7. Land Use, Land-Use Change, and Forestry

This chapter provides an assessment of the net greenhouse gas flux[1] resulting from the uses and changes in land types and forests in the United States. The Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003) recommends reporting fluxes according to changes within and conversions between certain land-use types, termed forest land, cropland, grassland, and settlements (as well as wetlands). The greenhouse gas flux from *Forest Land Remaining Forest Land* is reported using estimates of changes in forest carbon (C) stocks, non-carbon dioxide (CO_2) emissions from forest fires, and the application of synthetic fertilizers to forest soils. The greenhouse gas flux reported in this chapter from agricultural lands (i.e., cropland and grassland) includes changes in organic C stocks in mineral and organic soils due to land use and management, and emissions of CO_2 due to the application of crushed limestone and dolomite to managed land (i.e., soil liming) and urea fertilization. Fluxes are reported for four agricultural land use/land-use change categories: *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*. Fluxes resulting from *Settlements Remaining Settlements* include those from urban trees and soil fertilization. Landfilled yard trimmings and food scraps are accounted for separately under *Other*.

The estimates in this chapter, with the exception of CO_2 fluxes from wood products and urban trees, and CO_2 emissions from liming and urea fertilization, are based on activity data collected at multiple-year intervals, which are in the form of forest, land-use, and municipal solid waste surveys. CO_2 fluxes from forest C stocks (except the wood product components) and from agricultural soils (except the liming component) are calculated on an average annual basis from data collected in intervals ranging from 1 to 10 years. The resulting annual averages are applied to years between surveys. Calculations of non-CO_2 emissions from forest fires are based on forest CO_2 flux data. Agricultural mineral and organic soil C flux calculations are based primarily on national surveys, so these results are largely constant over multi-year intervals, with large discontinuities between intervals. For the landfilled yard trimmings and food scraps source, periodic solid waste survey data were interpolated so that annual storage estimates could be derived. In addition, because the most recent national forest, and land-use surveys were completed prior to 2005, the estimates of CO_2 flux from forests, agricultural soils, and landfilled yard trimmings and food scraps are based in part on extrapolation. CO_2 flux from urban trees is based on neither annual data nor periodic survey data, but instead on data collected over the period 1990 through 1999. This flux has been applied to the entire time series, and periodic U.S. census data on changes in urban area have been used to develop annual estimates of CO_2 flux.

Land use, land-use change, and forestry activities in 2006 resulted in a net C sequestration of 883.7 Tg CO_2 Eq. (241.0 Tg C) (Table 7-1 and Table 7-2). This represents an offset of approximately 14.8 percent of total U.S. CO_2 emissions. Total land use, land-use change, and forestry net C sequestration[2] increased by approximately 20 percent between 1990 and 2006. This increase was primarily due to an increase in the rate of net C accumulation in forest C stocks. Net C accumulation in *Settlements Remaining Settlements*, *Land Converted to Grassland*, and *Cropland Remaining Cropland* increased, while net C accumulation in landfilled yard trimmings and food scraps slowed over this period. The *Grassland Remaining Grassland* land-use category resulted in a net C sink from 1990 through 1994 and then remained a fairly constant emission source. Emissions from *Land Converted to Cropland* declined between 1990 and 2006.

Table 7-1: Net CO_2 Flux from Carbon Stock Changes in Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

---

[1] The term “flux” is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal of C from the atmosphere. Removal of C from the atmosphere is also referred to as “carbon sequestration.”

[2] Carbon sequestration estimates are net figures. The C stock in a given pool fluctuates due to both gains and losses. When losses exceed gains, the C stock decreases, and the pool acts as a source. When gains exceed losses, the C stock increases, and the pool act as a sink. This is also referred to as net C sequestration.

Sink Category	1990	1995	2000	2001	2002	2003	2004	2005	2006
Forest Land Remaining Forest Land[1]	(621.7)	(659.9)	(550.7)	(623.4)	(697.3)	(730.9)	(741.4)	(743.6)	(745.1)
Cropland Remaining Cropland	(30.1)	(39.4)	(38.4)	(40.0)	(40.3)	(40.5)	(40.9)	(41.0)	(41.8)
Land Converted to Cropland	14.7	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4
Grassland Remaining Grassland	(1.9)	16.6	16.4	16.4	16.4	16.4	16.3	16.3	16.2
Land Converted to Grassland	(14.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)	(16.3)
Settlements Remaining Settlements[2]	(60.6)	(71.5)	(82.4)	(84.6)	(86.8)	(88.9)	(91.1)	(93.3)	(95.5)
Other (Landfilled Yard Trimmings and Food Scraps)	(23.9)	(14.1)	(11.5)	(11.6)	(11.8)	(10.0)	(9.6)	(10.0)	(10.5)
Total	**(737.7)**	**(775.3)**	**(673.6)**	**(750.2)**	**(826.8)**	**(860.9)**	**(873.7)**	**(878.6)**	**(883.7)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

[1] Estimates include C stock changes on both Forest Land Remaining Forest Land and Land Converted to Forest Land.

[2] Estimates include C stock changes on both Settlements Remaining Settlements and Land Converted to Settlements.

Table 7-2: Net CO_2 Flux from Carbon Stock Changes in Land Use, Land-Use Change, and Forestry (Tg C)

Sink Category	1990	1995	2000	2001	2002	2003	2004	2005	2006
Forest Land Remaining Forest Land[1]	(169.6)	(180.0)	(150.2)	(170.0)	(190.2)	(199.3)	(202.2)	(202.8)	(203.2)
Cropland Remaining Cropland	(8.2)	(10.7)	(10.5)	(10.9)	(11.0)	(11.0)	(11.1)	(11.2)	(11.4)
Land Converted to Cropland	4.0	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Grassland Remaining Grassland	(0.5)	4.5	4.5	4.5	4.5	4.5	4.5	4.4	4.4
Land Converted to Grassland	(3.9)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)	(4.5)
Settlements Remaining Settlements[2]	(16.5)	(19.5)	(22.5)	(23.1)	(23.7)	(24.3)	(24.9)	(25.4)	(26.0)
Other (Landfilled Yard Trimmings and Food Scraps)	(6.5)	(3.9)	(3.1)	(3.2)	(3.2)	(2.7)	(2.6)	(2.7)	(2.9)
Total	**(201.2)**	**(211.4)**	**(183.7)**	**(204.6)**	**(225.5)**	**(234.8)**	**(238.3)**	**(239.6)**	**(241.0)**

Note: 1 Tg C = 1 teragram C = 1 million metric tons C. Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

[1] Estimates include C stock changes on both Forest Land Remaining Forest Land and Land Converted to Forest Land.

[2] Estimates include C stock changes on both Settlements Remaining Settlements and Land Converted to Settlements.

Emissions from Land Use, Land-Use Change, and Forestry are shown in Table 7-3 and Table 7-4. Liming of agricultural soils and urea fertilization in 2006 resulted in CO_2 emissions of 8.0 Tg CO_2 Eq. (8,012 Gg). The application of synthetic fertilizers to forest and settlement soils in 2006 resulted in direct N_2O emissions of 1.8 Tg CO_2 Eq. (6 Gg). Direct N_2O emissions from fertilizer application increased by approximately 174 percent between 1990 and 2006. Forest fires in 2006 resulted in methane (CH_4) emissions of 24.6 Tg CO_2 Eq. (1,169 Gg), and in N_2O emissions of 2.5 Tg CO_2 Eq. (8 Gg).

Table 7-3: Emissions from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Source Category	1990	1995	2000	2001	2002	2003	2004	2005	2006
CO_2	**7.1**	**7.0**	**7.5**	**7.8**	**8.5**	**8.3**	**7.6**	**7.9**	**8.0**
Cropland Remaining Cropland:									
Liming of Agricultural Soils &	7.1	7.0	7.5	7.8	8.5	8.3	7.6	7.9	8.0

Urea Fertilization									
CH_4	**4.5**	**4.7**	**19.0**	**9.4**	**16.4**	**8.7**	**6.9**	**12.3**	**24.6**
Forest Land Remaining Forest Land: Forest Fires	4.5	4.7	19.0	9.4	16.4	8.7	6.9	12.3	24.6
N_2O	**1.5**	**1.8**	**3.5**	**2.7**	**3.5**	**2.7**	**2.6**	**3.1**	**4.3**
Forest Land Remaining Forest Land: Forest Fires	0.5	0.5	1.9	1.0	1.7	0.9	0.7	1.2	2.5
Forest Land Remaining Forest Land: Forest Soils[1]	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Settlements Remaining Settlements: Settlement Soils[2]	1.0	1.2	1.2	1.4	1.5	1.5	1.6	1.5	1.5
Total	**13.1**	**13.6**	**30.0**	**20.0**	**28.4**	**19.7**	**17.1**	**23.2**	**36.9**

Note: These estimates include direct emissions only. Indirect N_2O emissions are reported in the Agriculture chapter. Totals may not sum due to independent rounding.

