23
2008	0.08	0.0 to 0.13	0.14	0.0 to 0.22
2009	0.07	0.0 to 0.12	0.12	0.0 to 0.18
2010	0.08	0.0 to 0.12	0.11	0.0 to 0.18
2011	0.09	0.0 to 0.14	0.12	0.0 to 0.19
2012	0.09	0.0 to 0.15	0.12	0.0 to 0.19
2013	0.09	0.0 to 0.15	0.12	0.0 to 0.19
2014	0.09	0.0 to 0.15	0.12	0.0 to 0.19
2015	0.09	0.0 to 0.15	0.12	0.0 to 0.19
Organic Soils				
1990	0.03	.0 to .06	0.62	.30 to 1.07
1991	0.03	.0 to .07	0.63	.29 to 1.10
1992	0.03	.0 to .06	0.63	.34 to 1.03
1993	0.03	.0 to .06	0.81	.48 to 1.23
1994	0.05	.02 to .09	0.96	.56 to 1.48
1995	0.04	.01 to .07	0.99	.61 to 1.49
1996	0.05	.02 to .09	1.01	.59 to 1.55
1997	0.04	.01 to .07	1.00	.58 to 1.55
1998	0.04	.01 to .08	0.95	.55 to 1.49
1999	0.04	.01 to .08	0.95	.54 to 1.50
2000	0.04	.01 to .08	0.86	.48 to 1.36
2001	0.04	.01 to .08	0.83	.44 to 1.33
2002	0.04	.01 to .08	0.81	.44 to 1.29
2003	0.03	.0 to .06	0.69	.36 to 1.13

2004	0.03	.0 to .07	0.72	.40 to 1.14
2005	0.03	.0 to .08	0.71	.40 to 1.14
2006	0.03	.0 to .08	0.71	.40 to 1.14
2007	0.05	.02 to .10	0.69	.36 to 1.16
2008	0.05	.01 to .11	0.55	.31 to .87
2009	0.05	.01 to .10	0.50	.29 to .78
2010	0.05	.01 to .10	0.50	.28 to .80
2011	0.07	.02 to .15	0.53	.30 to .84
2012	0.09	.04 to .17	0.53	.31 to .83
2013	0.09	.03 to .18	0.53	.30 to .83
2014	0.09	.03 to .18	0.53	.30 to .83
2015	0.09	.03 to .18	0.53	.30 to .83

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-218: 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	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990	-0.43	(1.02) to (.03)	-2.90	(4.17) to (1.74)	-0.75	(1.09) to (0.45)	-0.54	(0.78) to (0.33)
1991	-0.54	(1.18) to (.08)	-2.90	(4.16) to (1.75)	-0.77	(1.10) to (0.46)	-0.56	(0.81) to (0.34)
1992	-0.54	(1.50) to (.13)	-2.79	(4.01) to (1.68)	-0.75	(1.08) to (0.45)	-0.58	(0.83) to (0.35)
1993	-0.44	(1.05) to (.04)	-2.94	(4.22) to (1.77)	-0.74	(1.07) to (0.45)	-0.67	(0.96) to (0.40)
1994	-0.09	(0.52) to 0.28	-3.10	(4.46) to (1.86)	-0.72	(1.04) to (0.44)	-0.79	(1.14) to (0.47)
1995	-0.09	(0.49) to 0.26	-2.89	(4.16) to (1.73)	-0.70	(1.01) to (0.42)	-0.80	(1.15) to (0.48)
1996	-0.10	(0.49) to 0.23	-2.69	(3.87) to (1.62)	-0.70	(1.0) to (0.42)	-0.79	(1.13) to (0.47)
1997	-0.22	(0.65) to 0.07	-2.59	(3.69) to (1.59)	-0.70	(0.99) to (0.43)	-0.84	(1.20) to (0.51)
1998	-0.09	(0.51) to 0.27	-3.22	(4.61) to (1.94)	-0.70	(1.01) to 0(.42)	-0.92	(1.32) to (0.56)
1999	-0.06	(0.45) to 0.29	-3.11	(4.46) to (1.89)	-0.69	(0.99) to (0.42)	-0.96	(1.37) to (0.58)
2000	-0.13	(0.54) to 0.17	-3.16	(4.52) to (1.91)	-0.70	(1.01) to (0.43)	-1.12	(1.61) to (0.68)
2001	-0.10	(0.48) to 0.21	-3.06	(4.39) to (1.84)	-0.67	(0.96) to (0.40)	-1.16	(1.66) to (0.70)
2002	-0.06	(0.41) to 0.24	-2.78	(4.0) to (1.67)	-0.62	(0.90) to (0.37)	-1.09	(1.57) to (0.65)
2003	-0.01	(0.32) to 0.29	-2.51	(3.62) to (1.49)	-0.55	(0.79) to (0.33)	-1.03	(1.49) to (0.61)
2004	0.06	(0.23) to 0.39	-2.65	(3.83) to (1.58)	-0.53	(0.76) to (0.31)	-1.07	(1.54) to (0.64)
2005	0.05	(0.24) to 0.39	-2.43	(3.51) to (1.44)	-0.47	(0.68) to (0.28)	-1.08	(1.56) to (0.64)
2006	0.05	(0.25) to 0.40	-1.91	(2.82) to (1.07)	-0.35	(0.52) to (0.20)	-0.90	(1.33) to (0.51)
2007	0.10	(0.17) to 0.43	-1.59	(2.37) to (0.88)	-0.29	(0.43) to (0.16)	-0.83	(1.25) to (0.46)
2008	0.16	(0.08) to 0.52	-1.45	(2.15) to (0.80)	-0.25	(0.37) to (0.14)	-0.83	(1.24) to (0.46)
2009	0.26	(0.02) to 0.69	-1.38	(2.06) to (0.77)	-0.24	(0.36) to (0.14)	-0.85	(1.26) to (0.47)
2010	0.31	0.02 to 0.73	-1.31	(1.95) to (0.73)	-0.23	(0.34) to (0.13)	-0.84	(1.25) to (0.47)
2011	0.31	0.02 to 0.76	-1.22	(1.83) to (0.67)	-0.21	(0.31) to (0.12)	-0.81	(1.22) to (0.45)
2012	0.24	(0.01) to 0.65	-1.16	(1.73) to (0.64)	-0.20	(0.29) to (0.11)	-0.80	(1.19) to (0.44)
2013	0.27	0.0 to 0.68	-1.15	(1.73) to (0.63)	-0.19	(0.29) to (0.11)	-0.79	(1.19) to (0.44)
2014	0.28	0.0 to 0.72	-1.15	(1.73) to (0.63)	-0.19	(0.29) to (0.11)	-0.79	(1.19) to (0.44)
2015	0.29	0.01 to 0.73	-1.15	(1.73) to (0.63)	-0.19	(0.29) to (0.11)	-0.79	(1.19) to (0.44)

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Non-Federal Grasslands:	Settlements Converted to Grassland		Wetlands Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI
Mineral Soils				
1990	-0.08	(0.12) to (0.05)	-0.32	(0.46) to (0.19)
1991	-0.09	(0.13) to (0.05)	-0.39	(0.56) to (0.23)
1992	-0.09	(0.12) to (0.05)	-0.46	(0.66) to (0.28)
1993	-0.10	(0.14) to (0.06)	-0.48	(0.69) to (0.29)
1994	-0.11	(0.15) to (0.06)	-0.50	(0.72) to (0.30)

1995	-0.10	(0.15) to (0.06)	-0.48	(0.70) to (0.29)
1996	-0.11	(0.16) to (0.07)	-0.47	(0.67) to (0.28)
1997	-0.11	(0.16) to (0.07)	-0.47	(0.66) to (0.29)
1998	-0.12	(0.18) to (0.07)	-0.49	(0.70) to (0.29)
1999	-0.13	(0.18) to (0.08)	-0.48	(0.69) to (0.29)
2000	-0.13	(0.19) to (0.08)	-0.50	(0.71) to (0.30)
2001	-0.14	(0.20) to (0.08)	-0.49	(0.70) to (0.29)
2002	-0.14	(0.19) to (0.08)	-0.45	(0.65) to (0.27)
2003	-0.12	(0.17) to (0.07)	-0.42	(0.61) to (0.25)
2004	-0.12	(0.18) to (0.07)	-0.44	(0.63) to (0.26)
2005	-0.12	(0.18) to (0.07)	-0.43	(0.62) to (0.26)
2006	-0.11	(0.16) to (0.06)	-0.36	(0.53) to (0.20)
2007	-0.10	(0.15) to (0.05)	-0.32	(0.48) to (0.18)
2008	-0.09	(0.14) to (0.05)	-0.26	(0.39) to (0.15)
2009	-0.09	(0.13) to (0.05)	-0.23	(0.34) to (0.13)
2010	-0.09	(0.14) to (0.05)	-0.19	(0.29) to (0.11)
2011	-0.09	(0.14) to (0.05)	-0.16	(0.23) to (0.09)
2012	-0.09	(0.14) to (0.05)	-0.11	(0.17) to (0.06)
2013	-0.09	(0.14) to (0.05)	-0.11	(0.16) to (0.06)
2014	-0.09	(0.14) to (0.05)	-0.11	(0.16) to (0.06)
2015	-0.09	(0.14) to (0.05)	-0.11	(0.16) to (0.06)

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-219: 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	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990	-0.20	(8.94) to 9.45	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1991	-0.30	(9.28) to 8.76	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1992	-0.30	(10.08) to 8.06	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1993	-1.16	(11.03) to 7.60	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1994	-1.50	(11.79) to 7.18	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1995	-1.52	(12.0) to 7.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1996	-0.90	(10.65) to 7.01	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1997	-0.83	(10.42) to 7.27	0.00	0.0 to 0.0	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1998	-1.62	(13.58) to 7.15	0.00	(0.03) to 0.02	-0.10	(0.75) to 0.52	-0.01	(0.04) to 0.03
1999	-1.44	(13.27) to 7.24	0.00	(0.03) to 0.02	-0.10	(0.74) to 0.52	-0.01	(0.04) to 0.03
2000	-1.70	(12.68) to 6.38	0.00	(0.03) to 0.02	-0.10	(0.74) to 0.51	-0.01	(0.04) to 0.03
2001	-1.71	(12.81) to 6.44	0.00	(0.03) to 0.02	-0.10	(0.73) to 0.51	-0.01	(0.04) to 0.03
2002	-2.72	(14.63) to 7.05	0.00	(0.03) to 0.02	-0.11	(0.70) to 0.45	-0.01	(0.04) to 0.03
2003	-2.73	(14.72) to 7.76	0.00	(0.03) to 0.02	-0.11	(0.70) to 0.45	-0.01	(0.04) to 0.03
2004	-1.28	(11.29) to 8.85	0.00	(0.03) to 0.02	-0.11	(0.70) to 0.46	-0.01	(0.04) to 0.03
2005	-1.37	(11.44) to 8.50	0.00	0.0 to 0.0	-0.07	(0.86) to 0.70	0.00	(0.02) to 0.02
2006	-1.51	(11.82) to 8.56	0.00	0.0 to 0.0	-0.07	(0.86) to 0.70	0.00	(0.02) to 0.02
2007	-1.63	(11.93) to 8.11	0.00	0.0 to 0.0	-0.07	(0.86) to 0.70	0.00	(0.02) to 0.02
2008	-1.67	(12.11) to 8.20	0.00	0.0 to 0.0	-0.07	(0.86) to 0.70	0.00	(0.02) to 0.02
2009	-1.46	(11.57) to 7.14	0.00	0.0 to 0.0	-0.07	(0.85) to 0.70	0.00	(0.02) to 0.02
2010	-1.53	(11.51) to 7.48	0.00	0.0 to 0.0	-0.07	(0.86) to 0.69	0.00	(0.02) to 0.02
2011	-1.15	(10.79) to 8.01	0.00	0.0 to 0.0	-0.07	(0.85) to 0.69	0.00	(0.02) to 0.02
2012	-0.67	(9.89) to 8.69	0.00	0.0 to 0.0	-0.07	(0.85) to 0.69	0.00	(0.02) to 0.02
2013	-0.38	(9.23) to 9.19	0.00	0.0 to 0.0	-0.06	(0.85) to 0.69	0.00	(0.02) to 0.02
2014	-0.36	(9.27) to 9.45	0.00	0.0 to 0.0	-0.06	(0.85) to 0.69	0.00	(0.02) to 0.02
2015	-0.98	(10.56) to 9.30	0.00	0.0 to 0.0	-0.06	(0.85) to 0.69	0.00	(0.02) to 0.02

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Federal Grasslands:	Settlements Converted to Grassland		Wetlands Converted to Grassland	
Year	Estimate	95% CI	Estimate	95% CI
Mineral Soils				

1990	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1991	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1992	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1993	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1994	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1995	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1996	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1997	0.00	0.0 to 0.0	0.00	0.0 to 0.0
1998	0.00	0.0 to 0.0	-0.01	(0.05) to 0.03
1999	0.00	0.0 to 0.0	-0.01	(0.05) to 0.03
2000	0.00	0.0 to 0.0	-0.01	(0.05) to 0.03
2001	0.00	0.0 to 0.0	-0.01	(0.05) to 0.03
2002	0.00	0.0 to 0.0	-0.01	(0.04) to 0.03
2003	0.00	0.0 to 0.0	-0.01	(0.04) to 0.03
2004	0.00	0.0 to 0.0	-0.01	(0.04) to 0.03
2005	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2006	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2007	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2008	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2009	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2010	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2011	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2012	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2013	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2014	0.00	0.0 to 0.0	0.00	(0.04) to 0.03
2015	0.00	0.0 to 0.0	0.00	(0.04) to 0.03