[1] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.

[2] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.

Table 7-4: Non-CO_2 Emissions from Land Use, Land-Use Change, and Forestry (Gg)

Source Category	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
CO_2	**7,084**	**7,049**	**7,541**	**7,825**	**8,549**	**8,260**	**7,555**	**7,854**	**8,012**
Cropland Remaining Cropland: Liming of Agricultural Soils & Urea Fertilization	7,084	7,049	7,541	7,825	8,549	8,260	7,555	7,854	8,012
CH_4	**213**	**224**	**904**	**448**	**780**	**416**	**330**	**586**	**1,169**
Forest Land Remaining Forest Land: Forest Fires	213	224	904	448	780	416	330	586	1,169
N_2O	**5**	**6**	**11**	**9**	**11**	**9**	**8**	**10**	**14**
Forest Land Remaining Forest Land: Forest Fires	1	2	6	3	5	3	2	4	8
Forest Land Remaining Forest Land: Forest Soils[1]	0	1	1	1	1	1	1	1	1
Settlements Remaining Settlements: Settlement Soils[2]	3	4	4	5	5	5	5	5	5

Note: These estimates include direct emissions only. Indirect N_2O emissions are reported in the Agriculture chapter. Totals may not sum due to independent rounding.

[1] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.

[2] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.

7.1. Representation of the U.S. Land Base

A national land-use categorization system that is consistent and complete both temporally and spatially is needed in order to assess land use and land-use change status and the associated greenhouse gas fluxes over the inventory time series. This system should be consistent with IPCC (2006), such that all countries reporting on national greenhouse gas fluxes to the UNFCCC should (1) describe the methods and definitions used to determine areas of managed and unmanaged lands in the country (2) describe and apply a consistent set of definitions for land-use categories over the entire national land base and time series associated with the greenhouse gas inventory, such that increases in the land areas within particular land use categories are balanced by decreases in the land areas of other categories, and (3) account for greenhouse gas fluxes on all managed lands. The implementation of such a system helps to ensure that estimates of greenhouse gas fluxes are as accurate as possible. This section of the national greenhouse gas inventory has been developed in order to comply with this guidance.

Multiple databases are utilized to track land management in the United States, which are also used as the basis to categorize the land area into the following six IPCC land-use categories:[3] Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land (IPCC 2006). The primary databases are the U.S. Department of Agriculture (USDA) National Resources Inventory (NRI)[4] and the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) Database.[5] The U.S. Geological Survey (USGS) National Land Cover Dataset (NLCD)[6] is also used to identify land uses in regions that were not included in the NRI or FIA. In 1990, the United States had a total of 243 million hectares of Forest Land, 169 million hectares of Cropland, 301 million hectares of Grassland, 32 million hectares of Wetlands, 32 million hectares of Settlements, and 28 million hectares in the Other Land[7] category (Table 7-5). By 2006, the total area in Forest Land had increased by 3.9 percent to 252 million hectares, Cropland had declined by 4.0 percent to 162 million hectares, Grassland declined by 2.8 percent to 293 million hectares, Wetlands decreased by 4.8 percent to 31 million hectares, Settlements increased by 32.2 percent to 42 million hectares, and Other Land decreased by 11.1 percent to 25 million hectares.

Table 7-5. Land use areas during the inventory reporting period (millions of hectares)

Land Use	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Forest Land	243	246	249	250	250	251	251	252	252
Cropland	169	166	163	163	162	162	162	162	162
Grassland	301	296	296	295	295	294	294	293	293
Wetlands	32	32	31	31	31	31	31	31	31
Settlements	32	36	40	41	41	42	42	42	42
Other Land	28	28	25	25	25	25	25	25	25

Note: Unmanaged land is not currently estimated because the only land designated as unmanaged occurs in Alaska, which has not been included in the current US land representation assessment. See planned improvements for discussion on plans to include Alaska in future inventory reports.

Dominant land uses vary by region, largely due to climate patterns, soil types, geology, proximity to coastal regions, and historical settlement patterns, although all land-uses occur within each of the fifty states (Figure 7-1). Forest Land tends to be more common in the eastern states, mountainous regions of the western United States, and Alaska. Cropland is concentrated in the mid-continent region of the United States, and Grassland is more common in the western United States. Wetlands are fairly ubiquitous throughout the United States, though they are more common in the upper Midwest and eastern portions of the country. Settlements are more concentrated along the coastal margins and in the eastern states.

Figure 7-1. Percent of Total Land Area in Each Land-Use Category by State

Methodology

IPCC Approaches for Representing Land Areas

IPCC (2006) describes three approaches for representing land areas. Approach 1 provides data on the total area for each individual land-use category, but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level. With Approach 1, total net conversions between categories can be detected, but not the individual changes between the land-use categories that led to those

---

[3] Land-use category definitions are provided in the Methodology section.

[4] NRI data is available at <http://www.ncgc.nrcs.usda.gov/ products/nri/index.html>.

[5] FIA data is available at <http://fia.fs.fed .us/tools-data/data/>.

[6] NLCD data is available at <http://www.mrlc.gov/>.

[7] *Other Land* is a miscellaneous category that includes lands that are not classified into the other five land-use categories. It also allows the total of identified land areas to match the national area.

net changes. Approach 2 introduces tracking of individual land-use changes between the categories (e.g. forest land to cropland, cropland to forest land, grassland to cropland, etc.). Approach 3 extends Approach 2 by allowing each land-use conversion to be tracked on a spatially explicit basis. The three approaches are not presented as hierarchical tiers and are not mutually exclusive.

According to IPCC (2003), the approach or mix of approaches selected by an inventory agency should reflect the calculation needs and national circumstances. For this analysis, the NRI, FIA, and the NLCD have been combined to provide a complete representation of land use for managed lands. These data sources are described in more detail later in this section. The NRI and the FIA data surveys meet the standards for Approach 3, but the data from NLCD that are currently utilized only meet the standards for Approach 1.[8] Consequently, Approach 1 is being used to provide a full representation of land use in the current inventory. The United States is pursuing an effort to analyze available data with the intent of moving beyond Approach 1 in future inventories.

Definitions of Land Use in the United States

Managed and Unmanaged Land

The U.S. definitions of managed and unmanaged lands are similar to the basic IPCC (2006) definition of managed land, but with some additional elaboration to reflect national circumstances. Based on the following definitions, most lands in the United States are classified as managed:

- *Managed Land*: Land is considered managed if direct human intervention has influenced its condition. Direct intervention includes altering or maintaining the condition of the land to produce commercial or non-commercial products or services; to serve as transportation corridors or locations for buildings, landfills, or other developed areas for commercial or non-commercial purposes; to extract resources or facilitate acquisition of resources; or to provide social functions for personal, community or societal objectives. Managed land also includes legal protection of lands (e.g., wilderness, preserves, parks, etc.) for conservation purposes (i.e., meets societal objectives).[9]

- *Unmanaged Land:* All other land is considered unmanaged. Unmanaged land is largely comprised of areas inaccessible to human intervention due to the remoteness of the locations, or lands with essentially no development interest or protection due to limited personal, commercial or social value. Though these lands may be influenced indirectly by human actions such as atmospheric deposition of chemical species produced in industry, they are not influenced by a direct human intervention.[10]

Land-Use Categories

As with the definition of managed lands, IPCC (2003, 2006) provide general non-prescriptive definitions for the six main land-use categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. In order to reflect U.S. circumstances, country-specific definitions have been developed, based predominantly on criteria used in the land-use surveys for the United States. Specifically, the definition of Forest Land is based on the FIA

---

[8] A new NLCD product is being developed that will meet the standards of Approach 3 data, with explicit information on land cover change, opposed to information based solely on land cover for individual years.

[9] Wetlands are an exception to this general definition, because these lands, as specified by IPCC (2006), are only considered managed if they are created through human activity, such as dam construction, or the water level is artificially altered by human activity. Distinguishing between managed and unmanaged wetlands is difficult, however, due to limited data availability. Wetlands are not characterized by use within the NRI. Therefore, unless wetlands are managed for cropland or grassland, it is not possible to know if they are artificially created or if the water table is managed based on the use of NRI data.

[10] There will be some areas that qualify as Forest Land or Grassland according to the land use criteria, but are classified as unmanaged land due to the remoteness of their location.

definition of forest,[11] while definitions of Cropland, Grassland, and Settlements are based on the NRI.[12] The definitions for Other Land and Wetlands are based on the IPCC (2006) definitions for these categories.