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Table A-220: 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	
Year	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Mineral Soils								
1990	-0.62	(9.39) to 9.03	-2.90	(4.17) to (1.74)	-0.75	(1.09) to (0.45)	-0.54	(0.78) to (0.33)
1991	-0.84	(9.85) to 8.23	-2.90	(4.16) to (1.75)	-0.77	(1.10) to (0.46)	-0.56	(0.81) to (0.34)
1992	-0.84	(10.83) to 7.36	-2.79	(4.01) to (1.68)	-0.75	(1.08) to (0.45)	-0.58	(0.83) to (0.35)
1993	-1.60	(11.49) to 7.16	-2.94	(4.22) to (1.77)	-0.74	(1.07) to (0.45)	-0.67	(0.96) to (0.40)
1994	-1.59	(11.89) to 7.09	-3.10	(4.46) to (1.86)	-0.72	(1.04) to (0.44)	-0.79	(1.14) to (0.47)
1995	-1.61	(12.10) to 6.93	-2.89	(4.16) to (1.73)	-0.70	(1.01) to (0.42)	-0.80	(1.15) to (0.48)
1996	-1.00	(10.76) to 6.92	-2.69	(3.87) to (1.62)	-0.70	(1.0) to (0.42)	-0.79	(1.13) to (0.47)
1997	-1.05	(10.65) to 7.06	-2.59	(3.69) to (1.59)	-0.70	(.99) to (0.43)	-0.84	(1.20) to (0.51)
1998	-1.71	(13.68) to 7.07	-3.22	(4.61) to (1.95)	-0.80	(1.52) to (0.12)	-0.92	(1.32) to (0.56)
1999	-1.49	(13.34) to 7.19	-3.12	(4.46) to (1.89)	-0.79	(1.50) to (0.12)	-0.96	(1.38) to (0.58)
2000	-1.84	(12.83) to 6.25	-3.16	(4.52) to (1.91)	-0.80	(1.51) to (0.14)	-1.13	(1.61) to (0.68)
2001	-1.81	(12.91) to 6.35	-3.06	(4.39) to (1.84)	-0.77	(1.46) to (0.10)	-1.17	(1.67) to (0.70)
2002	-2.78	(14.69) to 7.0	-2.78	(4.0) to (1.67)	-0.74	(1.38) to (0.12)	-1.10	(1.57) to (0.66)
2003	-2.74	(14.73) to 7.75	-2.51	(3.62) to (1.49)	-0.66	(1.30) to (0.06)	-1.04	(1.50) to (0.62)
2004	-1.22	(11.23) to 8.91	-2.66	(3.84) to (1.58)	-0.63	(1.27) to (0.03)	-1.08	(1.55) to (0.64)
2005	-1.32	(11.39) to 8.56	-2.43	(3.51) to (1.44)	-0.54	(1.36) to 0.25	-1.08	(1.56) to (0.64)
2006	-1.45	(11.77) to 8.62	-1.91	(2.82) to (1.07)	-0.42	(1.23) to 0.36	-0.90	(1.34) to (0.51)
2007	-1.53	(11.84) to 8.21	-1.59	(2.37) to (.88)	-0.35	(1.16) to 0.42	-0.84	(1.25) to (0.46)
2008	-1.50	(11.95) to 8.37	-1.45	(2.15) to (.80)	-0.31	(1.12) to 0.46	-0.84	(1.24) to (0.47)
2009	-1.20	(11.32) to 7.41	-1.38	(2.06) to (.77)	-0.31	(1.10) to 0.46	-0.85	(1.26) to (0.47)
2010	-1.22	(11.20) to 7.80	-1.31	(1.95) to (.73)	-0.29	(1.09) to 0.47	-0.84	(1.25) to (0.47)
2011	-0.84	(10.48) to 8.34	-1.22	(1.83) to (.67)	-0.28	(1.07) to 0.49	-0.82	(1.23) to (0.45)
2012	-0.43	(9.65) to 8.94	-1.16	(1.73) to (.64)	-0.26	(1.05) to 0.50	-0.80	(1.19) to (0.44)
2013	-0.11	(8.97) to 9.47	-1.15	(1.73) to (.64)	-0.26	(1.05) to 0.50	-0.79	(1.19) to (0.44)
2014	-0.08	(8.99) to 9.74	-1.15	(1.73) to (.63)	-0.26	(1.05) to 0.50	-0.79	(1.19) to (0.44)
2015	-0.69	(10.27) to 9.60	-1.15	(1.73) to (.63)	-0.26	(1.05) to 0.50	-0.79	(1.19) to (0.44)
Organic Soils								
1990	7.21	4.07 to 11.35	0.53	.23 to .98	0.01	.0 to .03	0.04	.01 to .09
1991	7.16	4.0 to 11.43	0.53	.23 to .97	0.01	.0 to .03	0.04	.01 to .09
1992	7.08	3.95 to 11.25	0.51	.22 to .94	0.01	.0 to .03	0.04	.01 to .09

1993	7.03	3.90 to 11.26	0.57	.26 to 1.0	0.02	.01 to .04	0.04	.01 to .09
1994	6.99	3.91 to 11.08	0.70	.32 to 1.27	0.02	.01 to .04	0.04	.01 to .09
1995	6.93	3.88 to 11.02	0.70	.31 to 1.27	0.02	.01 to .03	0.04	.01 to .09
1996	6.85	3.82 to 10.90	0.68	.30 to 1.24	0.02	.01 to .03	0.04	.01 to .09
1997	6.77	3.77 to 10.77	0.69	.32 to 1.23	0.02	.01 to .03	0.03	.0 to .07
1998	6.67	3.70 to 10.68	0.86	.43 to 1.49	0.02	.0 to .03	0.03	.0 to .07
1999	6.62	3.67 to 10.58	0.84	.41 to 1.44	0.01	.0 to .03	0.03	.0 to .07
2000	6.50	3.61 to 10.34	0.88	.44 to 1.51	0.05	.01 to .10	0.03	.0 to .07
2001	6.20	3.42 to 9.91	0.99	.50 to 1.67	0.06	.02 to .12	0.03	.0 to .08
2002	6.14	3.39 to 9.79	1.10	.55 to 1.84	0.06	.02 to .12	0.03	.0 to .08
2003	6.05	3.33 to 9.69	1.03	.53 to 1.74	0.07	.03 to .14	0.03	.0 to .08
2004	6.01	3.28 to 9.65	1.13	.57 to 1.91	0.09	.04 to .16	0.04	.01 to .09
2005	5.97	3.27 to 9.58	1.13	.58 to 1.91	0.09	.04 to .16	0.04	.01 to .09
2006	5.76	3.12 to 9.33	1.13	.57 to 1.90	0.09	.04 to .17	0.04	.01 to .09
2007	5.73	3.11 to 9.26	1.11	.57 to 1.87	0.09	.04 to .17	0.04	.01 to .09
2008	5.69	3.08 to 9.18	1.07	.54 to 1.82	0.10	.04 to .19	0.05	.01 to .10
2009	5.68	3.08 to 9.17	1.15	.59 to 1.92	0.10	.04 to .18	0.03	.01 to .07
2010	5.64	3.07 to 9.12	1.15	.59 to 1.92	0.10	.04 to .18	0.03	.01 to .07
2011	5.61	3.05 to 9.08	1.14	.58 to 1.93	0.10	.04 to .19	0.05	.02 to .11
2012	5.53	3.0 to 8.91	1.12	.57 to 1.88	0.10	.04 to .19	0.05	.02 to .11
2013	5.51	2.99 to 8.87	1.12	.58 to 1.87	0.10	.05 to .19	0.05	.02 to .11
2014	5.51	3.0 to 8.90	1.12	.57 to 1.89	0.10	.04 to .19	0.05	.02 to .11
2015	5.52	3.0 to 8.87	1.12	.57 to 1.88	0.10	.04 to .19	0.05	.02 to .11

Note: Estimates after 2012 are based on NRI data from 2012 and therefore do not fully reflect changes occurring in the latter part of the time series.

Total Grasslands:	**Settlements Converted to Grassland**		**Wetlands Converted to Grassland**	
Year	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Mineral Soils				
1990	-0.08	(0.12) to (0.05)	-0.32	(0.46) to (0.19)
1991	-0.09	(0.13) to (0.05)	-0.39	(0.56) to (0.23)
1992	-0.09	(0.12) to (0.05)	-0.46	(0.66) to (0.28)
1993	-0.10	(0.14) to (0.06)	-0.48	(0.69) to (0.29)
1994	-0.11	(0.15) to (0.06)	-0.50	(0.72) to (0.30)
1995	-0.10	(0.15) to (0.06)	-0.48	(0.70) to (0.29)
1996	-0.11	(0.16) to (0.07)	-0.47	(0.67) to (0.28)
1997	-0.11	(0.16) to (0.07)	-0.47	(0.66) to (0.29)
1998	-0.12	(0.18) to (0.07)	-0.49	(0.71) to (0.30)
1999	-0.13	(0.18) to (0.08)	-0.49	(0.70) to (0.29)
2000	-0.13	(0.19) to (0.08)	-0.50	(0.72) to (0.30)
2001	-0.14	(0.20) to (0.08)	-0.49	(0.71) to (0.30)
2002	-0.14	(0.19) to (0.08)	-0.46	(0.66) to (0.28)
2003	-0.12	(0.17) to (0.07)	-0.43	(0.62) to (0.25)
2004	-0.12	(0.18) to (0.07)	-0.45	(0.65) to (0.26)
2005	-0.12	(0.18) to (0.07)	-0.43	(0.63) to (0.25)
2006	-0.11	(0.16) to (0.06)	-0.36	(0.54) to (0.20)
2007	-0.10	(0.15) to (0.05)	-0.33	(0.49) to (0.18)
2008	-0.09	(0.14) to (0.05)	-0.26	(0.40) to (0.14)
2009	-0.09	(0.13) to (0.05)	-0.23	(0.34) to (0.12)
2010	-0.09	(0.14) to (0.05)	-0.20	(0.30) to (0.10)
2011	-0.09	(0.14) to (0.05)	-0.16	(0.24) to (0.08)
2012	-0.09	(0.14) to (0.05)	-0.11	(0.18) to (0.05)
2013	-0.09	(0.14) to (0.05)	-0.11	(0.18) to (0.05)
2014	-0.09	(0.14) to (0.05)	-0.11	(0.18) to (0.05)
2015	-0.09	(0.14) to (0.05)	-0.11	(0.18) to (0.05)
Organic Soils				
1990	0.00	.0 to .0	0.12	.05 to .23
1991	0.00	.0 to .0	0.12	.05 to .22
1992	0.00	.0 to .0	0.12	.02 to .30
1993	0.00	.0 to .01	0.18	.07 to .36
1994	0.01	.0 to .02	0.24	.11 to .42
1995	0.01	.0 to .02	0.24	.12 to .40
1996	0.01	.0 to .02	0.24	.13 to .39
1997	0.01	.0 to .03	0.24	.13 to .40

1998	0.02	.0 to .04	0.25	.13 to .41
1999	0.02	.0 to .04	0.25	.13 to .41
2000	0.02	.0 to .04	0.30	.16 to .48
2001	0.02	.0 to .04	0.30	.16 to .49
2002	0.02	.0 to .04	0.28	.15 to .45
2003	0.02	.0 to .04	0.24	.14 to .38
2004	0.02	.0 to .04	0.24	.13 to .39
2005	0.02	.0 to .04	0.26	.14 to .42
2006	0.02	.0 to .04	0.28	.15 to .44
2007	0.02	.0 to .04	0.28	.15 to .45
2008	0.02	.0 to .04	0.28	.16 to .46
2009	0.02	.0 to .04	0.33	.19 to .52
2010	0.02	.0 to .04	0.34	.19 to .54
2011	0.02	.0 to .04	0.33	.19 to .53
2012	0.02	.0 to .04	0.33	.19 to .52
2013	0.02	.0 to .04	0.33	.19 to .52
2014	0.02	.0 to .04	0.33	.19 to .53
2015	0.02	.0 to .04	0.33	.19 to .53

Note: Estimates after 2012 are based on NRI data from 2012 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 2012, 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 2012 from the NRI. The results for 2012 are applied to the years 2013 through 2015. 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-222). 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-215 and Table A-218.

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 are provided in Table A-223 and implied Tier 3 emission factors are in Table A-226 and Table A-227.

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-224 and implied Tier 3 emission factors are in Table A-226 and Table A-227. 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-225.

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-229). On a per area unit basis, direct N_2O emissions are high in some Northeast, Midwest, 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. Note that although the total crop area in the northeast is relatively low, emissions are high on a per unit area basis because of freeze/thaw cycles during spring that saturate surface soil layers and enhance denitrification rates.

Direct emissions from non-federal grasslands are typically lower than the emissions from croplands (Table A-229) because N inputs tend to be lower, particularly from synthetic fertilizer. Texas, Oklahoma, Kansas, Montana, Missouri, and Kentucky are the highest emitters for this category due to large land areas used for pastures and rangeland (Table A-229). On a per unit of area basis, direct N_2O emissions are higher in the some of the Southeastern, Appalachians, and Midwestern states because these grasslands are more intensively managed (legume seeding, fertilization) while western rangelands receive few, if any, N inputs. 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.

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-230. The states with highest total amounts of C sequestration are California, Illinois, Iowa, Kentucky, Missouri, North Dakota and Tennessee (Table A-231). 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.

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-228. The states with highest total emissions are Arkansas, California, Louisiana and Texas (Table A-232). 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-221: Assumptions and Calculations to Estimate the Contribution to Soil Organic Carbon Stocks from Application of Biosolids (i.e., Sewage Sludge) to Mineral Soils

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Biosolids 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	88,736
Assimilative Capacity (Mg N/ha)b	0.12	0.12	0.12	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
Area covered by Available Biosolids 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	727,341
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]	**-0.60**	**-0.64**	**-0.68**	**-0.71**	**-0.74**	**-0.77**	**-0.82**	**-0.86**	**-0.89**	**-0.92**	**-0.95**	**-0.98**	**-1.01**

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Biosolids N Applied to Agricultural Land (Mg N)[a]	91,358	93,991	98,400	101,314	104,222	107,123	110,018	112,909	115,797	118,681	121,563	124,443	127,322
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 Biosolids N (ha)[c]	748,836	770,418	806,559	830,447	854,276	878,055	901,790	925,487	949,154	972,796	996,417	1,020,025	1,043,622
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]	**-1.04**	**-1.07**	**-1.12**	**-1.16**	**-1.19**	**-1.22**	**-1.26**	**-1.29**	**-1.32**	**-1.36**	**-1.39**	**-1.42**	**-1.45**

[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 biosolids 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 1993-2015.
[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 biosolids 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-222: 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	14.3±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-223: Indirect N_2O Emissions from Volatilization and Atmospheric Deposition (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	2015
Croplands	12.0	12.3	12.0	11.8	12.9	13.3	13.1	13.2	13.4	12.7	12.8	12.6	12.7	13.1	13.0	13.0	13.6	13.4	13.2	12.7	13.1	12.9	12.7	12.5	12.5	12.7
Grasslands	4.3	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.7	4.4	4.2	4.4	4.4	4.4	4.8	4.5	4.5	4.5	4.4	4.5	4.6	4.2	4.2	4.2	4.2	4.2
Total	**16.4**	**16.7**	**16.4**	**16.2**	**17.3**	**17.8**	**17.6**	**17.6**	**18.0**	**17.0**	**17.0**	**17.0**	**17.1**	**17.6**	**17.8**	**17.5**	**18.1**	**17.8**	**17.7**	**17.2**	**17.7**	**17.2**	**16.9**	**16.7**	**16.6**	**16.9**

Table A-224: 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	2015
Croplands	25.0	21.3	24.3	31.4	18.0	23.7	23.5	21.4	27.3	22.0	19.4	25.2	21.9	24.2	28.6	21.4	24.9	26.8	29.1	29.2	28.6	29.0	18.9	18.4	18.4	18.4
Grasslands	3.2	3.1	2.9	3.5	2.9	3.0	3.0	3.0	3.7	2.7	2.5	3.2	3.3	2.6	3.5	2.5	2.8	3.2	3.3	3.6	2.8	3.5	2.6	2.6	2.6	2.6
Total	**28.2**	**24.4**	**27.2**	**34.9**	**20.9**	**26.7**	**26.5**	**24.4**	**31.0**	**24.7**	**21.8**	**28.4**	**25.2**	**26.8**	**32.1**	**23.9**	**27.7**	**30.1**	**32.4**	**32.8**	**31.5**	**32.5**	**21.5**	**21.0**	**20.9**	**21.1**

Table A-225: 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	2002	2003	2004	2005
Total Direct	**212.0**	**213.0**	**212.1**	**212.8**	**213.3**	**213.7**	**218.7**	**217.1**	**228.5**	**212.6**	**214.0**	**215.8**	**216.7**	**219.3**	**236.7**	**218.5**
Direct Emissions from Mineral Cropland Soils	**144.1**	**144.2**	**143.9**	**143.0**	**147.1**	**146.2**	**148.2**	**147.0**	**154.3**	**148.1**	**149.2**	**148.9**	**148.0**	**152.4**	**159.5**	**150.6**
Synthetic Fertilizer	53.6	53.9	55.0	52.4	58.0	53.2	57.4	56.0	56.4	54.9	55.9	52.7	54.2	55.4	57.0	54.6
Organic Amendment[a]	10.0	10.2	10.3	10.0	10.4	10.5	10.6	10.7	10.6	10.7	11.0	10.9	11.1	11.1	10.8	10.9
Residue N[b]	22.1	23.4	21.7	22.0	21.7	23.3	22.2	22.2	21.8	25.0	23.1	22.9	22.8	23.3	22.2	22.9
Mineralization and Asymbiotic Fixation	58.4	56.7	56.9	58.5	56.9	59.2	58.1	58.3	65.5	57.5	59.2	62.4	59.8	62.6	69.6	62.2
Direct Emissions from Drained Organic Cropland Soils	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.4**	**3.4**	**3.3**	**3.3**	**3.3**
Direct Emissions from Mineral Grassland Soils	**61.3**	**62.3**	**61.6**	**63.2**	**59.6**	**61.0**	**63.9**	**63.4**	**67.6**	**58.0**	**58.2**	**60.0**	**61.8**	**60.1**	**70.4**	**61.1**
Synthetic Mineral Fertilizer	0.9	0.9	0.9	0.8	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.8	0.8
PRP Manure	16.1	15.9	16.2	16.5	16.6	16.5	16.9	15.8	16.2	14.5	14.6	14.4	14.6	14.0	14.7	13.8
Managed Manure	0.9	0.8	0.8	0.9	0.9	0.9	0.9	0.9	1.1	0.9	1.0	1.0	1.1	1.0	1.2	1.1
Biosolids (i.e., 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
Residue[b]	14.5	14.6	14.7	15.3	13.4	15.0	14.6	15.2	15.1	15.3	13.9	15.0	14.9	14.9	15.8	15.8
Mineralization and Asymbiotic Fixation	28.5	29.9	28.6	29.5	27.5	27.5	30.3	30.4	33.9	26.0	27.5	28.5	30.0	29.0	37.5	29.2
Direct Emissions from Drained Organic Grassland Soils	**3.3**	**3.2**	**3.2**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.4**	**3.5**	**3.5**	**3.5**	**3.5**	**3.5**
Total Indirect	**44.6**	**41.1**	**43.6**	**51.1**	**38.2**	**44.5**	**44.0**	**42.0**	**49.0**	**41.7**	**38.8**	**45.3**	**42.2**	**44.4**	**49.9**	**41.4**
Volatilization	16.4	16.7	16.4	16.2	17.3	17.8	17.6	17.6	18.0	17.0	17.0	17.0	17.1	17.6	17.8	17.5
Leaching/Runoff	28.2	24.4	27.2	34.9	20.9	26.7	26.5	24.4	31.0	24.7	21.8	28.4	25.2	26.8	32.1	23.9
Total Emissions	**256.6**	**254.1**	**255.7**	**263.9**	**251.5**	**258.2**	**262.8**	**259.1**	**277.5**	**254.4**	**252.8**	**261.2**	**258.9**	**263.7**	**286.6**	**259.8**

Activity	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total Direct	**223.6**	**229.2**	**222.1**	**226.4**	**231.1**	**220.4**	**215.6**	**212.8**	**212.4**	**213.3**
Direct Emissions from Mineral Cropland Soils	**153.1**	**157.4**	**153.3**	**154.1**	**159.5**	**155.1**	**153.5**	**151.0**	**151.1**	**151.4**
Synthetic Fertilizer	56.2	58.2	55.7	53.7	55.0	58.0	60.4	58.3	58.2	58.3
Organic Amendment[a]	11.3	11.4	11.2	11.1	11.0	11.2	11.3	11.3	11.2	11.4
Residue N[b]	22.6	22.8	21.7	22.1	24.0	23.9	23.5	23.7	23.8	23.9

Mineralization and Asymbiotic Fixation	63.0	64.9	64.7	67.2	69.6	62.1	58.2	57.8	57.8	57.8
Direct Emissions from Drained Organic Cropland Soils	**3.3**	**3.3**	**3.3**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**
Direct Emissions from Mineral Grassland Soils	**63.7**	**65.1**	**62.2**	**65.8**	**65.1**	**58.8**	**55.7**	**55.3**	**54.9**	**55.4**
Synthetic Mineral Fertilizer	0.8	0.8	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.7
PRP Manure	14.4	13.7	13.5	14.1	13.7	13.6	13.3	13.0	12.5	13.2
Managed Manure	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Biosolids (i.e., Sewage Sludge)	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Residue[b]	15.6	16.5	15.5	15.4	16.5	14.8	14.2	14.2	14.2	14.2
Mineralization and Asymbiotic Fixation	31.3	32.6	30.9	33.8	32.4	28.1	25.8	25.8	25.8	25.7
Direct Emissions from Drained Organic Grassland Soils	**3.5**	**3.4**	**3.4**	**3.4**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
Total Indirect	**45.8**	**47.9**	**50.1**	**50.1**	**49.2**	**49.7**	**38.4**	**37.7**	**37.6**	**38.0**
Volatilization	18.1	17.8	17.7	17.2	17.7	17.2	16.9	16.7	16.6	16.9
Leaching/Runoff	27.7	30.1	32.4	32.8	31.5	32.6	21.5	21.0	20.9	21.1
Total Emissions	**269.3**	**277.1**	**272.2**	**276.4**	**280.3**	**270.1**	**254.1**	**250.5**	**250.0**	**251.3**

[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-226: Implied Tier 3 Cropland Indirect Emission Factors

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Indirect N Inputs													
N Inputs Volatilization (N fertilizer + N manure)	10,500	10,383	10,665	10,754	10,468	10,174	10,523	10,527	10,414	10,308	10,674	10,486	10,518
N Inputs Leachnig (N fertilizer + N manure + N residue)	14,379	14,488	14,387	14,805	14,208	14,357	14,457	14,494	14,305	14,912	14,897	14,685	14,721
Total Indirect Activity													
Volatilization	866.3	869.5	832.0	870.2	870.7	906.5	876.0	888.6	959.2	938.2	965.0	970.6	945.0
Leaching/Runoff	6330.6	5268.8	6149.5	8208.6	4102.8	5841.1	5695.1	5147.7	6797.5	5258.9	4591.5	6382.3	5393.7
Implied EF Volotilization	0.083	0.084	0.078	0.081	0.083	0.089	0.083	0.084	0.092	0.091	0.090	0.093	0.090
Implied EF Leaching	0.440	0.364	0.427	0.554	0.289	0.407	0.394	0.355	0.475	0.353	0.308	0.435	0.366

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Indirect N Inputs													
N Inputs Volatilization (N fertilizer + N manure)	10,526	10,482	10,618	10,382	11,242	10,787	10,743	10,926	10,950	11,127	11,127	11,127	11,127
N Inputs Leachnig (N fertilizer + N manure + N residue)	14,829	14,436	14,836	14,464	15,413	14,755	14,815	15,411	15,376	15,497	15,497	15,497	15,497
Total Indirect Activity													
Volatilization	973.9	1010.6	998.3	989.5	991.1	979.6	995.5	1101.7	996.5	925.2	917.4	917.4	917.4
Leaching/Runoff	5949.8	7191.6	5232.5	6129.7	6739.7	7415.4	7543.1	7333.1	7323.4	4375.4	4339.9	4340.1	4340.5
Implied EF Volotilization	0.093	0.096	0.094	0.095	0.088	0.091	0.093	0.101	0.091	0.083	0.082	0.082	0.082
Implied EF Leaching	0.401	0.498	0.353	0.424	0.437	0.503	0.509	0.476	0.476	0.282	0.280	0.280	0.280

Table A-227: Implied Tier 3 Grassland Indirect Emission Factors

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Indirect N Inputs													
N Inputs Volatilization (N fertilizer + N PRP manure + N managed manure)	3,875	3,892	4,041	4,078	4,242	4,287	4,286	4,258	4,293	4,250	4,172	4,130	4,183
N Inputs Leachnig (N residue)	7,967	7,946	8,192	8,392	7,653	8,588	8,073	8,226	7,540	9,150	8,131	8,490	8,117
N Inputs Leachnig (N fertilizer + N PRP manure + N	11,841	11,838	12,233	12,470	11,896	12,875	12,360	12,483	11,832	13,400	12,304	12,620	12,300

managed manure + N residue)													
Total Indirect Activity													
Volatilization	701.5	714.9	712.8	707.1	703.9	731.8	729.0	737.7	789.6	730.7	695.9	741.0	745.9
Leaching/Runoff	664.2	638.1	575.2	726.1	571.8	599.1	594.9	612.9	834.5	561.4	493.0	709.5	731.2
Implied Fraction of N Volatilization	0.181	0.184	0.176	0.173	0.166	0.171	0.170	0.173	0.184	0.172	0.167	0.179	0.178
Implied Fraction of N Leaching/Runoff	0.056	0.054	0.047	0.058	0.048	0.047	0.048	0.049	0.071	0.042	0.040	0.056	0.059

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Indirect N Inputs													
N Inputs Volatilization (N fertilizer + N PRP manure + N managed manure)	4,221	4,224	4,261	4,318	4,231	4,195	4,194	4,179	4,074	3,992	3,989	3,990	3,975
N Inputs Leachnig (N residue)	8,549	7,746	8,722	8,070	8,757	8,454	8,242	8,903	8,508	9,005	8,997	8,988	8,980
N Inputs Leachnig (N fertilizer + N PRP manure + N managed manure + N residue)	12,770	11,971	12,984	12,389	12,988	12,649	12,436	13,082	12,582	12,997	12,986	12,979	12,955
Total Indirect Activity													
Volatilization	768.0	843.0	779.0	776.7	788.2	771.1	782.9	798.3	722.7	716.7	716.0	715.6	715.1
Leaching/Runoff	559.5	792.2	515.6	599.6	731.8	759.1	844.4	612.7	802.0	545.9	544.8	545.0	545.1
Implied Fraction of N Volatilization	0.182	0.200	0.183	0.180	0.186	0.184	0.187	0.191	0.177	0.180	0.180	0.179	0.180
Implied Fraction of N Leaching/Runoff	0.044	0.066	0.040	0.048	0.056	0.060	0.068	0.047	0.064	0.042	0.042	0.042	0.042

Table A-228: 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**
Tier 1	1.63	1.64	1.70	1.70	1.75	1.53	1.57	1.58	1.76	3.25	3.29	1.93	1.84	1.72	1.85	1.74	1.48
Tier 3	14.39	15.18	15.17	15.24	13.10	14.23	14.40	14.22	14.35	14.82	14.98	13.62	14.62	12.58	12.26	14.93	11.38
Total	**16.02**	**16.82**	**16.87**	**16.94**	**14.84**	**15.76**	**15.97**	**15.80**	**16.10**	**18.08**	**18.27**	**15.56**	**16.46**	**14.31**	**14.11**	**16.68**	**12.86**

Approach	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Tier 1	1.40	1.59	1.70	1.79	1.51	1.38	1.40	1.50	1.30
Tier 3	12.54	9.92	12.76	14.09	12.59	9.96	9.95	9.90	9.92
Total	**13.94**	**11.51**	**14.45**	**15.88**	**14.10**	**11.34**	**11.34**	**11.39**	**11.22**

Table A-229: Total 2015 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	1.57	1.27	3.00	2.44	4.13
AR	4.84	1.38	6.50	5.18	9.10
AZ	0.55	0.87	1.84	1.45	3.14
CA	4.17	1.12	8.69	5.85	18.38
CO	2.87	2.06	5.13	4.33	6.80
CT	0.11	0.02	0.14	0.10	0.24
DE	0.16	0.01	0.19	0.13	0.34
FL	1.91	2.98	5.72	4.45	10.09
GA	2.47	0.94	3.68	2.76	5.69
HI[c4]	0.01	0.13	0.14	0.04	0.27
IA	13.34	1.38	15.12	12.13	20.45
ID	2.74	0.86	3.81	3.04	5.67
IL	12.68	0.71	13.40	10.32	18.72
IN	7.58	0.63	8.19	6.24	11.80
KS	10.22	2.93	13.44	11.16	17.35
KY	3.26	2.33	5.60	4.62	7.31

LA	3.09	0.98		4.51	3.65	6.13
MA	0.14	1.26		0.20	0.15	0.30
MD	0.73	0.12		1.00	0.75	1.57
ME	0.23	0.17		0.38	0.27	0.58
MI	3.99	0.65		5.08	4.03	7.26
MN	9.62	0.91		11.33	9.22	14.99
MO	7.33	3.08		10.61	8.64	14.08
MS	3.45	0.94		4.44	3.52	6.13
MT	3.29	3.04		6.34	5.33	7.94
NC	2.84	0.68		3.76	2.75	6.03
ND	6.02	1.05		7.02	5.61	9.08
NE	9.49	1.42		11.27	9.13	15.34
NH	0.07	0.02		0.13	0.09	0.20
NJ	0.15	0.11		0.23	0.17	0.36
NM	0.74	2.30		2.95	2.41	4.28
NV	0.25	1.23		0.76	0.61	1.18
NY	2.93	0.73		4.01	3.13	6.12
OH	6.39	0.71		8.32	6.51	12.36
OK	3.05	3.61		6.75	5.68	8.68
OR	1.25	1.02		2.51	2.06	3.63
PA	2.76	0.57		3.68	2.85	5.74
RI	0.01	0.01		0.02	0.01	0.04
SC	1.13	0.40		1.51	1.08	2.39
SD	5.33	1.83		7.16	5.86	9.23
TN	2.50	1.80		4.35	3.53	5.83
TX	12.07	11.64		24.67	20.69	31.66
UT	0.59	0.76		1.44	1.16	2.16
VA	1.43	1.24		2.71	2.23	3.60
VT	0.45	0.12		0.64	0.48	1.04
WA	2.05	0.63		3.06	2.54	4.35
WI	5.84	1.01		7.64	6.24	11.05
WV	0.28	0.41		0.70	0.58	0.91
WY	0.95	1.56		2.76	2.33	3.77

[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 biosolids (i.e., 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-230: 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
Net emissions based on Tier 3 Century-based analysis (Step 2)																
CRC	(65.7)	(71.6)	(63.0)	(43.6)	(55.5)	(49.2)	(57.7)	(55.5)	(44.2)	(59.7)	(65.4)	(58.3)	(54.7)	(47.6)	(47.6)	(50.8)
GCC	20.6	21.4	23.6	18.0	14.4	20.0	16.9	19.0	12.6	12.8	13.0	11.2	11.2	13.1	12.6	12.4
GRG	(10.2)	(12.5)	(6.8)	1.7	(24.1)	(1.0)	(22.3)	(9.1)	(16.0)	(4.0)	(33.1)	(8.8)	(9.6)	(6.3)	0.4	2.0
CCG	(5.1)	(5.2)	(4.9)	(5.5)	(7.4)	(6.4)	(7.6)	(7.5)	(8.1)	(8.5)	(10.5)	(9.8)	(10.5)	(10.5)	(9.9)	(10.2)
Net emissions based on the IPCC Tier 2 analysis (Step 3)																
Mineral Soils																
CRC	(5.4)	(6.2)	(6.6)	(6.9)	(6.7)	(6.5)	(6.1)	(7.6)	(7.3)	(7.1)	(6.7)	(6.7)	(6.7)	(6.0)	(5.4)	(5.4)
GCC	1.3	1.3	1.3	1.3	1.5	1.6	1.6	1.4	1.6	1.5	1.5	1.5	1.5	1.4	1.6	1.5
FCC	0.2	0.2	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
OCC	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	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
WCC	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GRG	(0.6)	(0.8)	(1.4)	(1.6)	(1.6)	(1.6)	(1.0)	(1.0)	(1.7)	(1.5)	(1.8)	(1.8)	(2.8)	(2.7)	(1.2)	(1.3)
CCG	(2.9)	(2.9)	(2.8)	(2.9)	(3.1)	(2.9)	(2.7)	(2.6)	(3.2)	(3.1)	(3.2)	(3.1)	(2.8)	(2.5)	(2.7)	(2.4)
FCG	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.8)	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.6)	(0.5)
OCG	(0.5)	(0.6)	(0.6)	(0.7)	(0.8)	(0.8)	(0.8)	(0.8)	(0.9)	(1.0)	(1.1)	(1.2)	(1.1)	(1.0)	(1.1)	(1.1)
SCG	(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)
WCG	(0.3)	(0.4)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.4)	(0.4)	(0.4)
Organic Soils																
CRC	30.3	29.8	29.7	29.5	29.4	29.3	29.3	29.3	28.8	24.4	24.5	29.0	29.3	29.6	29.9	29.7
GCC	2.5	2.5	2.6	2.7	2.7	2.9	3.0	3.0	3.5	3.5	3.3	4.2	4.2	4.0	3.4	3.3
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	0.1	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	0.1	0.1
SCC	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
WCC	0.6	0.6	0.6	0.8	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.7
GRG	7.2	7.2	7.1	7.0	7.0	6.9	6.8	6.8	6.7	6.6	6.5	6.2	6.1	6.1	6.0	6.0