- *Forest Land:* A land-use category that includes land that is at least 10 percent stocked[13] by forest trees of any size, or land formerly having such tree cover, and not currently developed for a non-forest use. The minimum area for classification as Forest Land is one acre (0.40 ha). Roadside, stream-side, and shelterbelt strips of timber must be at least 120 feet (36.58 m) wide to qualify as Forest Land. Unimproved roads and trails, streams and other bodies of water, or natural clearings in forested areas are classified as Forest Land, if less than 120 feet (36.58 m) in width or one acre (0.40 ha) in size. Improved roads within Forest Land, however, are extracted from forest area estimates and included in Other Land. Grazed woodlands, fields reverting to forest, and pastures that are not actively maintained are included if the above qualifications are satisfied. Forest Land consists of three main subcategories: timberland, reserved forest land, and other forest land.[14] Forest Land also includes woodlands, which describes forest types consisting primarily of species that have their diameter measured at root collar, and for which there are no site index equations, nor stocking guides. These may include areas with degrees of stocking between 5 and 9.9 percent. The FIA regions with woodland areas are, however, considering new definitions that should result in all Forest Land meeting the minimum 10 percent stocking threshold.

- *Cropland:* A land-use category that includes areas used for the production of adapted crops for harvest, this category includes both cultivated and non-cultivated lands. Cultivated crops include row crops or close-grown crops and also hay or pasture in rotation with cultivated crops. Non-cultivated cropland includes continuous hay, perennial crops (e.g., orchards) and horticultural cropland. Cropland also includes land with alley cropping and windbreaks,[15] as well as lands in temporary fallow or enrolled in conservation reserve programs (i.e., set-asides[16]). Roads through Cropland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Cropland area estimates and are, instead, classified as Other Land.

- *Grassland:* A land-use category on which the plant cover is composed principally of grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and includes both pastures and native rangelands. This includes areas where practices such as clearing, burning, chaining, and/or chemicals are applied to maintain the grass vegetation. Savannas, some wetlands and deserts, in addition to tundra are considered Grassland.[17] Woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also classified as Grassland if they do not meet the criteria for Forest Land. Grassland includes land managed with agroforestry practices such as silvipasture and windbreaks, assuming the stand or woodlot does not meet the criteria for Forest Land. Roads through Grassland, including interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from Grassland area estimates and are, instead, classified as Other Land.

- *Wetlands:* A land-use category that includes land covered or saturated by water for all or part of the year. Managed Wetlands are those where the water level is artificially changed, or were created by human activity.

---

[11] See <http://socrates.lv-hrc.nevada.edu/fia/ab/issues/pending/glossary/Glossary_5_30_06.pdf>.

[12] See <http://www.nrcs.usda.gov/technical/land/nri01/glossary.html>.

[13] The percentage stocked refers to the degree of occupancy of land by trees, measured either by basal area or number of trees by size and spacing or both, compared to a stocking standard.

[14] These subcategory definitions are fully described in the Forest Land Remaining Forest Land section.

[15] Currently, there is no data source to account for biomass C stock change associated with woody plant growth and losses in alley cropping systems and windbreaks in cropping systems, although these areas are included in the cropland land base.

[16] A set-aside is cropland that has been taken out of active cropping and converted to some type of vegetative cover, including, for example, native grasses or trees.

[17] IPCC guidelines (2006) do not include provisions to separate desert and tundra as land categories.

IPCC (2006) provides guidance under “Wetlands” for managed peatlands and flooded lands, such as reservoirs developed for hydroelectricity, irrigation, and navigation. Certain areas that fall under the managed Wetlands definition are covered in other areas of the IPCC guidance and/or the inventory, including Cropland (e.g., rice cultivation), Grassland, and Forest Land (including drained or undrained forested wetlands).

- *Settlements:* A land-use category consisting of units of 0.25 acres (0.1 ha) or more that includes residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; parks within urban and built-up areas; and highways, railroads, and other transportation facilities if they are surrounded by urban or built-up areas. Also included are tracts of less than 10 acres (4.05 ha) that may meet the definitions for Forest Land, Cropland, Grassland, or Other Land but are completely surrounded by urban or built-up land, and so are included in the settlement category.

- *Other Land:* A land-use category that includes bare soil, rock, ice, non-settlement transportation corridors, and all land areas that do not fall into any of the other five land-use categories. It allows the total of identified land areas to match the managed national area. It also specifically includes roads through forests (excluding unimproved roads/trails) and all types of roads through Grassland and Cropland areas that are discernible using aerial photography or remote sensing imagery (i.e., interstate highways, state highways, other paved roads, gravel roads, dirt roads, and railroads).

Land Use Data Sources: Description and Application to U.S. Land Area Classification

U.S. Land Use Data Sources

The three main data sources for land area and use data in the United States are the NRI, FIA, and the NLCD. The NRI is conducted by the USDA Natural Resources Conservation Service and is designed to assess soil, water, and related environmental resources on nonfederal 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). The NRI survey utilizes data derived from remote sensing imagery and site visits in order to provide detailed information on land use and management, particularly for croplands, and is used as the basis to account for C stock changes in agricultural lands. The NRI survey was conducted every 5 years between 1982 and 1997, but shifted to annualized data collection in 1998.

The FIA program, conducted by the USFS, is used to obtain forest area and management data FIA engages in a hierarchical system of sampling, with sampling categorized as Phases 1 through 3, in which sample points for phases are subsets of the previous phase. Phase 1 refers to collection of remotely-sensed data (either aerial photographs or satellite imagery) primarily to classify land into forest or non-forest and to identify landscape patterns like fragmentation and urbanization. Phase 2 is the collection of field data on a network of ground plots that enable classification and summarization of area, tree, and other attributes associated with forest land uses. Phase 3 plots are a subset of Phase 2 plots where data on indicators of forest health are measured. Data from all three phases are also used to estimate C stock changes for forest land. Historically, FIA inventory surveys had been conducted periodically, with all plots in a state being measured at a frequency of every 5 to 14 years. A new national plot design and annual sampling design was introduced by FIA about ten years ago. Most states, though, have only recently been brought into this system. Annualized sampling means that a portion of plots throughout each state is sampled each year, with the goal of measuring all plots once every 5 years. See Annex 3.12 to see the specific survey data available by state.

Because NRI only includes land use information for non-federal land, and the FIA only records for forest land,[18] major gaps exist when the datasets are combined, such as federal grassland operated by the Bureau of Land Management (BLM), USDA, and National Park Service, as well as most of Alaska[19]. Consequently, the NLCD is used as a supplementary database to account for federal land areas that are not included in the NRI and FIA databases. The NLCD is a land cover classification scheme, available for 1992 and 2001, that has been applied over the conterminous United States. It is based primarily on Landsat Thematic Mapper imagery. The NLCD contains 21 categories of land cover information, which have been aggregated into the six IPCC land-use categories, and the data are available at a spatial resolution of 30 meters. The NLCD is strictly a source of land cover information, however, and does not provide the necessary site conditions, crop types and management information from which to estimate C stock changes on those lands.

Along with the incorporation of NLCD data, another major step has been taken to address gaps, as well as overlaps in the representation of the U.S. land base between the Agricultural Carbon Stock Inventory (*Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, *Land Converted to Grassland*) and Forest Land Carbon Stock Inventory (*Forest Land Remaining Forest Land* and *Land Converted to Forest Land*), which are based on the NRI and FIA databases, respectively. NRI, which covers only non-federal land, and FIA have different criteria for classifying forest land, leading to discrepancies in the resulting estimates of forest land area on non-federal land. Similarly, there are discrepancies between the NLCD and FIA data for forest land on federal lands. Moreover, dependence exists between the Forest Land area and the amount of land designated as other land uses in the NRI and NLCD, such as grassland, cropland and wetland, and thus there are inconsistencies in the Forest Land definitions among the three databases. FIA is the main database for forest statistics, and consequently, the NRI and NLCD were adjusted to achieve consistency with FIA estimates of Forest Land. The adjustments were made at a state-scale, and it was assumed that the majority of the discrepancy in forest area was associated with an under- or over-prediction of grassland and wetland area in the NRI and NLCD due to differences in Forest Land definitions. Specifically, the Forest Land area for a given state according to the NRI and NLCD was adjusted to match the FIA estimates for non-federal and federal land, respectively. Adjustments were allotted to grassland and wetlands, based on the proportion of land within each of these land-use categories at the state-level. A higher proportion of grassland led to a larger adjustment in grassland area and vice versa. In a second step, corresponding increases or decreases were made in the area estimates of grassland and wetland from the NRI and NLCD, in order to balance the change in forest area, and therefore not change the overall amount of managed land within an individual state.

There are minor differences between the U.S. Census Survey[20] land area estimates and the land use surveys derived for the inventory because of discrepancies in the reporting approach for the census and the methods used in the NRI, FIA and NLCD. The area estimates of land-use categories, based on NRI, FIA and NLCD, are derived from remote sensing data instead of the land survey approach used by the U.S. Census Survey. More importantly, the U.S. Census Survey does not provide a time series of land-use change data or land management information, which is critical for conducting emission inventories and is provided from the NRI and FIA surveys. Regardless, the total difference between the U.S. Census Survey and the data sources used in the inventory is relatively minor, estimated at about 6 million hectares for the total land base of over 800 million hectares currently included in the Inventory, or a 0.7 percent difference.