CCG	0.5	0.5	0.5	0.6	0.7	0.7	0.7	0.7	0.9	0.8	0.9	1.0	1.1	1.0	1.1	1.1
FCG	0.0	0.0	0.0	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
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
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
WCG	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.3
Additional changes in net emissions from mineral soils based on application of biosolids (i.e.,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)
Additional changes in net emissions from mineral soils based on additional enrollment of CRP land (Step 4)																
CRC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Stock Changes by Land Use/Land-Use Change Category (Step 5)																
CRC	(40.9)	(48.1)	(40.0)	(21.1)	(32.8)	(26.3)	(34.5)	(33.8)	(22.7)	(42.3)	(47.7)	(36.0)	(32.1)	(24.0)	(23.0)	(26.5)
GCC	24.5	25.2	27.5	22.0	18.6	24.6	21.6	23.4	17.7	17.8	17.7	16.9	16.8	18.5	17.6	17.3
FCC	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1
OCC	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
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
WCC	0.7	0.7	0.7	0.9	1.1	1.1	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.8	0.9	0.8
GRG	(4.2)	(6.9)	(1.8)	6.4	(19.5)	3.6	(17.3)	(4.2)	(12.0)	0.2	(29.4)	(5.4)	(7.3)	(4.1)	4.1	5.5
CCG	(7.5)	(7.6)	(7.2)	(7.9)	(9.8)	(8.6)	(9.6)	(9.4)	(10.5)	(10.8)	(12.8)	(11.9)	(12.2)	(12.0)	(11.4)	(11.5)
FCG	(0.7)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.7)	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.6)	(0.5)	(0.4)
OCG	(0.5)	(0.5)	(0.5)	(0.6)	(0.8)	(0.8)	(0.8)	(0.8)	(0.9)	(0.9)	(1.1)	(1.1)	(1.1)	(1.0)	(1.0)	(1.0)
SCG	(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)
WCG	(0.2)	(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)
Total [a]	**(28.3)**	**(37.5)**	**(21.9)**	**(0.8)**	**(43.5)**	**(6.7)**	**(39.7)**	**(24.1)**	**(27.7)**	**(35.5)**	**(72.8)**	**(37.0)**	**(35.3)**	**(22.2)**	**(13.3)**	**(15.8)**

Note: Totals may not sum due to independent rounding.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Net emissions based on Tier 3 Century-based analysis (Step 2)										
CRC	(47.5)	(45.6)	(34.4)	(29.3)	(29.4)	(43.6)	(46.6)	(46.6)	(46.6)	(46.6)
GCC	13.2	11.8	12.7	12.6	14.5	14.3	13.4	13.4	13.4	13.4
GRG	(14.8)	1.8	(10.1)	(5.7)	1.3	(16.0)	(24.6)	(24.5)	(24.4)	(24.2)
CCG	(12.2)	(10.9)	(10.8)	(10.6)	(10.8)	(11.0)	(11.2)	(11.2)	(11.2)	(11.2)
Net emissions based on the IPCC Tier 2 analysis (Step 3)										
Mineral Soils										
CRC	(4.4)	(4.0)	(3.4)	(3.5)	(3.6)	(3.5)	(2.9)	(2.7)	(2.7)	(2.7)
GCC	1.8	1.8	1.9	1.7	1.7	1.7	1.7	1.7	1.7	1.7
FCC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
OCC	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
WCC	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
GRG	(1.5)	(1.5)	(1.5)	(1.2)	(1.2)	(0.8)	(0.4)	(0.1)	(0.1)	(0.7)
CCG	(1.9)	(1.6)	(1.4)	(1.4)	(1.3)	(1.2)	(1.2)	(1.2)	(1.2)	(1.2)
FCG	(0.4)	(0.4)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
OCG	(0.9)	(0.8)	(0.8)	(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)
WCG	(0.4)	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)
Organic Soils										
CRC	29.6	29.5	29.3	29.7	29.6	27.9	28.1	28.1	28.1	28.0
GCC	3.3	3.2	3.0	2.9	2.9	3.0	3.0	3.0	3.0	3.0
FCC	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	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
SCC	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1
WCC	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
GRG	5.8	5.7	5.7	5.7	5.6	5.6	5.5	5.5	5.5	5.5
CCG	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
FCG	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
OCG	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
SCG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WCG	0.3	0.3	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 biosolids (i.e., sewage sludge) to agricultural land (Step 4)										
GRG	(1.2)	(1.2)	(1.2)	(1.3)	(1.3)	(1.3)	(1.4)	(1.4)	(1.4)	(1.5)
Additional changes in net emissions from mineral soils based on additional enrollment of CRP land (Step 4)										
CRC	-	-	-	-	-	-	-	1.6	2.5	3.3
Total Stock Changes by Land Use/Land-Use Change Category (Step 5)										
CRC	(22.2)	(20.1)	(8.5)	(3.2)	(3.4)	(19.1)	(21.4)	(19.6)	(18.7)	(18.0)
GCC	18.2	16.9	17.5	17.2	19.1	19.0	18.1	18.1	18.1	18.1
FCC	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	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
SCC	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
WCC	0.9	0.8	0.7	0.6	0.6	0.7	0.7	0.7	0.7	0.7
GRG	(11.7)	4.8	(7.1)	(2.4)	4.5	(12.5)	(20.8)	(20.5)	(20.4)	(20.9)
CCG	(13.0)	(11.4)	(11.2)	(10.9)	(10.9)	(11.0)	(11.3)	(11.2)	(11.2)	(11.2)
FCG	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
OCG	(0.9)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)
SCG	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
WCG	(0.1)	(0.0)	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Total [a]	**(28.7)**	**(9.6)**	**(9.1)**	**0.9**	**9.4**	**(23.5)**	**(35.0)**	**(32.8)**	**(31.8)**	**(31.6)**

Note: Totals may not sum due to independent rounding.

Table A-231: Soil C Stock Change for Mineral and Organic Soils in 2015 within individual states (MMT CO_2 Eq.)

State	Mineral Soil	Organic Soil	Total
AL	(1.03)	0.01	(1.02)
AR	(1.00)	-	(1.00)
AZ	(0.42)	-	(0.42)
CA	(3.72)	1.58	(2.13)
CO	(0.02)	0.00	(0.01)
CT	(0.02)	0.01	(0.02)
DE	(0.04)	-	(0.04)
FL	0.12	12.21	12.32
GA	0.18	-	0.18
HI	(0.08)	0.77	0.69
IA	(9.18)	0.73	(8.45)
ID	(1.25)	0.03	(1.22)
IL	(6.20)	0.52	(5.68)
IN	(1.64)	2.36	0.72
KS	(2.43)	-	(2.43)
KY	(1.39)	-	(1.39)
LA	(0.13)	0.51	0.39
MA	(0.06)	0.28	0.23
MD	(0.19)	0.01	(0.18)
ME	(0.11)	0.01	(0.10)
MI	(0.02)	3.40	3.37
MN	(4.11)	7.65	3.55
MO	(5.91)	-	(5.91)
MS	(1.05)	0.01	(1.04)
MT	(4.40)	0.15	(4.26)
NC	(0.57)	1.89	1.32
ND	(10.32)	0.01	(10.30)
NE	(5.17)	0.00	(5.16)
NH	(0.03)	0.02	(0.01)
NJ	(0.02)	0.12	0.10
NM	2.64	-	2.64
NV	(1.08)	0.00	(1.08)
NY	(0.33)	0.53	0.20
OH	(1.52)	0.48	(1.04)
OK	(0.62)	-	(0.62)
OR	(0.61)	0.30	(0.31)
PA	(0.43)	0.05	(0.38)
RI	(0.00)	0.02	0.02
SC	(0.56)	0.02	(0.54)
SD	(5.89)	-	(5.89)
TN	(1.51)	-	(1.51)
TX	2.44	-	2.44
UT	0.95	0.08	1.02
VA	(1.29)	0.00	(1.29)
VT	(0.08)	0.06	(0.02)
WA	(0.60)	0.38	(0.23)
WI	(0.06)	2.90	2.85
WV	(0.53)	-	(0.53)
WY	(2.96)	-	(2.96)

Note: Parentheses indicate net C accumulation. Estimates do not include soil C stock change associated with federal croplands and grasslands, CRP enrollment after 2012, or biosolids (i.e., 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 biosolids and CRP enrollment after 2012 are not included, and differences arise due to rounding of values in this table.

Table A-232: Total 2015 CH_4 Emissions from Rice Cultivation by State (MMT CO_2 Eq.)

State	Total
AL	-
AR	3.75
AZ	-
CA	2.04
CO	-
CT	-
DE	-
FL	-
GA	-
HI	-
IA	-
ID	-
IL	-
IN	-
KS	-
KY	-
LA	3.79
MA	-
MD	-
ME	-
MI	-
MN	0.03
MO	0.29
MS	0.47
MT	-
NC	-
ND	-
NE	-
NH	-
NJ	-
NM	-
NV	-
NY	-
OH	-
OK	-
OR	-
PA	-
RI	-
SC	-
SD	-
TN	-
TX	0.85
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*

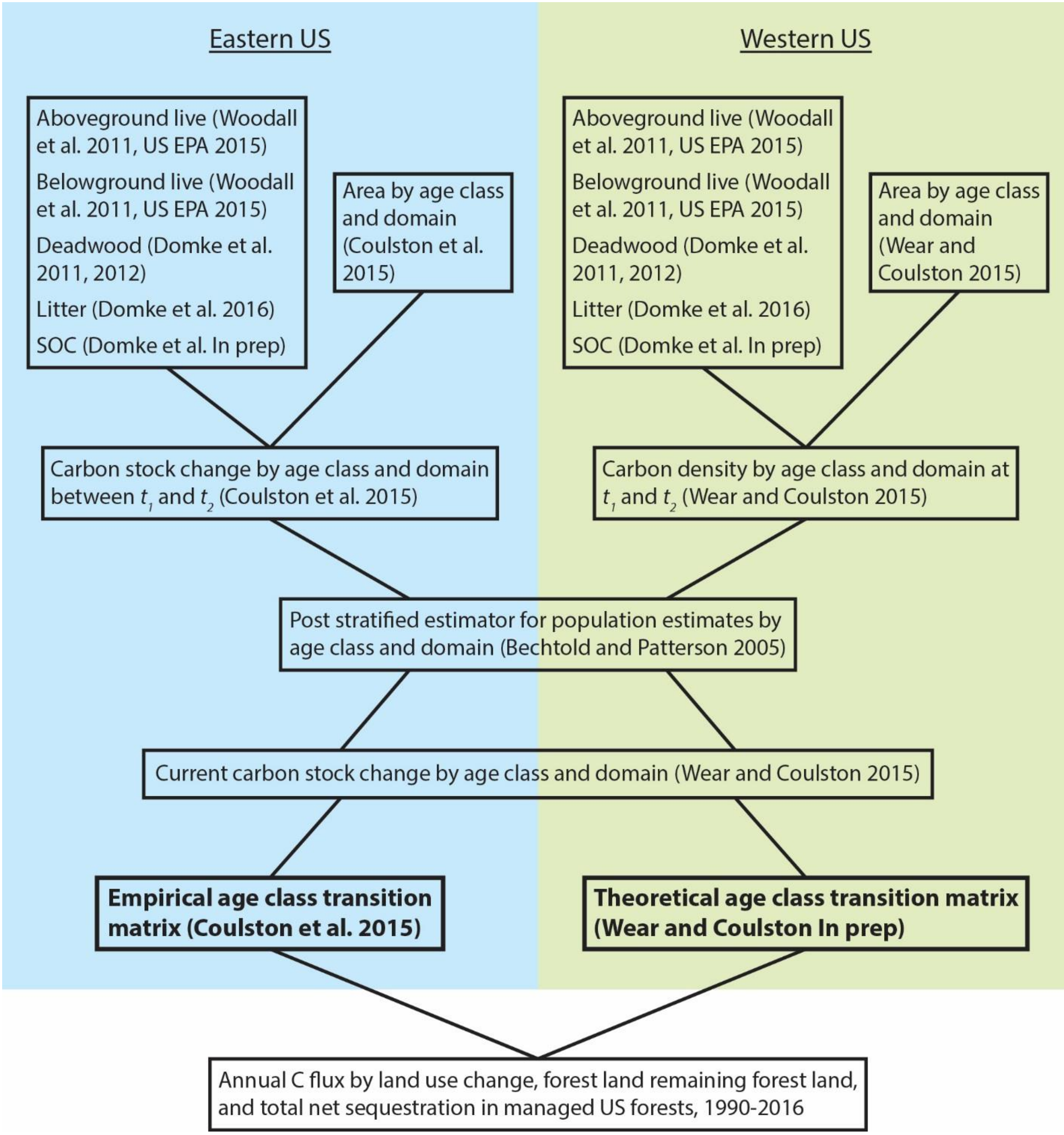
This sub-annex expands on the methodology used to estimate net changes in carbon (C) stocks in forest ecosystems and harvested wood products for *Forest Land Remaining Forest Land* and *Land Converted to Forest Land* as well as non-CO_2 emissions from forest fires. Full details of the C conversion factors 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 a combination of approaches (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-16).

The following subsections of this annex will describe the estimation system used this year (Figure A-16) 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-16: 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

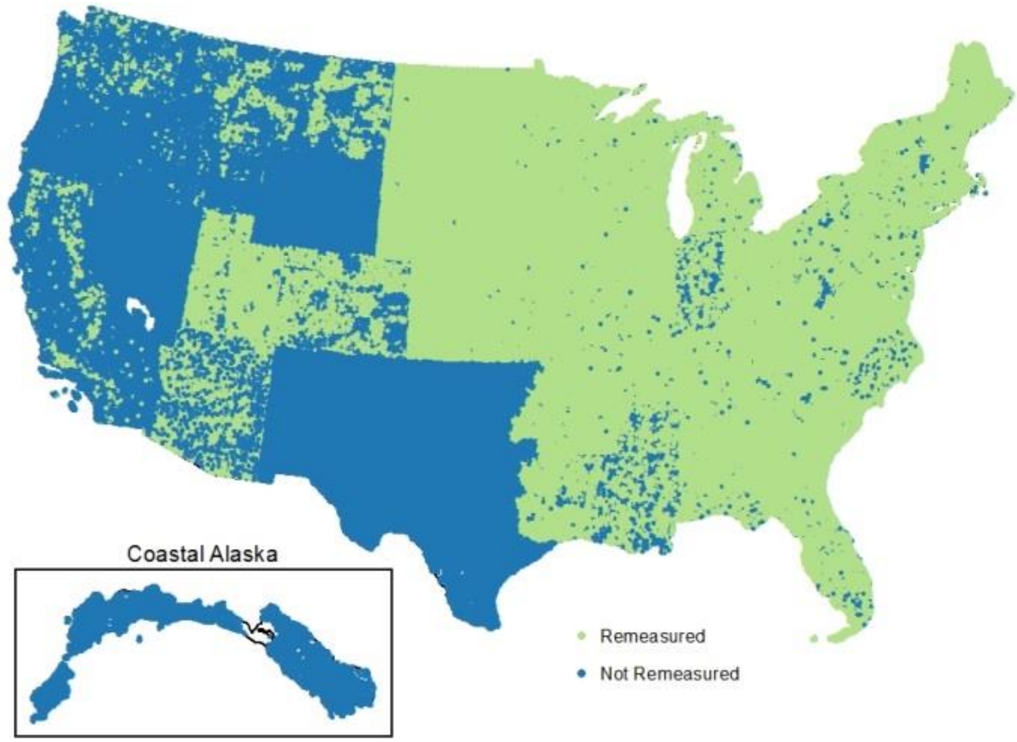
The definition of forest land within the U.S. and used for this Inventory is defined in Oswalt et al. (2014) as "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectare) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such 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, Domke et. al. In press). 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 m2. 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 6.2 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 United States (Figure A-17). 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., 2016) 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-233 and this list can be compared with the full set of summaries available for download (USDA Forest Service 2015b).

Figure A-17: Annual FIA plots (remeasured and not remeasured) across the U.S. including coastal Alaska through the 2015 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 FIA program. 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. 2016). These plots were identified as "other wooded lands" (i.e., not forest land use) and were removed from forest estimates and classified as grassland.[108] Note that minor differences in identifying and classifying 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 report (Coulston et al. 2016).

[108] See the *Grassland Remaining Grassland* section for details.

Table A-233: 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 - 2011	2006 - 2015	Alaska (Coastal)	2004 - 2008	2009 - 2013
Arkansas	2006 - 2010	2011 - 2015	Arizona	2004 - 2008	2009 - 2013
Connecticut	2005 - 2010	2010 - 2015	California	2001 - 2005	2006 - 2010
Delaware	2005 - 2010	2010 - 2015	Colorado	2004 - 2008	2009 - 2013
Florida	2002 - 2011	2010 - 2014	Idaho	2004 - 2008	2009 - 2013
Georgia	2005 - 2009	2010 - 2014	Montana	2004 - 2008	2009 - 2013
Illinois	2005 - 2010	2010 - 2015	Nevada	2004 - 2008	2009 - 2013
Indiana	2005 - 2010	2010 - 2015	New Mexico	1999	2005 - 2013
Iowa	2005 - 2010	2010 - 2015	Oklahoma (West)	2009 - 2010	2011 - 2013
Kansas	2005 - 2010	2010 - 2015	Oregon	2001 - 2005	2006 - 2010
Kentucky	2000 - 2009	2006 - 2013	Texas (West)	2004 - 2007	2008 - 2012
Louisiana	2001 - 2008	2009 - 2014	Utah	2004 - 2008	2009 - 2013
Maine	2006 - 2010	2011 - 2015	Washington	2002 - 2006	2007 - 2011
Maryland	2004 - 2009	2009 - 2014	Wyoming	2000	2011 - 2013
Massachusetts	2005 - 2010	2010 - 2015			
Michigan	2005 - 2010	2010 - 2015			
Minnesota	2006 - 2010	2011 - 2015			
Mississippi	2006	2009 - 2014			
Missouri	2005 - 2010	2010 - 2015			
Nebraska	2005 - 2010	2010 - 2015			
New Hampshire	2004 - 2010	2010 - 2015			
New Jersey	2004 - 2009	2009 - 2014			
New York	2003 - 2009	2009 - 2014			
North Carolina	2003 - 2007	2009 - 2015			
North Dakota	2005 - 2010	2010 - 2015			
Ohio	2003 - 2009	2009 - 2014			
Oklahoma (East)	2008	2010 - 2014			
Pennsylvania	2005 - 2010	2010 - 2015			
Rhode Island	2005 - 2010	2010 - 2015			
South Carolina	2002 - 2011	2009 - 2015			
South Dakota	2005 - 2010	2010 - 2015			
Tennessee	2000 - 2009	2005 - 2013			
Texas (East)	2002 - 2008	2005 - 2012			
Vermont	2005 - 2010	2010 - 2015			
Virginia	2002 - 2011	2009 - 2014			
West Virginia	2004 - 2009	2009 - 2014			
Wisconsin	2005 - 2010	2010 - 2015			

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:

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

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-234. 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:

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

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-234) are set to coefficient A, which is a C density (T C/ha) for these types only.

Table A-234: Coefficients for Estimating the Ratio of C Density of Understory Vegetation (above- and belowground, T C/ha) by Region and Forest Type

Region[b]	Forest Type[b]	A	B	Maximum ratio[c]
	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
NE	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-235. 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-236. 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-235 (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-235 (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-235: Ratio for Estimating Downed Dead Wood by Region and Forest Type

Region[a]	Forest type[a]	Ratio[b]
NE	Aspen-Birch	0.078
	MBB/Other Hardwood	0.071
	Oak-Hickory	0.068
	Oak-Pine	0.061
	Other Pine	0.065
	Spruce-Fir	0.092
	White-Red-Jack Pine	0.055
	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
PWW	Douglas-fir	0.100
	Fir-Spruce	0.090
	Other Conifer	0.073
	Other Hardwoods	0.062
	Red Alder	0.095
	Western Hemlock	0.099
	Nonstocked	0.020
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-236: 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•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 (*CSsoc*) 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 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 in 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 16th 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 (4), SOC_{20-100} = predicted SOC from 20.32 to 100 cm from model (5).

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:

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

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.

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 t0 and at a subsequent time t1=t0+s, where s is the time step (time measured in years) and is indexed by discrete (5 year) forest age classes. The inventory from t0 is then backcasted to the year 1990 (on average about 16 years) and projected from t1 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 t0 and t1. In the remainder of the regions (Pacific Coast including Alaska, west Texas, and west Oklahoma), only one inventory was available (t0) so transition matrices were derived from theory but informed by the condition of the observed inventory to backcast from t0 to 1990 and project from t0 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 ($\mathbf{T}_{\mathrm{qr}}$) 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:

$$\boldsymbol{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{pmatrix} \tag{8}$$

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:

$$\boldsymbol{T} = \begin{pmatrix} 1-t_1-d_1 & d_2 & d_3 & d_4 & d_5 \\ t_1 & 1-t_2-d_2 & 0 & 0 & 0 \\ 0 & t_2 & 1-t_3-d_3 & 0 & 0 \\ 0 & 0 & t_3 & 1-t_4-d_4 & 0 \\ 0 & 0 & 0 & t_4 & 1-d_5 \end{pmatrix} \tag{9}$$

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* ($\mathbf{T}_{\mathrm{qr}}$).

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:

$$\Delta \mathrm{C_t} = \mathrm{C_{t+m}} - \mathrm{C_t} = (\mathbf{F_t T} - \mathbf{F_t}) \cdot \mathbf{Den} + \mathbf{L_t} \cdot \mathbf{Den} \tag{10}$$

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 **F**t**T**-**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 **L**t·**Den,** where **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):

$$\boldsymbol{F}_{t-s} = \boldsymbol{F}_t \cdot \boldsymbol{B} \qquad (11)$$

B is constructed based on similar logic used for creating **T**. The matrix cannot simply be derived as the inverse of **T** ($\boldsymbol{F}_{t-s} = \boldsymbol{F}_t \boldsymbol{T}^{-1}$) 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).109 However, **B** can be constructed using observed changes from the inventory and assumptions about transition/accumulation including nonstationary elements of the transition model:

$$\boldsymbol{B} = \begin{pmatrix} 1-\sum_q d_q & \mathrm{b}_2 & 0 & 0 & 0 \\ d_1 & 1-b_2 & \mathrm{b}_3 & 0 & 0 \\ d_2 & 0 & 1-b_3 & \mathrm{b}_4 & 0 \\ d_3 & 0 & 0 & 1-b_4 & \mathrm{b}_r \\ d_4 & 0 & 0 & 0 & 1-\mathrm{b}_r \end{pmatrix} \qquad (12)$$

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

$$\boldsymbol{F}_{t-s} = \boldsymbol{F}_t \boldsymbol{B} - \boldsymbol{L}_t \qquad (13)$$

Where **Lt** is the forest area change between t1 and t0 as previously defined.

In the Rocky Mountains, age class transition matrices were empirically derived from observed changes in age classes between t0 and t1. The frequency of transitions was constructed between age classes observed at t0 and t1 to define **T** and between age classes t1 and t0 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 (**L**t) was backcasted/projected using the change in forest area observed for the period t0 to t1. 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 ΔCt=Ft·δC, 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: ΔCt+s = Ft·T·δC. 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:

[109] 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.

$$\Delta C_{t+s} = \sum_{d \in L} (A_{td} \cdot T_d \cdot \delta C_d) \quad (14)$$

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

L = (FF, NFF, FNF, Fcut, Ffire, Fweather, Fid) where FF=undisturbed forest remaining as undisturbed forest, NFF=nonforest to forest conversion, FNF=forest to nonforest conversion, Fcut=cut forest remaining as forest, Ffire=forest remaining as forest disturbed by fire, Fweather=forest remaining as forest disturbed by weather, and Fid=forest remaining as forest disturbed by insects and diseases. In the case of land transfers (FNF and NFF), Td is an n x n identity matrix and δCd 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 Ft+s or At+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 Fcut 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-237). 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).

Estimates of five HWP variables that can be used to calculate HWP contribution for the stock change and atmospheric flow approaches for imports and exports are provided in Table A-235. The HWP variables estimated are:

(1A) annual change of C in wood and paper products in use in the United States,

(1B) annual change of C in wood and paper products in SWDS in the United States,

(2A) annual change of C in wood and paper products in use in the United States and other countries where the wood came from trees harvested in the United States,

(2B) annual change of C in wood and paper products in SWDS in the United States and other countries where the wood came from trees harvested in the United States,

(3) Carbon in imports of wood, pulp, and paper to the United States,

(4) Carbon in exports of wood, pulp and paper from the United States, and

(5) Carbon in annual harvest of wood from forests in the United States. The sum of these variables yield estimates for HWP contribution under the production accounting approach.

Table A-237: 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	-35.9	-17.7	-18.3	1,895	1,249	646
1991	-33.8	-14.9	-18.8	1,929	1,264	665
1992	-33.8	-16.3	-17.4	1,963	1,280	683
1993	-32.9	-15.0	-17.9	1,996	1,295	701
1994	-33.4	-15.9	-17.5	2,029	1,311	718
1995	-32.3	-15.1	-17.2	2,061	1,326	735
1996	-30.6	-14.1	-16.5	2,092	1,340	752
1997	-32.0	-14.7	-17.3	2,124	1,355	769
1998	-31.1	-13.4	-17.7	2,155	1,368	787
1999	-32.5	-14.1	-18.4	2,188	1,382	805
2000	-30.8	-12.8	-18.0	2,218	1,395	823
2001	-25.5	-8.7	-16.8	2,244	1,404	840
2002	-26.8	-9.6	-17.2	2,271	1,414	857
2003	-25.6	-9.5	-16.2	2,296	1,423	873
2004	-28.6	-12.3	-16.3	2,325	1,435	890
2005	-28.1	-11.8	-16.3	2,353	1,447	906
2006	-29.5	-12.2	-17.3	2,382	1,459	923
2007	-28.1	-10.7	-17.4	2,411	1,470	941
2008	-20.9	-3.8	-17.1	2,431	1,474	958
2009	-14.6	2.1	-16.7	2,446	1,472	974
2010	-16.2	0.4	-16.6	2,462	1,471	991
2011	-18.3	-1.6	-16.8	2,481	1,473	1,008
2012	-17.9	-1.1	-16.9	2,498	1,474	1,025
2013	-18.9	-1.9	-17.0	2,517	1,476	1,042
2014	-20.6	-3.5	-17.1	2,538	1,479	1,059
2015	-20.8	-3.7	-17.1	2,559	1,483	1,076
2016	-	-	-	2,585	1,491	1,093

- Not reported or zero

Table A-238: Comparison of Net Annual Change in Harvested Wood Products C Stocks Using Alternative Accounting Approaches (kt CO_2 Eq./year)

HWP Contribution to LULUCF Emissions/ removals (MMT CO_2 Eq.)			
Inventory Year	Stock-Change Approach	Atmospheric Flow Approach	Production Approach
1990	(129,622)	(138,416)	(131,772)
1991	(116,345)	(131,436)	(123,758)
1992	(119,985)	(131,633)	(123,791)
1993	(126,805)	(127,819)	(120,708)
1994	(129,954)	(129,882)	(122,498)
1995	(125,981)	(128,010)	(118,411)
1996	(122,340)	(122,495)	(112,219)
1997	(131,434)	(127,378)	(117,344)
1998	(137,218)	(122,781)	(114,188)
1999	(147,057)	(127,427)	(119,182)
2000	(141,195)	(120,395)	(112,969)
2001	(125,039)	(100,417)	(93,479)
2002	(130,714)	(103,339)	(98,188)
2003	(125,812)	(98,663)	(93,967)
2004	(143,193)	(108,453)	(104,747)
2005	(142,102)	(107,342)	(103,215)
2006	(138,130)	(113,897)	(108,034)
2007	(115,181)	(111,489)	(102,984)
2008	(73,134)	(88,392)	(76,807)
2009	(41,284)	(68,789)	(53,386)

2010	(47,980)	(78,261)	(59,367)
2011	(50,802)	(90,214)	(67,279)
2012	(54,008)	(89,470)	(65,710)
2013	(64,774)	(94,413)	(69,154)
2014	(80,511)	(102,379)	(75,552)
2015	(85,209)	(102,765)	(76,356)

Table A-239: Harvested Wood Products Sectoral Background Data for LULUCF—U.S.