Approach for Combining Data Sources

The managed land base in the United States has been classified into the six IPCC land-use categories using definitions[21] developed to meet national circumstances, while adhering to IPCC (2006). In practice, the land was

---

[18] FIA does collect some data on nonforest land use, but these are held in regional databases versus the national database. The status of these data is being investigated.

[19] The survey programs also do not include U.S. Territories with the exception of non-federal lands in Puerto Rico, which are included in the NRI survey. Furthermore, NLCD does not include coverage for U.S. Territories.

[20] See <http://www.census.gov/geo/www/tiger>.

[21] Definitions are provided in the previous section.

initially classified into a variety of land-use categories using the NRI, FIA and NLCD, and then aggregated into the six broad land uses identified in IPCC (2006). Details on the approach used to combine data sources for each land use are described below along with gaps that will be reconciled as part of ongoing planned improvements:

- *Forest Land*: Both non-federal and federal forest lands on both the continental United States and coastal Alaska are covered by FIA. FIA is used as the basis for both Forest Land area data as well as to estimate C stocks and fluxes on Forest Land. Interior Alaska is not currently surveyed by FIA and at this time the NLCD cannot be used to classify land use in this region. FIA surveys are currently being conducted on U.S. territories and will become available in the future. FIA data will also be collected in Hawaii in the future.

- *Cropland*: Cropland is classified using the NRI, which covers all non-federal lands, within 49 states, including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Cropland area data as well as to estimate C stocks and fluxes on Cropland. Cropland in Alaska and U.S. territories are excluded from both NRI data collection and the NLCD[22]. Though crops are grown on some federal lands, these Cropland areas are considered minimal and are excluded from the inventory.

- *Grassland*: Grassland on non-federal lands is classified using the NRI within 49 states, including state and local government-owned land as well as tribal lands. NRI is used as the basis for both Grassland area data as well as to estimate C stocks and fluxes on Grassland. Alaska and U.S. territories are excluded from both NRI data collection and the current release of the NLCD product[23]. Grassland on federal BLM lands, National Parks and within USFS lands are covered by the NLCD. Department of Defense grasslands are also included in area estimates using the NLCD.

- *Wetlands*: NRI captures wetlands on non-federal lands within 49 states, while federal wetlands are covered by the NLCD. Alaska and U.S. territories are excluded. This currently includes both managed and unmanaged wetlands as no database has yet been applied to make this distinction. See *Planned Improvements* for details.

- *Settlements*: The NRI captures non-federal settlement area in 49 states. If areas of Forest Land or Grassland under 10 acres (4.05 ha) are contained within settlements or urban areas, they are classified as Settlements (urban) in the NRI database. If these parcels exceed the 10 acre (4.05 ha) threshold and are grassland, they will be classified as such by NRI. If within an urban area, a forested area is classified as nonforest by FIA, regardless of size. Settlements on federal lands are covered by NLCD. Settlements in Alaska and U.S. territories are currently excluded from NRI and NLCD.

- *Other Land*: Any land not falling into the other five land categories and, therefore, categorized as Other Land is classified using the NRI and NLCD. Other land in Alaska and U.S. territories are excluded from the NLCD.

Some lands can be classified into one or more categories due to multiple uses that meet the criteria of more than one definition. However, a ranking has been developed for assignment priority in these cases. The ranking process is initiated by distinguishing between managed and unmanaged lands. The managed lands are then assigned, from highest to lowest priority, in the following manner:

Settlements > Cropland > Forest Land > Grassland > Wetlands > Other Land

Settlements are given the highest assignment priority because they are extremely heterogeneous with a mosaic of patches that include buildings, infrastructure and travel corridors, but also open grass areas, forest patches, riparian areas, and gardens. The latter examples could be classified as Grassland, Forest Land, Wetlands, and Cropland, respectively, but when located in close proximity to settlement areas they tend to be managed in a unique manner

---

[22] With the exception of non-federal cropland in Puerto Rico, which are included in the NRI survey.

[23] With the exception of non-federal grasslands in Puerto Rico, which are included in the NRI survey.

compared to non-settlement areas. Consequently, these areas are assigned to the Settlements land-use category. Cropland is given the second assignment priority, because cropping practices tend to dominate management activities on areas used to produce food, forage or fiber. The consequence of this ranking is that crops in rotation with grass will be classified as Cropland, and land with woody plant cover that is used to produce crops (e.g., orchards) is classified as Cropland, even though these areas may meet the definitions of Grassland or Forest Land, respectively. Similarly, Wetlands that are used for rice production are considered Croplands. Forest Land occurs next in the priority assignment because traditional forestry practices tend to be the focus of the management activity in areas with woody plant cover that are not croplands (e.g., orchards) or settlements (e.g., housing subdivisions with significant tree cover). Grassland occurs next in the ranking, while Wetlands and Other Land complete the list.

Priority does not reflect the level of importance for reporting GHG emissions and removals on managed land, but is intended to classify all areas into a single land use. Currently, the IPCC does not make provisions in the guidelines for assigning land to multiple uses. For example, a Wetland is classified as Forest Land if the area has sufficient tree cover to meet the stocking and stand size requirements. Similarly, Wetlands are classified as Cropland if they are used to produce a crop, such as rice. In either case, emissions from Wetlands are included in the inventory if human interventions are influencing emissions from Wetlands in accordance with the guidance provided in IPCC (2006).

Planned Improvements

Area data by land-use category are not estimated for major portions of Alaska and any of the U.S. territories. A key planned improvement is to incorporate land use data from these areas in the national greenhouse gas emissions inventory. For Alaska, a new NLCD 2001 data product will be used to cover those land areas presently omitted. Fortunately, most of the managed land in the United States is included in the current land use statistics, but a complete accounting is a key goal for the near future. Data sources will be evaluated for representing land use in U.S. Territories.

Another planned improvement is to utilize Approach 3-type area data for the U.S. land base. A new NLCD product, with spatially-explicit information on land-use change is currently being developed and will qualify as Approach 3. By using this new data product in combination with the existing NRI and FIA databases, land-use statistics will be further subdivided by land-use change categories as recommended in IPCC (2006). This will include land remaining in a land-use category and land converted to another land-use category (e.g., *Forest Land Remaining Forest Land*, *Cropland Converted to Forest Land*, *Grassland Converted to Forest Land*). The additional subdivisions will provide more explicit land-use change statistics than currently reported, and also provide better accounting of emissions and stock changes associated with land use activities.

Additional work will be done to reconcile differences in Forest Land estimates between the NRI and FIA, evaluating the assumption that the majority of discrepancies in Forest Land areas are associated with an over- or under-estimation of Grassland and Wetland area. In some regions of the United States, a discrepancy in Forest Land areas between NRI and FIA may be associated with an over- or under-prediction of other land uses.

There are also other databases that may need to be reconciled with the NRI and NLCD datasets, particularly for Settlements and Wetlands. Urban area estimates, used to produce C stock and flux estimates from urban trees, are currently based on population data (1990 and 2000 U.S. Census data). Using the population statistics, "urban clusters" are defined as areas with more than 500 people per square mile. The USFS is currently moving ahead with an urban forest inventory program so that urban forest area estimates will be consistent with FIA forest area estimates outside of urban areas, which would be expected to reduce omissions and overlap of forest area estimates along urban boundary areas. For Wetlands, current estimates using the NRI and NLCD databases will be compared and reconciled to the extent possible with the Army Corps of Engineers National Inventory of Dams (ACE 2005) which provides data on the total surface area of reservoirs created by dams.

7.2. Forest Land Remaining Forest Land

Changes in Forest Carbon Stocks (IPCC Source Category 5A1)

For estimating C stocks or stock change (flux), C in forest ecosystems can be divided into the following five storage pools (IPCC 2003):

- Aboveground biomass, which includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, which includes all living biomass of coarse living roots greater than 2 mm diameter.
- Dead wood, which includes all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, which includes the litter, fumic, and humic layers, and all non-living biomass with a diameter less than 7.5 cm at transect intersection, lying on the ground.
- Soil organic C (SOC), including all organic material in soil to a depth of 1 meter but excluding the coarse roots of the aboveground pools.

In addition, there are two harvested wood pools necessary for estimating C flux:

- Harvested wood products in use.
- Harvested wood products in solid waste disposal sites (SWDS).

C is continuously cycled among these storage pools and between forest ecosystems and the atmosphere as a result of biological processes in forests (e.g., photosynthesis, respiration, growth, mortality, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, clearing, and replanting). As trees photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees die and otherwise deposit litter and debris on the forest floor, C is released to the atmosphere or transferred to the soil by organisms that facilitate decomposition.