Inventory year	1A Annual Change in stock of HWP in use from consumption	1B Annual Change in stock of HWP in SWDS from consumption	2A Annual Change in stock of HWP in use produced from domestic harvest	2B Annual Change in stock of HWP in SWDS produced from domestic harvest	3 Annual Imports of wood, and paper products plus wood fuel, pulp, recovered paper, roundwood/ chips	4 Annual Exports of wood, and paper products plus wood fuel, pulp, recovered paper, roundwood/ chips	5 Annual Domestic Harvest	6 Annual release of C to the atmosphere from HWP consumption (from fuelwood and products in use and products in SWDS)	7 Annual release of C to the atmosphere from HWP (including firewood) where wood came from domestic harvest (from products in use and products in SWDS)	8 HWP Contribution to AFOLU CO_2 emissions/ removals
	ΔCHWP IU DC	ΔCHWP SWDS DC	ΔC HWP IU DH	ΔCHWP SWDS DH	PIM	PEX	H	↑CHWP DC	↑CHWP DH	
									kt C/yr	kt CO_2/yr
1990	17,044	18,308	17,659	18,278	12,680	15,078	142,297	104,547	106,359	(131,772)
1991	13,129	18,602	14,940	18,812	11,552	15,667	144,435	108,588	110,682	(123,758)
1992	15,718	17,006	16,334	17,427	12,856	16,032	139,389	103,489	105,627	(123,791)
1993	16,957	17,627	14,971	17,949	14,512	14,788	134,554	99,694	101,633	(120,708)
1994	18,221	17,221	15,930	17,479	15,685	15,665	134,750	99,328	101,342	(122,498)
1995	17,307	17,051	15,065	17,229	16,712	17,266	137,027	102,115	104,733	(118,411)
1996	17,018	16,348	14,092	16,513	16,691	16,733	134,477	101,069	103,872	(112,219)
1997	18,756	17,090	14,740	17,263	17,983	16,877	135,439	100,699	103,436	(117,344)
1998	19,654	17,769	13,404	17,738	18,994	15,057	134,206	100,720	103,064	(114,188)
1999	21,444	18,662	14,146	18,359	20,599	15,245	134,193	99,440	101,689	(119,182)
2000	20,000	18,508	12,840	17,970	21,858	16,185	133,694	100,859	102,884	(112,969)
2001	16,491	17,610	8,713	16,781	22,051	15,336	127,896	100,510	102,402	(93,479)
2002	17,414	18,235	9,566	17,213	23,210	15,744	126,866	98,683	100,087	(98,188)
2003	16,986	17,326	9,453	16,175	23,707	16,303	123,606	96,698	97,978	(93,967)
2004	21,409	17,644	12,273	16,294	26,428	16,953	118,852	89,274	90,284	(104,747)
2005	20,990	17,765	11,826	16,324	26,793	17,312	120,393	91,118	92,244	(103,215)
2006	19,085	18,587	12,158	17,306	25,445	18,836	118,544	87,481	89,080	(108,034)
2007	13,104	18,309	10,661	17,425	21,663	20,657	115,827	85,421	87,740	(102,984)
2008	2,434	17,512	3,825	17,122	16,997	21,159	101,525	77,418	80,577	(76,807)
2009	(5,364)	16,623	(2,098)	16,657	13,115	20,616	90,576	71,815	76,016	(53,386)
2010	(3,191)	16,277	(383)	16,574	14,162	22,420	92,792	71,448	76,601	(59,367)
2011	(2,281)	16,136	1,559	16,790	13,923	24,672	97,134	72,530	78,785	(67,279)
2012	(1,299)	16,028	1,055	16,866	13,580	23,252	99,934	75,533	82,013	(65,710)
2013	1,555	16,110	1,900	16,960	14,700	22,783	103,331	77,582	84,471	(69,154)
2014	5,600	16,358	3,535	17,070	16,881	22,845	118,155	90,233	97,550	(75,552)
2015	6,764	16,475	3,731	17,094	17,478	22,266	108,071	80,044	87,247	(76,356)

Annual estimates of variables 1A, 1B, 2A and 2B 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. In the case of variables 2A and 2B, the pools include products exported and held in other countries and the pools in the United States 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-262. 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 strongly influences the estimate of variable 1A, and to a lesser extent 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-241. Estimates of 1B and 2B also reflect the change over time in the fraction of products discarded to SWDS (versus burning or recycling) and the fraction of SWDS that are sanitary landfills versus dumps.

Variables 2A and 2B are used to estimate HWP contribution under the production accounting approach. A key assumption for estimating these variables is that products exported from the United States 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 Table A-237 and Table A-238. The decline in net additions to HWP C stocks continued through 2009 from the recent high point in 2006. This is due to sharp declines in U.S. production of solidwood and paper products in 2009 primarily due to the decline in housing construction. The low level of gross additions to solidwood and paper products in use in 2009 was exceeded by discards from uses. The result is a net reduction in the amount of HWP C that is held in products in use during 2009. For 2009 additions to landfills still exceeded emissions from landfills and the net additions to landfills have remained relatively stable. Overall, there were net C additions to HWP in use and in landfills combined.

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-240: 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-241: 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-242: Net CO_2 Flux from Forest Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT CO_2 Eq.)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Forest	**(574.7)**	**(577.4)**	**(523.0)**	**(518.3)**	**(521.3)**	**(524.6)**	**(526.3)**	**(557.3)**	**(563.8)**	**(572.2)**	**(578.9)**	**(584.5)**	**(602.0)**	**(605.0)**	**(598.5)**	**(596.1)**	**(593.7)**	**(571.1)**
Aboveground Biomass	(327.9)	(328.8)	(268.6)	(272.9)	(275.0)	(277.0)	(279.2)	(314.4)	(314.5)	(320.3)	(324.7)	(328.0)	(334.4)	(337.2)	(331.5)	(329.6)	(327.7)	(310.0)
Belowground Biomass	(70.0)	(70.2)	(56.4)	(57.4)	(57.8)	(58.2)	(58.6)	(66.6)	(66.4)	(67.5)	(68.4)	(69.0)	(70.3)	(71.0)	(69.7)	(69.2)	(68.7)	(64.6)
Dead Wood	(33.5)	(38.3)	(45.6)	(35.1)	(35.3)	(35.6)	(34.5)	(40.3)	(42.3)	(42.7)	(43.2)	(43.8)	(45.6)	(48.5)	(49.1)	(49.2)	(49.2)	(43.7)
Litter	(17.0)	(16.8)	(12.8)	(13.5)	(13.6)	(13.7)	(13.9)	(14.3)	(14.0)	(14.1)	(14.3)	(14.1)	(16.5)	(16.5)	(16.3)	(16.3)	(16.3)	(15.2)
Soil (Mineral)	(126.1)	(123.3)	(139.6)	(139.4)	(139.6)	(140.0)	(140.1)	(121.7)	(126.6)	(127.6)	(128.4)	(129.6)	(135.3)	(131.9)	(132.0)	(131.9)	(131.9)	(137.6)
Soil (Organic)	(0.1)	(0.1)	(+)	(+)	(+)	0.0	0.0	(+)	+	0.0	0.1	+	0.1	0.1	0.1	0.1	0.1	0.1
Harvested Wood	**(123.8)**	**(112.2)**	**(93.5)**	**(98.2)**	**(94.0)**	**(104.7)**	**(103.2)**	**(108.0)**	**(103.0)**	**(76.8)**	**(53.4)**	**(59.4)**	**(67.3)**	**(65.7)**	**(69.2)**	**(75.6)**	**(76.4)**	**(95.9)**
Products in Use	(54.8)	(51.7)	(31.9)	(35.1)	(34.7)	(45.0)	(43.4)	(44.6)	(39.1)	(14.0)	7.7	1.4	(5.7)	(3.9)	(7.0)	(13.0)	(13.7)	(31.4)
SWDS	(69.0)	(60.5)	(61.5)	(63.1)	(59.3)	(59.7)	(59.9)	(63.5)	(63.9)	(62.8)	(61.1)	(60.8)	(61.6)	(61.8)	(62.2)	(62.6)	(62.7)	(64.4)
Total Net Flux	**(698.5)**	**(689.6)**	**(616.5)**	**(616.5)**	**(615.2)**	**(629.3)**	**(629.5)**	**(665.4)**	**(666.8)**	**(649.0)**	**(632.3)**	**(643.9)**	**(669.3)**	**(670.7)**	**(667.6)**	**(671.6)**	**(670.0)**	**(666.9)**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.
Note: Parentheses indicate negative values.

Table A-243: Net C Flux from Forest Pools in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Forest	**(156.7)**	**(157.5)**	**(142.6)**	**(141.4)**	**(142.2)**	**(143.1)**	**(143.5)**	**(152.0)**	**(153.8)**	**(156.0)**	**(157.9)**	**(159.4)**	**(164.2)**	**(165.0)**	**(163.2)**	**(162.6)**	**(161.9)**	**(155.7)**
Aboveground Biomass	(89.4)	(89.7)	(73.3)	(74.4)	(75.0)	(75.6)	(76.2)	(85.7)	(85.8)	(87.3)	(88.5)	(89.4)	(91.2)	(92.0)	(90.4)	(89.9)	(89.4)	(84.6)
Belowground Biomass	(19.1)	(19.2)	(15.4)	(15.7)	(15.8)	(15.9)	(16.0)	(18.2)	(18.1)	(18.4)	(18.7)	(18.8)	(19.2)	(19.4)	(19.0)	(18.9)	(18.7)	(17.6)
Dead Wood	(9.1)	(10.4)	(12.4)	(9.6)	(9.6)	(9.7)	(9.4)	(11.0)	(11.5)	(11.6)	(11.8)	(11.9)	(12.4)	(13.2)	(13.4)	(13.4)	(13.4)	(11.9)
Litter	(4.6)	(4.6)	(3.5)	(3.7)	(3.7)	(3.7)	(3.8)	(3.9)	(3.8)	(3.9)	(3.9)	(3.9)	(4.5)	(4.5)	(4.4)	(4.4)	(4.4)	(4.1)
Soil (Mineral)	(34.4)	(33.6)	(38.1)	(38.0)	(38.1)	(38.2)	(38.2)	(33.2)	(34.5)	(34.8)	(35.0)	(35.3)	(36.9)	(36.0)	(36.0)	(36.0)	(36.0)	(37.5)
Soil (Organic)	(0.0)	(0.0)	(+)	(+)	(+)	0.0	0.0	(+)	+	0.0	+	+	+	+	+	+	+	+
Harvested Wood	**(33.8)**	**(30.6)**	**(25.5)**	**(26.8)**	**(25.6)**	**(28.6)**	**(28.1)**	**(29.5)**	**(28.1)**	**(20.9)**	**(14.6)**	**(16.2)**	**(18.3)**	**(17.9)**	**(18.9)**	**(20.6)**	**(20.8)**	**(26.1)**
Products in Use	(14.9)	(14.1)	(8.7)	(9.6)	(9.5)	(12.3)	(11.8)	(12.2)	(10.7)	(3.8)	2.1	0.4	(1.6)	(1.1)	(1.9)	(3.5)	(3.7)	(8.6)
SWDS	(18.8)	(16.5)	(16.8)	(17.2)	(16.2)	(16.3)	(16.3)	(17.3)	(17.4)	(17.1)	(16.7)	(16.6)	(16.8)	(16.9)	(17.0)	(17.1)	(17.1)	(17.6)
Total Net Flux	**(190.5)**	**(188.1)**	**(168.1)**	**(168.1)**	**(167.8)**	**(171.6)**	**(171.7)**	**(181.5)**	**(181.9)**	**(177.0)**	**(172.5)**	**(175.6)**	**(182.5)**	**(182.9)**	**(182.1)**	**(183.2)**	**(182.7)**	**(181.9)**

+ Absolute value does not exceed 0.05 MMT C
Note: Parentheses indicate negative values.

Table A-244 Forest area (1,000 ha) and C Stocks in *Forest Land Remaining Forest Land* and Harvested Wood Pools (MMT C)

	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Forest Area (1000 ha)	**262,119**	**263,516**	**265,022**	**267,479**	**268,044**	**268,618**	**269,163**	**269,710**	**270,258**	**270,654**	**271,064**	**271,512**	**271,812**	**272,113**	**272,260**
Carbon Pools															

Forest	**46,967**	**47,753**	**48,510**	**49,223**	**49,375**	**49,529**	**49,685**	**49,843**	**50,002**	**50,166**	**50,331**	**50,494**	**50,657**	**50,819**	**50,975**
Aboveground Biomass	11,889	12,335	12,748	13,122	13,208	13,294	13,381	13,470	13,559	13,650	13,742	13,833	13,922	14,012	14,096
Belowground Biomass	2,439	2,534	2,622	2,700	2,718	2,737	2,755	2,774	2,792	2,812	2,831	2,850	2,869	2,888	2,905
Dead Wood	2,262	2,310	2,373	2,424	2,435	2,446	2,458	2,470	2,482	2,494	2,507	2,521	2,534	2,548	2,560
Litter	2,568	2,591	2,612	2,630	2,634	2,638	2,642	2,646	2,650	2,654	2,659	2,663	2,668	2,672	2,676
Soil (Mineral)	27,456	27,630	27,804	27,994	28,027	28,062	28,097	28,132	28,167	28,204	28,240	28,276	28,312	28,348	28,385
Soil (Organic)	352	352	352	352	352	352	352	352	352	352	352	352	352	352	352
Harvested Wood	**1,895**	**2,061**	**2,218**	**2,353**	**2,382**	**2,411**	**2,431**	**2,446**	**2,462**	**2,481**	**2,498**	**2,517**	**2,538**	**2,559**	**2,585**
Products in Use	1,249	1,326	1,395	1,447	1,459	1,470	1,474	1,472	1,471	1,473	1,474	1,476	1,479	1,483	1,492
SWDS	646	735	823	906	923	941	958	974	991	1,008	1,025	1,042	1,059	1,076	1,093
Total Stock	**48,862**	**49,814**	**50,729**	**51,576**	**51,757**	**51,939**	**52,116**	**52,289**	**52,464**	**52,647**	**52,830**	**53,012**	**53,195**	**53,378**	**53,560**

Land Converted to Forest Land

The following section includes a description of the methodology used to estimate stock changes in all forest C pools for *Land Converted to Forest Land*. Forest Inventory and Analysis data and IPCC (2006) defaults for reference C stocks were used to compile separate estimates for the five C storage pools within an age class transition matrix for the 20 year conversion period (where possible). The 2009 USDA National Resources Inventory (NRI) land-use survey points were classified according to land-use history records starting in 1982 when the NRI survey began. Consequently the classifications from 1990 to 2001 were based on less than 20 years. Furthermore, the FIA data used to compile estimates of carbon sequestration in the age class transition matrix are based on 5- to 10-yr remeasurements so the exact conversion period was limited to the remeasured data over the time series. Estimates for Aboveground and Belowground Biomass, Dead wood and Litter were based on data collected from the extensive array of permanent, annual forest inventory plots and associated models (e.g., live tree belowground biomass) in the U.S. (USDA Forest Service 2015b, 2015c). Carbon conversion factors were applied at the disaggregated level of each inventory plot and then appropriately expanded to population estimates. To ensure consistency in the *Land Converted to Forest Land* category where C stock transfers occur between land-use categories, all soil estimates are based on methods from Ogle et al. (2003, 2006) and 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. See model (1) in the *Forest Land Remaining Forest Land* section of the Annex.

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-234. Regions and forest types are the same classifications described in Smith et al. (2003). An example example calculation for understory C in aspen-birch forests in the Northeast is is provided in the *Forest Land Remaining Forest Land* section of the Annex.

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-234) are set to coefficient A, which is a C density (T C/ha) for these types only.

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-235. 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-236. 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).

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 model (3) and parameters are described in the *Forest Land Remaining Forest Land* section of the Annex.

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•ha−1.

Mineral Soil

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-245 summarizes the annual change in mineral soil C stocks from U.S. soils that were estimated using a Tier 2 method (MMT C/year). The range is a 95 percent confidence interval from 50,000 simulations (Ogle et al. 2003, 2006).

Table A-246 summarizes the total land areas by land use/land use change subcategory for mineral soils between 1990 and 2015 estimated with a Tier 2 approach and based on analysis of USDA National Resources Inventory data (USDA-NRCS 2013).

Table A-245: Annual change in Mineral Soil C stocks from U.S. agricultural soils that were estimated using a Tier 2 method (MMT C/year)

Category	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cropland Converted to Forest Land	0.01	0.01	0.03	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	(0.01 to - 0.01)	(0.01 to - 0.01)	(0.03 to - 0.01)	(0.02 to -0.02)	(-0.01 to -0.02)	(-0.01 to -0.03)	(-0.01 to -0.03)	(-0.01 to -0.03)	(-0.01 to -0.02)	(-0.01 to -0.02)	(-0.01 to -0.02)	(-0.01 to -0.02)	(-0.01 to -0.02)	(-0.01 to -0.02)
Grassland Converted to Forest Land	0.03	0.05	0.09	0.06	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	(0.03 to - 0.03)	(0.05 to - 0.04)	(0.09 to - 0.04)	(0.06 to -0.05)	(-0.02 to -0.07)	(-0.02 to -0.08)	(-0.02 to -0.08)	(-0.02 to -0.09)	(-0.02 to -0.09)	(-0.02 to -0.08)	(-0.02 to -0.08)	(-0.02 to -0.09)	(-0.02 to -0.09)	(-0.02 to -0.09)
Other Lands Converted to Forest Land	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0 to 0)	(0.01 to - 0.01)	(0.02 to - 0.01)	(0.01 to -0.01)	(0 to - 0.02)	(0 to - 0.02)	(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)
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	0.00	0.00	0.00	0.00
	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(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	0.00	0.00	0.00	0.00	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)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)	(0 to 0)
Total Lands Converted to Forest Lands	**0.05**	**0.08**	**0.15**	**0.10**	**-0.02**	**-0.03**	**-0.03**	**-0.04**	**-0.03**	**-0.03**	**-0.04**	**-0.04**	**-0.04**	**-0.04**

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

Table A-246: Total land areas (hectares) by land use/land use change subcategory for mineral soils between 1990 and 2015

Conversion Land Areas (Hectares x 106)	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cropland Converted to Forest Land	0.21	0.20	0.23	0.23	0.24	0.25	0.25	0.22	0.22	0.21	0.21	0.20	0.19	0.18	0.18	0.18	0.17	0.17
Grassland Converted to Forest Land	0.71	0.79	0.85	0.88	0.85	0.81	0.78	0.72	0.70	0.67	0.64	0.62	0.59	0.57	0.60	0.60	0.60	0.60
Other Lands Converted to Forest Land	0.09	0.10	0.11	0.11	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.10	0.10	0.10	0.09
Settlements Converted to Forest Land	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Wetlands Converted to Forest Land	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
Total Lands Converted to Forest Lands	**1.04**	**1.13**	**1.23**	**1.27**	**1.25**	**1.23**	**1.20**	**1.10**	**1.08**	**1.05**	**1.01**	**0.98**	**0.94**	**0.91**	**0.91**	**0.91**	**0.90**	**0.90**

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 Ct and the variances of the estimate of C stock for time *t* as Var(Ct). These calculations follow Bechtold and Patterson (2005). The variance of stock change is then:

$$Var(Ct2\text{-}Ct1)=Var(Ct2)+Var(Ct1)\text{-}2\cdot Cov(Ct2,Ct1) \qquad (15)$$

The uncertainty of a stock estimate associated with sampling error is U(Ct)s= Var(Ct)0.5. The uncertainty of a stock changes estimate associated with sampling error is U(ΔC)s=Var(Ct2-Ct1)0.5.

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

$$\%U(Ct)m = 100\cdot MSEm/dt \qquad (16)$$

Where dt is the total C stock density at time t calculated as Ct/At where At is the forest area at time *t*.

The uncertainty of Ct from modeling error is

$$U(Ct)m=Ct\cdot\%U(Ct)m/100 \qquad (17)$$

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

$$U(\Delta C)m=(\ U(Ct1)m + U(Ct2)m\ \text{-}\ 2\cdot Cov(U(Ct1m,Ct2m)))0.5 \qquad (18)$$

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):

$$U(\Delta C)=(\ U(\Delta C)m2+\ U(\Delta C)s2)0.5 \text{ and the 95 percent confidence bounds was } +\text{-}\ 2\cdot\ U(\Delta C) \qquad (19)$$

The mean square error (MSE) of pool models was (MSE, $[Mg\ C/ha]^2$): soil C (1143.0), 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_2O 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:

$$\text{Emissions} = \text{Area burned} \times \text{Fuel available} \times \text{Combustion factor} \times \text{Emission factor} \times 10^{-3} \qquad (20)$$

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,[110] 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.[111] 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 United States. 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 United States 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 2015 in U.S. EPA (2016). 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

[110] See <http://www.mtbs.gov/dataaccess.html>.
[111] 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; U.S. 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[112] 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-247 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-248. 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-247, and C emitted per year (Table A-247 and Table A-250) was based on multiplying by the conversion factor 12/44 (IPCC 2006).

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

Table A-247: Areas (Hectares) from Wildfire Statistics and Corresponding Estimates of C and CO_2 (MMT/year) Emissions for Wildfires and Prescribed Fires[a]

		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015[b]
Conterminous 48 States - Wildfires	Reported area burned (1000 ha)	462.8	544.0	2,257.6	1,723.9	3,603.2	3,219.6	1,608.5	1,489.9	579.2	3,187.2	3,421.8	1,092.1	1,994.5	1,994.5
	Forest area burned (1000 ha)	184.2	128.7	1,016.2	603.3	946.2	1,488.2	724.4	493.5	142.6	1,242.1	1,451.7	640.0	679.0	679.0
	C emitted (MMT/yr)	6.2	2.5	26.5	11.9	27.5	41.9	26.6	10.8	3.5	22.2	37.6	18.5	23.3	23.3
	CO_2 emitted (MMT/yr)	22.7	9.2	97.3	43.5	100.9	153.8	97.6	39.7	13.0	81.3	138.0	68.0	85.3	85.3
Alaska - Wildfires	Reported area burned (1000 ha)	546.5	11.7	311.3	1,950.1	98.7	217.5	26.4	1,078.3	257.4	90.1	90.9	454.7	90.8	90.8
	Forest area burned (1000 ha)	303.4	10.0	160.9	1,253.8	80.3	80.1	16.8	682.8	175.0	55.0	41.6	347.1	75.6	75.6
	C emitted (MMT/yr)	5.3	0.2	2.8	21.9	1.4	1.4	0.3	12.1	3.1	1.0	0.7	6.1	1.3	1.3
	CO_2 emitted (MMT/yr)	19.5	0.6	10.4	80.1	5.1	5.1	1.1	44.4	11.3	3.6	2.7	22.3	4.9	4.9
Prescribed Firesa (all 49 states)	Reported area burned (1000 ha)	10.3	16.0	83.1	107.1	108.5	156.5	319.3	407.9	763.9	993.7	149.6	275.8	311.5	311.5
	Forest area burned (1000 ha)	6.1	10.9	22.7	62.1	79.8	96.3	251.1	317.8	657.3	242.9	110.4	268.6	282.5	282.5
	C emitted (MMT/yr)	0.0	0.1	0.2	0.3	0.6	0.6	1.6	2.2	5.1	1.6	0.8	1.5	1.7	1.7
	CO_2 emitted (MMT/yr)	0.2	0.2	0.6	1.3	2.1	2.2	6.0	7.9	18.5	6.0	3.0	5.5	6.1	6.1
Wildfires (all 49 states)	CH_4 emitted (kt/yr)	127.1	29.8	320.3	373.8	319.7	478.8	284.4	251.4	72.7	254.7	422.6	272.4	273.7	273.7
	N_2O emitted (kt/yr)	6.9	1.6	17.8	20.5	17.7	26.3	15.9	13.8	4.0	14.2	23.3	14.9	15.0	15.0
	CO emitted (kt/yr)	2,820.2	694.4	7,264.9	8,400.6	7,168.7	10,556.4	6,418.4	5,711.1	1,664.8	5,730.1	9,612.4	6,276.2	6,220.0	6,220.0
	NO_x emitted (kt/yr)	79.7	19.5	207.4	236.6	202.9	294.4	179.6	158.0	46.2	160.3	270.0	174.3	176.3	176.3
Prescribed Firesa (all 49 states)	CH_4 emitted (kt/yr)	0.5	0.7	1.8	3.8	6.3	6.7	17.2	23.6	55.5	18.0	8.9	16.4	18.6	18.6
	N_2O emitted (kt/yr)	0.0	0.0	0.1	0.2	0.3	0.4	1.0	1.3	3.1	1.0	0.5	0.9	1.0	1.0
	CO emitted (kt/yr)	11.7	16.7	40.0	85.3	141.5	147.4	389.0	536.1	1,271.3	405.4	202.3	379.0	422.2	422.2
	NO_x emitted (kt/yr)	0.3	0.5	1.1	2.4	4.0	4.1	10.9	14.8	35.3	11.3	5.7	10.5	12.0	12.0

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

Table A-248: 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-250). 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-249, which also includes the estimates for managed forest land (both wildland and prescribed) that underlie the values provided in Table A-247. 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-249, 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-249: 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 gases–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-248. The summed annual estimates are provided in Table A-250. 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-248. An example application of these ratios for the current year's estimate of CH_4 emissions is: 7.34 MMT CO_2 Eq. = 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 the *2006 IPCC Guidelines* (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; U.S. 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-248) to represent estimates as CO_2 equivalent were not considered uncertain values for these results.

Table A-250: Estimated C Released and Estimates of Non-CO_2 Emissions (MMT/year) for U.S. forests

Year	C Emitted (MMT/yr)	CH_4 Emitted (MMT/yr)	N_2O (MMT/yr)
1990	42,358	128	7
1991	48,673	145	8
1992	21,699	64	4
1993	11,978	36	2
1994	77,051	231	13
1995	10,108	31	2
1996	50,857	152	8
1997	6,518	20	1
1998	28,247	84	5
1999	64,165	192	11
2000	108,225	322	18
2001	56,252	168	9
2002	154,090	460	25
2003	87,643	262	15
2004	151,670	452	25
2005	124,903	378	21
2006	108,114	326	18
2007	161,151	486	27
2008	104,612	302	17
2009	92,011	275	15
2010	42,803	128	7
2011	90,868	273	15
2012	143,614	431	24
2013	95,743	289	16
2014	96,271	292	16
2015[a]	96,271	292	16

[a] The data for 2015 were incomplete when these estimates were summarized; therefore 2014, the most recent available estimate, is applied to 2015.

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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.[113] 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.[114]

Methane emissions from landfills can be estimated using two primary methods. The first method uses the first order decay model as described by the *2006 IPCC Guidelines* to estimate CH_4 generation. The amount of CH_4 recovered and combusted from MSW landfills is subtracted from the CH_4 generation, and is then adjusted with an oxidation factor. The oxidation factor represents the amount of CH_4 in a landfill that is oxidized to CO_2 as it passes through the landfill cover (e.g., soil, clay, geomembrane, alternative daily cover). Annual CH_4 generation using the first order decay methodology 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 second method used to calculate CH_4 emissions from landfills, also called the back calculation method, is based off of directly measured amounts of recovered CH_4 from the landfill gas and is expressed below and by Equation HH-8 in CFR Part 98.343 of the EPA's Greenhouse Gas Reporting Program (GHGRP). The two parts of the equation consider the portion of CH_4 in the landfill gas that is not collected by the landfill gas collection system; and the portion that is collected. First, the recovered CH_4 is adjusted with the collection efficiency of the gas collection and control system and the fraction of hours the recovery system operated in the calendar year. This quantity represents the amount of CH_4 in the landfill gas that is not captured by the collection system; it is then adjusted for oxidation. The second portion of the equation adjusts the portion of CH_4 in the collected landfill gas with the efficiency of the destruction device(s), and the fraction of hours the destruction device(s) operated during the year.

$$CH_4\text{,Solid Waste} = [\left(\frac{R}{CE\ x\ f_{REC}} - R\right) x(1 - OX) + R\ x\ \left(1 - (DE\ x\ f_{Dest})\right)]$$

Where,

R	= Quantity of recovered CH_4 from Equation HH-4 of the EPA's GHGRP
CE	= Collection efficiency estimated at the landfill, taking into account system coverage, operation, and cover system materials from Table HH-3 of the EPA's GHGRP. If area by soil cover type information is not available, the default value of 0.75 should be used. (percent)
fREC	= fraction of hours the recovery system was operating (percent) OX = oxidation factor (percent)
DE	= destruction efficiency (percent)
fDest	= fraction of hours the destruction device was operating (fraction)

The current Inventory methodology uses both methods to estimate CH_4 emissions across the time series. In previous Inventories, only the first order decay method was used. Methodological changes have been made to this Inventory to incorporate higher tier data (i.e., directly reported CH_4 emissions to EPA's GHGRP), which cannot be directly applied to earlier years in the time series without significant bias. The overlap technique, as described in the Methodological Recalculations section of this Inventory, and in the Time-Series Consistency chapter of the *2006 IPCC Guidelines*, was used to merge the higher tier data with the previously used method.

To estimate the amount of CH_4 generated in a landfill in a given year, information is needed on the quantity and composition of the waste in the landfill for multiple decades, as well as the landfill characteristics (e.g., size, aridity, waste density). Estimates and/or directly measured amounts of waste placed in municipal solid waste (MSW) and industrial waste landfills are available through various studies, surveys, and regulatory reporting programs (i.e., EPA's GHGRP). The composition of the amount of waste placed in these landfills is not readily available for most years the landfills were in operation. Consequently, and for the purposes of estimating CH_4 generation, the Inventory methodology assumes that all

[113] 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.

[114] 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.

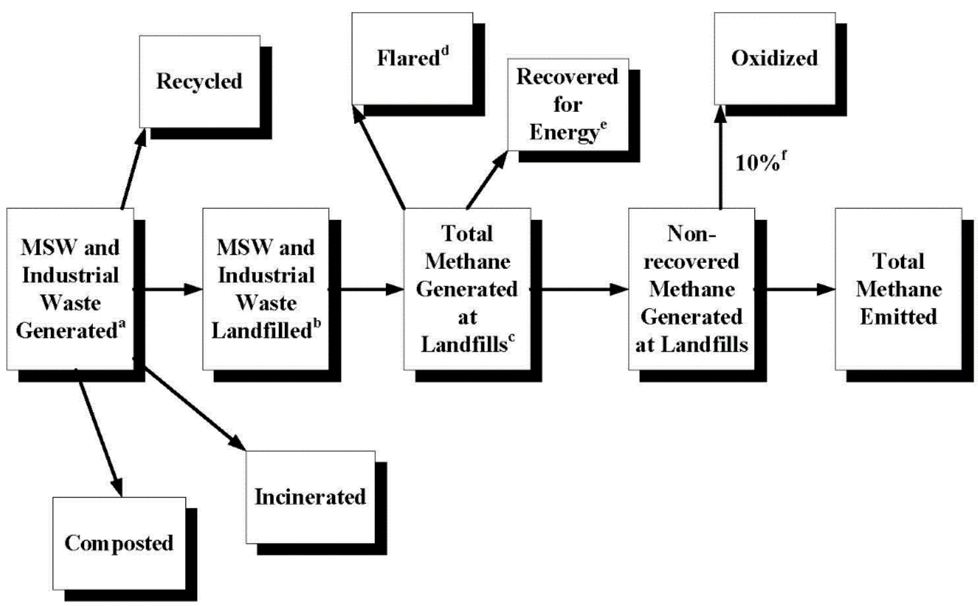
waste placed in MSW landfills is bulk MSW, and that all waste placed in industrial waste landfills is from either pulp and paper manufacturing facilities or food and beverage facilities.

A major methodological change was made for the current Inventory. Previous Inventories relied exclusively on the first order decay methodology. The current Inventory relies on directly reported net CH_4 emissions from the GHGRP data for MSW landfills for current and a portion of historical years (from 2005 to the current Inventory year), and on the first order decay methodology for years prior to 2005. The first order decay methodology relies on the annual quantity of waste placed in landfills nationwide, parameters from an analysis of measured CH_4 generation rates for U.S. landfills, and CH_4 recovery data for landfills with gas recovery systems. The first order decay model was applied to annual waste disposal estimates for each year (up to 2004) and for three ranges of precipitation to estimate CH_4 generation rates nationwide for the years of interest. Methane emissions from industrial waste landfills were also estimated using the first order decay model. A default fraction of industrial wastes disposed in these landfills was estimated from the organic content of the wastes; facility-specific landfill disposal information is not available for all industrial waste landfills.