The net change in forest C is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of C to the atmosphere. Instead, harvesting transfers C to a "product pool." Once in a product pool, the C is emitted over time as CO_2 when the wood product combusts or decays. The rate of emission varies considerably among different product pools. For example, if timber is harvested to produce energy, combustion releases C immediately. Conversely, if timber is harvested and used as lumber in a house, it may be many decades or even centuries before the lumber decays and C is released to the atmosphere. If wood products are disposed of in SWDS, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the SWDS.

This section quantifies the net changes in C stocks in the five forest C pools and two harvested wood pools. The net change in stocks for each pool is estimated, and then the changes in stocks are summed over all pools to estimate total net flux. The focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes do not need to be separately itemized in this report. Disturbances from forest fires and pest outbreaks are implicitly included in the net changes. For instance, an inventory conducted after fire counts only trees left. The change between inventories thus accounts for the C changes due to fires; however, it may not be possible to attribute the changes to the disturbance specifically. The IPCC (2003) recommends reporting C stocks according to several land-use types and conversions, specifically *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Currently, consistent datasets are not available for the entire United States to allow results to be partitioned in this way. Instead, net changes in all forest-related land, including non-forest land converted to forest and forests converted to non-forest are reported here.

Forest C storage pools, and the flows between them via emissions, sequestration, and transfers, are shown in Figure 7-1. In the figure, boxes represent forest C storage pools and arrows represent flows between storage pools or between storage pools and the atmosphere. Note that the boxes are not identical to the storage pools identified in this chapter. The storage pools identified in this chapter have been altered in this graphic to better illustrate the processes that result in transfers of C from one pool to another, and emissions to the atmosphere as well as uptake from the atmosphere.

Figure 7-2: Forest Sector Carbon Pools and Flows

Approximately 33 percent (303 million hectares) of the U.S. land area is forested (Smith et al. 2004b). The current forest inventory includes 249 million hectares in the conterminous 48 states (USDA Forest Service 2006b) that are considered managed and are included in this inventory. The additional forest lands are located in Alaska and Hawaii. This inventory includes approximately 3.7 million hectares of Alaska forest, which are in the southeast and south central regions of Alaska and represent the majority of the state's managed forest land. Survey data are not yet available from Hawaii. While Hawaii and U.S. territories have relatively small areas of forest land and will probably not affect the overall C budget to a great degree, these areas will be included as sufficient data becomes available. Agroforestry systems are also not currently accounted for in the inventory, since they are not explicitly inventoried by either of the two primary national natural resource inventory programs: the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture (USDA) Forest Service and the National Resources Inventory (NRI) of the USDA Natural Resources Conservation Service (Perry et al. 2005).

Sixty-seven percent of U.S. forests (204 million hectares) are classified as timberland, meaning they meet minimum levels of productivity and are available for timber harvest. Nine percent of Alaska forests and 79 percent of forests in the conterminous United States are classified as timberlands. Of the remaining nontimberland forests, 31 million hectares are reserved forest lands (withdrawn by law from management for production of wood products) and 68 million hectares are lower productivity forest lands (Smith et al. 2004b). Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than other forest lands.

Forest land declined by approximately 10 million hectares over the period from the early 1960s to the late 1980s. Since then, forest area has increased by about 7 million hectares. Current trends in forest area represent average annual change of only about 0.2 percent. Given the low rate of change in U.S. forest land area, the major influences on the current net C flux from forest land are management activities and the ongoing impacts of previous land-use changes. These activities affect the net flux of C by altering the amount of C stored in forest ecosystems. For example, intensified management of forests that leads to an increased rate of growth increases the eventual biomass density of the forest, thereby increasing the uptake of C.[24] Net volume of growing stock on U.S. timberlands increased by 36 percent from 1953 to 1997. Though harvesting forests removes much of the aboveground C, there is a positive growth to harvest ratio on U.S. timberlands (AF&PA 2001) . The reversion of cropland to forest land increases C storage in biomass, forest floor, and soils. The net effects of forest management and the effects of land-use change involving forest land are captured in the estimates of C stocks and fluxes presented in this chapter.

In the United States, improved forest management practices, the regeneration of previously cleared forest areas, as well as timber harvesting and use have resulted in net uptake (i.e., net sequestration) of C each year from 1990 through 2006. The rate of forest clearing begun in the 17th century following European settlement had slowed by the late 19th century. Through the later part of the 20th century many areas of previously forested land in the United States were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still affect C fluxes from these forest lands. More recently, the 1970s and 1980s saw a resurgence of federally-sponsored forest management programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on tree planting, improving timber management activities, combating soil erosion, and converting marginal cropland to forests. In addition to forest regeneration and management, forest harvests have also affected net C fluxes. Because most of the timber harvested from U.S. forests is used in wood products, and many discarded wood products are disposed of in SWDS rather than by incineration, significant quantities of C in harvested wood are transferred to long-term storage pools rather than

---

[24] The term "biomass density" refers to the mass of live vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is 50 percent C by weight.

being released rapidly to the atmosphere (Skog and Nicholson 1998, Skog in preparation). The size of these long-term C storage pools has increased during the last century.

Changes in C stocks in U.S. forests and harvested wood were estimated to account for net sequestration of 745.1 Tg CO_2 Eq. (203.2 Tg C) in 2006 (Table 7-6, Table 7-7, and Figure 7-2). In addition to the net accumulation of C in harvested wood pools, sequestration is a reflection of net forest growth and increasing forest area over this period. Overall, average C in forest ecosystem biomass (aboveground and belowground) increased from 71 to 75 Mg C/ha between 1990 and 2007 (see Table A-4 for average C densities by specific regions and forest types). Continuous, regular annual surveys are not available over the period for each state; therefore, estimates for non-survey years were derived by interpolation between known data points. Survey years vary from state to state, and national estimates are a composite of individual state surveys. Therefore, changes in sequestration over the interval 1990 to 2006 are the result of the sequences of new inventories for each state. Net annual sequestration increased by 20 percent for 2006 relative to 1990. C in forest ecosystem biomass had the greatest effect on total change. As discussed above, this was due to increased C density and total forest land. Management practices that increase C stocks on forest land, as well as afforestation and reforestation efforts influence the trends of increased C densities in forests and increased forest land in the United States.

Table 7-6. Net Annual Changes in C Stocks (Tg CO_2/yr) in Forest and Harvested Wood Pools

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005	2006
Forest	**(489.1)**	**(540.5)**	**(436.8)**	**(529.0)**	**(598.0)**	**(635.1)**	**(635.1)**	**(635.1)**	**(635.1)**
Aboveground Biomass	(287.6)	(318.4)	(335.4)	(367.7)	(384.4)	(406.5)	(406.5)	(406.5)	(406.5)
Belowground Biomass	(54.2)	(62.4)	(67.2)	(73.7)	(76.9)	(80.9)	(80.9)	(80.9)	(80.9)
Dead Wood	(40.1)	(57.5)	(44.9)	(50.0)	(53.0)	(56.9)	(56.9)	(56.9)	(56.9)
Litter	(63.3)	(34.9)	(17.3)	(36.3)	(47.7)	(56.2)	(56.2)	(56.2)	(56.2)
Soil Organic Carbon	(43.9)	(67.5)	28.0	(1.3)	(36.0)	(34.5)	(34.5)	(34.5)	(34.5)
Harvested Wood	**(132.6)**	**(119.4)**	**(113.9)**	**(94.5)**	**(99.2)**	**(95.9)**	**(106.3)**	**(108.5)**	**(110.0)**
Products in use	(64.8)	(55.2)	(47.0)	(31.9)	(35.1)	(35.4)	(45.5)	(47.3)	(45.3)
SWDS	(67.9)	(64.1)	(66.9)	(62.6)	(64.2)	(60.4)	(60.8)	(61.2)	(64.7)
Total Net Flux	**(621.7)**	**(659.9)**	**(550.7)**	**(623.4)**	**(697.3)**	**(730.9)**	**(741.4)**	**(743.6)**	**(745.1)**

Note: Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a large portion of Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Forest area estimates are based on interpolation and extrapolation of inventory data as described in the text and in Annex 3.12. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Table 7-7. Net Annual Changes in C Stocks (Tg C/yr) in Forest and Harvested Wood Pools

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005	2006
Forest	**(133.4)**	**(147.4)**	**(119.1)**	**(144.3)**	**(163.1)**	**(173.2)**	**(173.2)**	**(173.2)**	**(173.2)**
Aboveground Biomass	(78.4)	(86.8)	(91.5)	(100.3)	(104.8)	(110.9)	(110.9)	(110.9)	(110.9)
Belowground Biomass	(14.8)	(17.0)	(18.3)	(20.1)	(21.0)	(22.1)	(22.1)	(22.1)	(22.1)
Dead Wood	(10.9)	(15.7)	(12.2)	(13.6)	(14.5)	(15.5)	(15.5)	(15.5)	(15.5)
Litter	(17.3)	(9.5)	(4.7)	(9.9)	(13.0)	(15.3)	(15.3)	(15.3)	(15.3)
Soil Organic C	(12.0)	(18.4)	7.6	(0.4)	(9.8)	(9.4)	(9.4)	(9.4)	(9.4)
Harvested Wood	**(36.2)**	**(32.6)**	**(31.1)**	**(25.8)**	**(27.1)**	**(26.1)**	**(29.0)**	**(29.6)**	**(30.0)**
Products in Use	(17.7)	(15.1)	(12.8)	(8.7)	(9.6)	(9.7)	(12.4)	(12.9)	(12.3)
SWDS	(18.5)	(17.5)	(18.2)	(17.1)	(17.5)	(16.5)	(16.6)	(16.7)	(17.7)
Total Net Flux	**(169.6)**	**(180.0)**	**(150.2)**	**(170.0)**	**(190.2)**	**(199.3)**	**(202.2)**	**(202.8)**	**(203.2)**

Note: Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a large portion of Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Parentheses indicate net C sequestration (i.e., a net removal of C from the atmosphere). Total net flux is an estimate of the actual net flux between the total forest C pool and the atmosphere. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding.

Stock estimates for forest and harvested wood C storage pools are presented in Table 7-8. Together, the aboveground live and forest soil pools account for a large proportion of total forest C stocks. C stocks in all non-soil pools increased over time. Therefore, C sequestration was greater than C emissions from forests, as discussed above. Figure 7-4 shows county-average C densities for live trees on forest land, including both above- and belowground biomass.

Table 7-8. Forest area (1000 ha) and C Stocks (Tg C) in Forest and Harvested Wood Pools

	1990	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Forest Area (1000 ha)	**245,799**	**249,036**	**252,251**	**252,798**	**253,443**	**254,155**	**254,889**	**255,624**	**256,358**	**257,093**
Carbon Pools (Tg C)										
Forest	**40,106**	**40,810**	**41,535**	**41,654**	**41,798**	**41,962**	**42,135**	**42,308**	**42,481**	**42,654**
Aboveground Biomass	14,547	14,955	15,405	15,496	15,596	15,701	15,812	15,923	16,034	16,145
Belowground Biomass	2,896	2,974	3,063	3,081	3,102	3,123	3,145	3,167	3,189	3,211
Dead Wood	2,453	2,515	2,592	2,605	2,618	2,633	2,648	2,664	2,679	2,695
Litter	4,557	4,641	4,680	4,684	4,694	4,707	4,723	4,738	4,753	4,769
Soil Organic C	15,652	15,725	15,795	15,788	15,788	15,798	15,807	15,817	15,826	15,835
Harvested Wood	**1,862**	**2,033**	**2,193**	**2,224**	**2,250**	**2,277**	**2,303**	**2,332**	**2,362**	**2,392**
Products in Use	1,231	1,311	1,382	1,395	1,404	1,413	1,423	1,436	1,448	1,461
SWDS	631	722	810	829	846	863	880	896	913	931
Total C Stock	**41,968**	**42,843**	**43,728**	**43,878**	**44,048**	**44,238**	**44,438**	**44,640**	**44,843**	**43,376**

Forest Area estimates include portions of Alaska, which represents an addition relative to previous versions of this table. Forest C stocks do not include forest stocks in U.S. territories, Hawaii, a large portion of Alaska, or trees on non-forest land (e.g., urban trees, agroforestry systems). Wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Forest area estimates are based on interpolation and extrapolation of inventory data as described in Smith et al. (2007) and in Annex 3.12. Harvested wood estimates are based on results from annual surveys and models. Totals may not sum due to independent rounding. Inventories are assumed to represent stocks as of January 1 of the inventory year. Flux is the net annual change in stock. Thus, an estimate of flux for 2006 requires estimates of C stocks for 2006 and 2007.

Figure 7-3: Estimates of Net Annual Changes in C Stocks for Major C Pools

Figure 7-4: Average C Density in the Forest Tree Pool in the Conterminous United States, 2007

[BEGIN BOX]

Box 7-1: CO_2 Emissions from Forest Fires

As stated previously, the forest inventory approach implicitly accounts for emissions due to disturbances such as forest fires, because only C remaining in the forest is estimated. Net C stock change is estimated by subtracting consecutive C stock estimates. A disturbance removes C from the forest. The inventory data on which net C stock estimates are based already reflect this C loss. Therefore, estimates of net annual changes in C stocks for U.S. forestland already account for CO_2 emissions from forest fires occurring in the lower 48 states as well as in the proportion of Alaska's managed forest land captured in this inventory. Because it is of interest to quantify the magnitude of CO_2 emissions from fire disturbance, these estimates are being highlighted here, using the full extent of available data. Non-CO_2 greenhouse gas emissions from forest fires are also quantified in a separate section below.

The IPCC (2003) methodology was employed to estimate CO_2 emissions from forest fires. CO_2 emissions for the lower 48 states and Alaska in 2006 were estimated to be 267.9 Tg CO_2/yr. This amount is masked in the estimate of net annual forest carbon stock change for 2006, however, because this net estimate accounts for the amount sequestered minus any emissions.

Table 7-9: Estimates of CO_2 (Tg/yr) emissions for the lower 48 states and Alaska[1]

Year	CO_2 emitted in the Lower 48 States (Tg/yr)	CO_2 emitted in Alaska (Tg/yr)	Total CO_2 emitted (Tg/yr)
1990	36.8	12.0	48.8
1995	51.1	0.2	51.3
2000	196.9	10.3	207.2
2001	99.7	3.0	102.6
2002	149.0	29.7	178.7
2003	92.4	3.0	95.4
2004	43.4	32.1	75.5
2005	111.4	22.9	134.3
2006	266.6	1.3	267.9

[1] Note that these emissions have already been accounted for in the estimates of net annual changes in carbon stocks, which accounts for the amount sequestered minus any emissions.

[END BOX]

Methodology

The methodology described herein is consistent with IPCC (2003) and IPCC/UNEP/OECD/IEA (1997). Estimates of net annual C stock change, or flux, of forest ecosystems are derived from applying C estimation factors to forest inventory data and interpolating between successive inventory-based estimates of C stocks. C emissions from harvested wood are based on factors such as the allocation of wood to various primary and end-use products as well as half-life (the time at which half of amount placed in use will have been discarded from use) and expected disposition (e.g., product pool, SWDS, combustion). Different data sources are used to estimate the C stocks and stock change in forest ecosystems or harvested wood products. See Annex 3.12 for details and additional information related to the methods described below.

Forest Carbon Stocks and Fluxes

The first step in developing forest ecosystem estimates is to identify useful inventory data and resolve any inconsistencies among datasets. Forest inventory data were obtained from the USDA Forest Service FIA program (Frayer and Furnival 1999, USDA Forest Service 2006a). Inventories include forest lands[25] of the conterminous United States and are organized as a number of separate datasets, each representing a complete inventory, or survey, of an individual state at a specified time. Forest C calculations are organized according to these state surveys, and the frequency of surveys varies by state. To calculate a C stock change, at least two surveys are needed in each state. Thus, the most recent surveys for each state are used as well as all additional consistent inventory data back through 1990. Because C flux is based on change between successive C stocks, consistent representation of forest land in successive inventories is necessary. In order to achieve accurate representation of forests from 1990 to the present, state-level data are sometimes subdivided or additional inventory sources are used to produce the consistent state or sub-state inventories.

The principal FIA datasets employed are freely available for download at USDA Forest Service (2006b) as the Forest Inventory and Analysis Database (FIADB) Version 2.1. These data are identified as “snapshot” files, also identified as FISDB 2.1, and include detailed plot information, including individual-tree data. However, to achieve

---

[25] Forest land in the United States includes land that is at least 10 percent stocked with trees of any size. Timberland is the most productive type of forest land, which is on unreserved land and is producing or capable of producing crops of industrial wood.

consistent representation (spatial and temporal), two other general sources of past FIA data are included as necessary. First, older FIA plot- and tree-level data—not in the FIADB format—are used if available. Second, Resources Planning Act Assessment (RPA) databases, which are periodic, plot-level only, summaries of state inventories, are used mostly to provide the data at or before 1990. A detailed list of the specific inventory data used in this inventory is in Table A-188 of Annex 3.12.

Forest C stocks are estimated from inventory data by a collection of conversion factors and models referred to as FORCARB2 (Birdsey and Heath 1995, Birdsey and Heath 2001, Heath et al. 2003, Smith et al. 2004a), which have been formalized in an application referred to as the Carbon Calculation Tool (CCT), (Smith et al. 2007). The conversion factors and model coefficients are usually categorized by region and forest type, and forest C stock estimates are dependent on these particular sets of factors. Factors are applied to the data at the scale of FIA inventory plots. The results are estimates of C density (Mg per hectare) for the various forest pools. C density for live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic matter are estimated. All non-soil pools except forest floor can be separated into aboveground and belowground components. The live tree and understory C pools are pooled as biomass in this inventory. Similarly, standing dead trees and down dead wood are pooled as dead wood in this inventory. Definitions of ecosystem pools and the C conversion process follow, with additional information in Annex 3.12.