For years 1990 to 2004, total CH_4 emissions in a given year 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[115] and the amount oxidized in the soil at MSW and industrial landfills. As noted in the previous paragraph, directly reported net CH_4 emissions from the GHGRP data for MSW landfills were used for the years 2010 to 2015. The GHGRP data was also used to back-cast net CH_4 emissions for MSW landfills for 2005 to 2009. 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-18 presents the CH_4 emissions process—from waste generation to emissions—in graphical format. The remaining sections summarize the steps taken to estimate CH_4 emissions from MSW and industrial waste landfills. The steps and methodology are described starting from 2015 and working backwards through the time series (i.e., back to 1990).

Figure A-18: 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 2015 based on EREF 2016.
[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.

[115] 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 EPA's GHGRP have active landfill gas collection systems.

Step 1: Estimate Annual Quantities of Solid Waste Placed in MSW Landfills for 1940 to 2004

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).

For 1989 to 2004, 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 (BioCycle 2010) and recent data from the Environmental Research & Education Foundation (EREF), adjusted to include U.S. territories.[116] The SOG surveys and EREF (2016) provide state-specific landfill waste generation data and a national average disposal factor back to 1989. The SOG survey is no longer updated, but is available every two years for the years 2002, 2004, 2006, and 2008 (as published in BioCycle 2006; 2008, and 2010). EREF recently published a report using a similar methodology as the SOG surveys and plans to publish updated reports every three years. EREF data are available for years 2010 and 2013 (EREF 2016). A linear interpolation was used for the amount of waste generated in 2001, 2003, 2005, 2007, 2009, 2011, 2012; data were extrapolated for 2014 and 2015 based on national population growth because no data are available from these sources for those years. Upon publication of the next EREF report, the waste landfilled for 2014 to the current Inventory year 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. A waste disposal factor is determined for each year a SOG survey and EREF report is published and is the ratio of the total amount of waste landfilled to the total amount of waste generated. The waste disposal factor is interpolated for the years in-between the SOG surveys and EREF data, and extrapolated for years after the last year of data. 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.

Table A-251 shows estimates of waste quantities contributing to CH_4 emissions. The table shows SOG and EREF (EREF 2016) estimates of total waste generated and total waste landfilled (adjusted for U.S. territories) for various years over the 1990 to 2015 timeframe even though the Inventory methodology does not use the data for 2005 onward.

Table A-251: Solid Waste in MSW and Industrial Waste Landfills Contributing to CH_4 Emissions (MMT unless otherwise noted)

	1990	2000	2005	2010	2011	2012	2013	2014	2015
Total MSW Generated[a]	270	377	368	315	317	319	319	320	318
Percent of MSW Landfilled	77%	61%	64%	65%	63%	63%	64%	64%	64%
Total MSW Landfilled	**205**	**226**	**234**	**202**	**199**	**200**	**201**	**202**	**203**
MSW last 30 years	4,876	5,589	5,992	6,335	6,362	6,388	6,411	6,432	6,451
MSW since 1940[b]	6,808	8,787	9,925	11,075	11,274	11,474	11,675	11,878	12,081
Total Industrial Waste Landfilled	**9.7**	**11.4**	**10.9**	**10.4**	**10.5**	**10.5**	**10.4**	**10.3**	**10.5**
Food and Beverage Sector[c]	6.4	7.1	6.9	6.3	6.3	6.2	6.1	6.0	6.2
Pulp and Paper Sector[d]	3.3	4.3	4.0	4.1	4.2	4.2	4.2	4.2	4.2

[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* 2001, 2004, 2006, and 2010 for years 1989 to 2014 (1989, 1991 to 1999, and 2006 to 2009 are not presented in table). Values for years 2010 to 2015 are based on EREF (2016) and annual population data from the U.S. Census Bureau.
[b] 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* 2001, 2004, 2006, and 2010; and EREF 2016.
[c] Food production values for 1990 to 2015 are from ERG - inventory for Industrial Wastewater sector. USDA-NASS Agricultural Statistics 1995-2012, USDA-NASS QuickStats 2.0 (http://quickstats.nass.usda.gov/, (http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/).
[d] Production data from 1990 and 2000 are from Lockwood-Post's Directory, 2002. Production data from 2005, 2010-2014 from the FAOStat database available at: http://faostat3.fao.org/home/index.html#DOWNLOAD, Accessed on July 18, 2016. Production data form 2015 are extrapolated based on population growth and the Inventory disposal factor.

Step 2: Estimate CH_4 Generation at MSW Landfills for 1990 to 2004

The first order decay method is exclusively used for 1990 to 2004. For the first order decay method, methane generation is based on nationwide MSW generation data, to which a national average disposal factor is applied; it was not

[116] 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).

landfill-specific. Directly reported CH_4 emissions from EPA's GHGRP are used for years they are available (i.e., 2010 to 2015), and then back-casted for years 2005 to 2009. Landfill facilities reporting to EPA's GHGRP use a combination of the first order decay method and the back-calculation method to develop their CH_4 emissions values. Landfills reporting to EPA's GHGRP without gas collection and control apply the first order decay method, while the landfills with gas collection and control may apply either the first order decay method or the back-calculation method, whichever is most appropriate for their site-specific landfill condition. It should be noted that the majority of landfills with gas collection report using the back-calculation method.

The first order decay method is presented below, and is similar to Equation HH-5 in CFR Part 98.343 for MSW landfills, and Equation TT-6 in CFR Part 98.463 for industrial waste landfills.

$$CH_{4,\text{Solid Waste}} = [CH_{4,\text{MSW}} + CH_{4,\text{Ind}} - R] - Ox$$

where,

$CH_{4,\text{Solid Waste}}$	=	Net CH_4 emissions from solid waste
$CH_{4,\text{MSW}}$	=	CH_4 generation from MSW landfills
$CH_{4,\text{Ind}}$	=	CH_4 generation from industrial landfills
R	=	CH_4 recovered and combusted (only for MSW landfills)
Ox	=	CH_4 oxidized from MSW and industrial waste landfills before release to the atmosphere

The input parameters needed for the FOD model equations are the mass of waste disposed each year (discussed under Step 1), degradable organic carbon (DOC), and the decay rate constant (k). The equation below provides additional detail on the activity data and emission factors used in the $CH_{4,\text{MSW}}$ equation presented above.

$$CH_{4,\text{MSW}} = \left[\sum_{x=S}^{T-1}\left\{W_x \times Lo \times \frac{16}{12} \times \left(e^{-k(T-x-1)} - e^{-k(T-x)}\right)\right\}\right]$$

where,

G_{CH4}	=	Total amount of CH_4 generated
T	=	Reporting year for which emissions are calculated
x	=	Year in which waste was disposed
S	=	Start year of calculation
W_x	=	Quantity of waste disposed of in the landfill in a given year
L_o	=	Methane generation potential (100 m^3 CH_4/Mg waste; EPA 1998, 2008)
16/12	=	conversion factor from CH_4 to C
k	=	Decay rate constant (yr^{-1}, see Table A-273)

The DOC is determined from the CH_4 generation potential (L_0 in m^3 CH_4/Mg waste) as shown in 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 (100 m^3 CH_4/Mg waste; EPA 1998, 2008),
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).

DOC values can be derived for individual landfills if a good understanding of the waste composition over time is known. A default DOC value is used in the Inventory because waste composition data are not regularly collected for all landfills nationwide. When estimating CH_4 generation for the years 1990 to 2004, a default DOC value is used. This DOC value is calculated from a national CH_4 generation potential[117] of 100 m^3 CH_4/Mg waste (EPA AP-42) as described in the next few paragraphs.

The DOC value used in the CH_4 generation estimates from MSW landfills is 0.2028, and is based on the CH_4 generation potential of 100 m^3 CH_4/Mg waste (EPA 1998; EPA 2008). After EPA developed the L_o value, RTI analyzed data from a set of 52 representative landfills across the U.S. in different precipitation ranges to evaluate L_o, and ultimately the national 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 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 for years 1990-2004, and is the value used to derive the DOC value of 0.2028.

In 2004, the FOD model was also applied to the gas recovery data for the 52 landfills to calculate a decay rate constant (k) directly for L_0 = 100 m^3/Mg. The decay rate constant was found to increase with annual average precipitation; consequently, average values of k were developed for three precipitation ranges, shown in Table A-252 and recommended in EPA's compilation of emission factors (EPA 2008).

Table A-252: 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 versus 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 2010. 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-253.

Table A-253: 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.

The *2006 IPCC Guidelines* also require annual proportions of waste disposed of in managed landfills versus open dumps prior to 1980. 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

[117] Methane generation potential (L_o) varies with the amount of organic content of the waste material. A higher L_o occurs with a higher content of organic waste.

recommended IPCC default value for the MCF for managed landfills of 1 (IPCC 2006) has been used for the managed landfills for the years where the first order decay methodology was used (i.e., 1990 to 2004).

Step 3: Estimate CH_4 Generation at Industrial Waste Landfills for 1990 to the Current Inventory Year

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). In 2005, 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 2015. 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 2014 (ERG 2016). An extrapolation based on U.S. population was used for the years 1940 through 1989, and for the year 2015.

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 waste landfills: 1) quantity of waste that is disposed in industrial waste landfills (as a function of production), 2) CH_4 generation potential (L_0) from which a DOC value can be calculated, 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.[118] 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 EPA's 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 from MSW Landfills for 1990 to 2004

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

[118] 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.

- 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 2016a), and
- the flare vendor database (contains updated sales data collected from vendors of flaring equipment).

The fourth database, the EPA's GHGRP MSW landfills database, was first introduced as a data source for the 1990 to 2013 Inventory and only the annual amounts of CH_4 recovered were used. In the current Inventory, directly reported net CH_4 emissions data are used, which includes data on the facility-specific amounts of CH_4 recovered. 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.

For 1990-2004, a destruction efficiency of 99 percent was applied to amounts of CH_4 recovered to estimate CH_4 emissions avoided for the three databases with data available for those years. 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 2016a); and (3) the GHGRP MSW landfills dataset (EPA 2016b). 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 EPA's GHGRP for years 2010 through 2015, 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 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.

To avoid double-counting CH_4 recovery, a hierarchical approach is applied after matching landfills in one database to the other 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. The EIA database only includes facility-reported data through 2006; the amount of CH_4 recovered in this database for years 2007 and later were assumed to be the same as in 2006. Nearly all (93 percent) of landfills in the EIA database also report to EPA'sGHGRP.

If both the flare data and LFGTE recovery data were available for any of the remaining landfills (i.e., not in the EIA or EPA's GHGRP databases), then the CH_4 recovered 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 recent 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, EPA's GHGRP, or LFGTE databases). Several vendors have provided information on the size of the flare rather than the flare design gas flow rate for most years of the Inventory. Flares sales data has not been obtained for the past three Inventory years.

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

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 EPA's 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 EPA's 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 from MSW and Industrial Waste Landfills

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 Guidelines for managed and covered landfills, and was therefore applied to the estimates of CH_4 generation minus recovery for both MSW and industrial waste landfills for years 1990 to 2004. For years 2005 to 2015, directly reported CH_4 emissions to EPA's GHGRP, which include the adjustment for oxidation, are used. EPA's GHGRP allows facilities to use a range of oxidation factors: 0.0, 0.10, 0.25, 0.35.

In 2011, a literature review was conducted (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 for the years 1990 to 2004.

Step 6: Estimate Total CH_4 Emissions

For 1990 to 2004, 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-254. As stated earlier, directly reported CH_4 emissions to EPA's GHGRP are directly used for years 2010 to 2015, and also used to back-cast emissions for 2005 to 2009. The net emissions for years 2005 to 2015 are not the sum of the rows above; data for these years include directly reported GHGRP data, whereas the other rows are outputs from the first order decay methodology.

EPA's GHGRP requires landfills meeting or exceeding a threshold of 25,000 metric tons of CH_4 generation per year to report a variety of facility-specific information, including historical and current waste disposal quantities by year, CH_4 generation, gas collection system details, CH_4 recovery, and CH_4 emissions. EPA's GHGRP provides a consistent methodology, a broader range of values for the oxidation factor, and allows for facility-specific annual waste disposal data to be used, thus these data are considered Tier 3 (highest quality data) under the *2006 IPCC Guidelines*. This is the first Inventory that incorporates directly reported GHGRP net CH_4 emissions data. Using the GHGRP data is a methodological change and required a merging of the GHGRP methodology with the Inventory methodology used in previous years to ensure time-series consistency.

First, and for completeness, a scale-up factor was applied to the net CH_4 emissions from EPA's GHGRP. The landfills reporting to EPA's GHGRP are considered the largest emitters, but not all landfills are required to report. For this Inventory, EPA has applied a scale-up factor of 12.5 percent to the GHGRP net CH_4 emissions to account for the non-reporting landfills. This scale-up factor may be revised in future years after a thorough review of available data for the non-reporting landfills is completed. The value of the scale-up factor was determined after plotting net CH_4 emissions across the entire time series (1990 to 2015) generated using the previous Inventory methodology against different methodological scenarios with various scale-up factors. For most years across the time series, a 12.5 percent scale-up factor resulted in an overlapping of the net emissions data for several years where the methodology switches to the directly reported GHGRP data (2010 and later).

The EPA also investigated various back-casting approaches to estimate CH_4 emissions throughout the entire time series (back to 1990) while relying solely on the GHGRP emissions data. Back-casting CH_4 emissions back to 1990 with a limited set of data is not recommended in Volume 1: Chapter 5 of the *2006 IPCC Guidelines*, which provides best practices for time-series consistency when implementing methodological changes and refinements. Plotting the back-casted GHGRP emissions against the emissions estimates from the previously used method showed an alignment of the data in 2004 and later years. The *2006 IPCC Guidelines* recommend using a splicing technique if the data overlap for a period of years as the data do with the revised methodology. Therefore, EPA decided to back-cast the GHGRP emissions from 2009 to 2005 only, while also applying the 12.5 percent scale-up factor to the back-casted GHGRP data. .

Table A-254: CH_4 Emissions from Landfills (kt)

	1990		1995		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MSW CH_4 Generation	8,214		9,140		10,270	10,477	10,669	-	-	-	-	-	-	-	-	-	-	-
Industrial CH_4 Generation	484		537		618	625	629	636	639	643	648	653	656	657	659	661	662	662
MSW CH_4 Recovered	**(718)**		**(1,935)**		**(4,894)**	**(4,995)**	**(5,304)**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
MSW CH_4 Oxidized	(750)		(720)		(538)	(548)	(537)	-	-	-	-	-	-	-	-	-	-	-
Industrial CH_4 Oxidized	(48)		(54)		(62)	(63)	(63)	(64)	(64)	(64)	(65)	(65)	(66)	(66)	(66)	(66)	(66)	(66)
MSW Net CH_4 Emissions (GHGRP)	**-**		**-**		**-**	**-**	**-**	**4,800**	**4,717**	**4,635**	**4,553**	**4,471**	**4,513**	**4,169**	**4,241**	**4,074**	**4,067**	**4,032**
Net Emissions[a]	**7,182**		**6,967**		**5,394**	**5,496**	**5,395**	**5,372**	**5,292**	**5,213**	**5,136**	**5,058**	**5,103**	**4,760**	**4,834**	**4,669**	**4,663**	**4,628**

Notes: MSW and Industrial CH_4 generation in Table A-248 represents emissions before oxidation. Totals may not sum exactly to the last significant figure due to rounding. Parentheses denote negative values.

[a] MSW Net CH_4 emissions for years 2005 to 2015 are directly reported CH_4 emissions to the EPA's GHGRP for MSW landfills. The other rows are calculate by the first order decay methodology.

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