Live Biomass, Dead Wood, and Litter Carbon

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 full-tree and aboveground-only biomass in order to estimate the belowground component. If inventory plots include data on individual trees, tree C is based on Jenkins et al. (2003) and is a function of species and diameter. Some inventory data do not provide measurements of individual trees; tree C in these plots is estimated from plot-level volume of merchantable wood, or growing-stock volume, of live trees, which is calculated from updates of Smith et al. (2003). Some inventory data, particularly some of the older datasets, may not include sufficient information to calculate tree C because of incomplete or missing tree or volume data; C estimates for these plots are based on averages from similar, but more complete, inventory data.

Understory vegetation is a minor component of biomass, which is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 2.54 cm d.b.h. In this inventory, it is assumed that 10 percent of total understory C mass is belowground. Estimates of C density are based on information in Birdsey (1996).

The two components of dead wood—standing dead trees and down dead wood—are estimated separately. The standing dead tree C pools include aboveground and belowground (coarse root) mass and include trees of at least 2.54 cm d.b.h. Down 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. Down dead wood includes stumps and roots of harvested trees. Ratios of down dead wood to live tree are used to estimate this quantity. Litter C is the pool of organic C (also known as duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on equations of Smith and Heath (2002).

Forest Soil C

Soil organic C (SOC) includes all organic material in soil to a depth of 1 meter but excludes the coarse roots of the biomass or dead wood pools. Estimates of SOC are based on the national STATSGO spatial database (USDA 1991), and the general approach described by Amichev and Galbraith (2004). Links to FIA inventory data were developed with the assistance of the USDA Forest Service FIA Geospatial Service Center by overlaying FIA forest inventory plots on the soil C map. Thus, SOC is defined by region and forest type group.

C stocks and fluxes for *Forest Land Remaining Forest Land* are reported in pools following IPCC (2006). Total forest C stock and flux estimates start with the plot-level calculations described above. The separate C densities are summed and multiplied by the appropriate expansion factors to obtain a C stock estimate for the plot. In turn, these are summed to state or sub-state total C stocks. Annualized estimates of C stocks are based on interpolating or extrapolating as necessary to assign a C stock to each year. For example, the C stock of Alabama for 2007 is an extrapolation of the two most recent inventory datasets for that particular state, which are from 1999 and 2003. Flux, or net annual stock change, is simply the difference between two successive years with the appropriate sign convention so that net increases in ecosystem C are identified as negative flux. This methodological detail accounts for the constant estimates of flux from the second most recent inventory to the present (see 2003 through 2006 on Table 7-6 as an example).

Harvested Wood Carbon

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 (in preparation) using the WOODCARB II model. These methods are based on IPCC (2006) guidance for estimating HWP C. IPCC (2006) provides 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 that assumes there is no change in HWP C stocks (see Annex 3-12 for more details about each approach). The United States uses the production accounting approach to report HWP Contribution. Under the production approach, C in exported wood is estimated as if it remains in the United States, and C in imported wood is not included in inventory estimates. Though reported U.S. HWP estimates are based on the production approach, estimates resulting from use of the two alternative approaches, the stock change and atmospheric flow approaches, are also presented for comparison (see Annex 3.12). 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).

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 & forthcoming). Estimates for disposal of products reflect the change over time in the fraction of products discarded to SWDS (as opposed to burning or recycling) and the fraction of SWDS that are in sanitary landfills versus dumps.

There are 5 annual HWP variables that are used in varying combinations to estimate HWP Contribution using any one of the three main approaches listed above. These 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 product 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) C in imports of wood, pulp, and paper to the United States,

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

5) C in annual harvest of wood from forests in the United States.

The sum of variables 2A and 2B yields the estimate for 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 as they would in the United States.

Uncertainty

The 2006 flux estimate for forest C stocks is estimated to be between -579.0 and -913.2 Tg CO_2 Eq. at a 95 percent confidence level. This includes a range of -471.2 to -802.2 Tg CO_2 Eq. in forest ecosystems and -85.5 to -136.8 Tg CO_2 Eq. for HWP. The relatively smaller range of uncertainty, in terms of percentage, for the total relative to the two separate parts in because the total is based on summing the two independent uncertain parts, as discussed above. More information on the uncertainty estimates for Net CO_2 Flux from Forest Land Remaining Forest Land: Changes in Forest C Stocks is contained within the Uncertainty Annex.

Table 7-10: Tier 2 Quantitative Uncertainty Estimates for Net CO_2 Flux from Forest Land Remaining Forest Land: Changes in Forest C Stocks (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2006 Flux Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Flux Estimate[a] (Tg CO_2 Eq.)**		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Forest Ecosystem	CO_2	(635.1)	(802.2)	(471.2)	-26%	+26%
Harvested Wood Products	CO_2	(110.0)	(136.8)	(85.5)	-24%	+22%
Total Forest	**CO_2**	**(745.1)**	**(913.2)**	**(579.0)**	**-23%**	**+22%**

Note: Parentheses indicate negative values or net sequestration.

[a] Range of flux estimates predicted by Monte Carlo stochastic simulation for a 95 percent confidence interval.

QA/QC and Verification

As discussed above, the FIA program has conducted consistent forest surveys based on extensive statistically-based sampling of most of the forest land in the conterminous United States, dating back to 1952. The main purpose of the FIA program has been to estimate areas, volume of growing stock, and timber products output and utilization factors. The FIA program includes numerous quality assurance and quality control (QA/QC) procedures, including calibration among field crews, duplicate surveys of some plots, and systematic checking of recorded data. Because of the statistically-based sampling, the large number of survey plots, and the quality of the data, the survey databases developed by the FIA program form a strong foundation for C stock estimates. Field sampling protocols, summary data, and detailed inventory databases are archived and are publicly available on the Internet (USDA Forest Service 2006b).

Many key calculations for estimating current forest C stocks based on FIA data are based on coefficients from the FORCARB2 model (see additional discussion in the Methodology section above and in Annex 3.12). The model has been used for many years to produce national assessments of forest C stocks and stock changes. General quality control procedures were used in performing calculations to estimate C stocks based on survey data. For example, the derived C datasets, which include inventory variables such as areas and volumes, were compared with standard inventory summaries such as Resources Planning Act (RPA) Forest Resource Tables or selected population estimates generated from the FIA Database (FIADB), which are available at an FIA Internet site (USDA Forest Service 2006b). Agreement between the C datasets and the original inventories is important to verify accuracy of the data used. Finally, C stock estimates were compared with previous inventory report estimates to ensure that any differences could be explained by either new data or revised calculation methods (see the "Recalculations" discussion below).

Estimates of the HWP variables and the HWP Contribution under the production accounting approach use data from U.S. Census and USDA Forest Service surveys of production and trade. Factors to convert wood and paper from original units to C units are based on estimates by industry and Forest Service published sources. The WOODCARB II model uses estimation methods suggested by IPCC (2006). Estimates of annual C change in solidwood and paper products in use were verified by two independent criteria. The first criteria is that the WOODCARB II model estimate of C in houses standing in 2001 needs to match an independent estimate of C in housing based on U.S. Census and USDA Forest Service survey data. Meeting the first criteria resulted in an estimated half life of about 80 years for single family housing built in the 1920s, which is confirmed by other U.S. Census data on housing. The second criteria is that the WOODCARB II model estimate of wood and paper being discarded to SWDS needs to match EPA estimates of discards each year over the period 1990 to 2000. These criteria help reduce uncertainty in estimates of annual change in C in products in use in the United States and to a lesser degree reduces uncertainty in estimates of annual change in C in products made from wood harvested in the United States.

Recalculations Discussion

The overall process for developing annualized estimates of forest ecosystem C stocks based on the individual state surveys and the C conversion factors are identical to that presented in the previous inventory (Smith et al. 2007). However, revised estimates of forest ecosystem C stock increased by 3 percent for 1990 and 2005. Similarly, estimated net stock change increased by 4 percent for 1990 and by 6 percent for 2005. The addition of newly available forest inventory data as well as some refinements in previously existing data were the principal factors contributing to these changes. Inventory data changed for 31 of the 48 states included in the previous inventory. However, not all of the changes are apparent in the list of inventory data used for C estimates (Table A-186) because some changes involved reclassification and recalculation of existing data. In addition, a portion of Alaska forest is included in this inventory for the first time. Carbon stock and change estimates for the early 1990s are still sensitive to updates made over the last year, which are primarily associated with the most recent data per state, because 13 of the 49 states are still entirely or partly based on two C stock estimates (Table A-186). Thus, even an update for a 2006 C stock, for example, is propagated throughout the interval when stock change is linearly interpolated between the two stocks.

The basic model and data used to estimate HWP contribution under the production approach are unchanged since the previous inventory (Skog in preparation). However, minor modifications to some model coefficients resulted in slight increases in estimated C sequestration so that net annual additions to C in HWP increased by 0.5 and 5 percent for 1990 and 2005, respectively, with an average increase of 3 percent across the sixteen years. Modifications to parameters included: (1) shorter half-life for decay in dumps and (2) separation of decay in dumps from decay in landfills.

Planned Improvements

The ongoing annual surveys by the FIA Program will improve precision of forest C estimates as new state surveys become available (Gillespie 1999). The annual surveys will eventually include all states. To date, five states are not yet reporting any data from the annualized sampling design of FIA: Hawaii, Mississippi, Oklahoma, New Mexico and Wyoming. Estimates for these states are currently based on older, periodic data. Hawaii and U.S. territories will also be included when appropriate forest C data are available. In addition, the more intensive sampling of down dead wood, litter, and soil organic C on some of the permanent FIA plots continues and will substantially improve resolution of C pools at the plot level for all U.S. forest land when this information becomes available. Improved resolution, incorporating more of Alaska's forests, and using annualized sampling data as it becomes available for those states currently not reporting are planned for future reporting.

As more information becomes available about historical land use, the ongoing effects of changes in land use and forest management will be better accounted for in estimates of soil C (Birdsey and Lewis 2003, Woodbury et al. 2006, Woodbury et al. 2007). Currently, soil C estimates are based on the assumption that soil C density depends only on broad forest type group, not on land-use history. However, long-term residual effects on soil and forest floor C stocks are likely after land-use change. Estimates of such effects are being developed based on methods described by Woodbury et al. (2007), and preliminary results demonstrate effects on soil organic C and forest floor. Additional development is required to link model results with: 1) the C change methods used for this inventory (Smith et al. 2007), and 2) a consistent representation of the land base and land-use change for the United States (See *7.1 Representation of the U.S. Land Base in the National Greenhouse Gas Inventory* for more details).

Similarly, agroforestry practices, such as windbreaks or riparian forest buffers along waterways, are not currently accounted for in the inventory. In order to properly account for the C stocks and fluxes associated with agroforestry, research will be needed that provides the basis and tools for including these plantings in a nation-wide inventory, as well as the means for entity-level reporting.

Non-CO_2 Emissions From Forest Fires

Emissions of non-CO_2 gases from forest fires were estimated using the default IPCC (2003) methodology. Emissions from this source in 2006 were estimated to be 24.6 Tg CO_2 Eq. of CH_4 and 2.5 Tg CO_2 Eq. of N_2O, as shown in Table 7-10 and Table 7-11. The estimates of non-CO_2 emissions from forest fires account for both the lower 48 states and Alaska.

Table 7-11: Estimated Non-CO_2 Emissions from Forest Fires (Tg CO_2 Eq.) for U.S. forests[1]

Gas	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
CH_4	4.5	4.7	19.0	9.4	16.4	8.7	6.9	12.3	24.6
N_2O	0.5	0.5	1.9	1.0	1.7	0.9	0.7	1.2	2.5
Total	**4.9**	**5.2**	**20.9**	**10.4**	**18.0**	**9.6**	**7.6**	**13.6**	**27.0**

[1] Calculated based on C emission estimates in *Changes in Forest Carbon Stocks* and default factors in IPCC (2003).

Table 7-12: Estimated Non-CO_2 Emissions from Forest Fires (Gg Gas) for U.S. forests[1]

Gas	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
CH_4	213	224	904	448	780	416	330	586	1,169
N_2O	1	2	6	3	5	3	2	4	8

[1] Calculated based on C emission estimates in *Changes in Forest Carbon Stocks* and default factors in IPCC (2003).

Methodology

The IPCC (2003) Tier 2 default methodology was used to calculate non-CO2 emissions from forest fires. Estimates for CH_4 emissions were calculated by multiplying the total estimated C emitted (see Table 7-12) from forest burned by gas-specific emissions ratios and conversion factors. N_2O emissions were calculated in the same manner, but were also multiplied by an N-C ratio of 0.01 as recommended by IPCC (2003). The equations used were:

$$CH_4 \text{ Emissions} = (\text{C released}) \times (\text{emission ratio}) \times 16/12$$

$$N_2O \text{ Emissions} = (\text{C released}) \times (\text{N/C ratio}) \times (\text{emission ratio}) \times 44/28$$

Estimates for C emitted from forest fires, presented in Table 7-12 below, are the same estimates used to generate estimates of CO_2 emissions from forest fires, presented earlier in Box 7-1. See Table A-197 and explanation in Annex 3.12 for more details on the methodology used to estimate C emitted from forest fires.

Table 7-13: Estimated Carbon Released from Forest Fires for U.S. Forests

Year	**C Emitted (Tg/yr)**
1990	13.3
1995	14.0
2000	56.5
2001	28.0
2002	48.7
2003	26.0
2004	20.6
2005	36.6
2006	73.1

Uncertainty

Non-CO_2 gases emitted from forest fires depend on several variables, including forest area and average C density for forest land in both Alaska and the lower 48 states, emission ratios, and combustion factor values (proportion of biomass consumed by fire). To quantify the uncertainties for emissions from forest fires, a Monte Carlo (Tier 2) uncertainty analysis was performed using information about the uncertainty surrounding each of these variables.

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-14.

Table 7-14: Tier 2 Quantitative Uncertainty Estimates of Non-CO_2 Emissions from Forest Fires in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2006 Emission Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emission Estimate (Tg CO_2 Eq.)**		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Non-CO_2 Emissions from Forest Fires	CH_4	24.6	7.7	42.1	-69%	71%
	N_2O	2.5	0.8	4.4	-69%	75%

QA/QC and Verification

Tier 1 and Tier 2 QA/QC activities were conducted consistent with the U.S. QA/QC plan. The QA/QC plan for forest fires followed the QA/QC plan implemented for forest C. A source-specific QA/QC plan for forest fires will be developed and implemented for the next inventory. Quality control measures included checking input data, documentation, and calculations to ensure data were properly handled through the inventory process. Errors that were found during this process were corrected as necessary.

Recalculations Discussion

Average carbon density for Alaska was updated from 70 Mg/ha to 331 Mg/ha based on new data from the FIA National Program. In addition, the static ratio used in the previous inventory to estimate the proportion of forestland burned from data on total area burned was replaced with a ratio that varied across the inventory time series. See Annex 3.12 for details and additional information related to the methods described.

Direct N_2O Fluxes from Forest Soils (IPCC Source Category 5A1)

Of the synthetic N fertilizers applied to soils in the United States, no more than one percent is applied to forest soils. Application rates are similar to those occurring on cropped soils, but in any given year, only a small proportion of total forested land receives N fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once approximately 20 years later). Thus, although the rate of N fertilizer application for the area of forests that receives N fertilizer in any given year is relatively high, average annual applications, inferred by dividing all forest land that may undergo N fertilization at some point during its growing cycle by the amount of N fertilizer added to these forests in a given year, is quite low. N_2O emissions from forest soils are estimated to have increased by a multiple of 5.5 from 1990 to 2006. The trend toward increasing N_2O emissions is a result of an increase in the area of N fertilized pine plantations in the southeastern United States. Total forest soil N_2O emissions are summarized in Table 7-15.

Table 7-15. N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Gg)

Year	***Tg CO_2 Eq.***	***Gg***
1990	0.1	0.2
1995	0.2	0.5
2000	0.3	1.0
2001	0.3	1.1
2002	0.3	1.1
2003	0.3	1.1
2004	0.3	1.1
2005	0.3	1.1
2006	0.3	1.1

Note: These estimates include direct N_2O emissions from N fertilizer additions only. Indirect N_2O emissions from fertilizer additions are reported in the Agriculture chapter. These estimates include emissions from both *Forest Land Remaining Forest Land* and from *Land Converted to Forest Land*.

Methodology

The IPCC Tier 1 approach was used to estimate N_2O from soils within *Forest Land Remaining Forest Land*. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted were for timber, and about 60 percent of national total harvested forest area are in the southeastern United States. It was assumed that southeastern pine plantations represent the vast majority of fertilized forests in the United States. Therefore, estimates of direct N_2O emissions from fertilizer applications to forests were based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (North Carolina Sate Forest Nutrition Cooperative 2002). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995). For each year, the area of pine receiving N fertilizer was multiplied by the midpoint of the reported range of N fertilization rates (150 lbs. N per acre). Data for areas of forests receiving fertilizer outside the southeastern United States were not available, so N additions to non-southeastern forests are not included here. It should be expected, however, that emissions from the small areas of fertilized forests in other regions would not be substantial because the majority of trees planted and harvested for timber are in the southeastern United States (USDA Forest Service 2001). Area data for pine plantations receiving fertilizer in the Southeast were not available for 2002, 2003, 2004, 2005, and 2006, so data from 2001 were used for these years. The N applied to forests was multiplied by the IPCC (2006) default emission factor of 1 percent to estimate direct N_2O emissions. The volatilization and leaching/runoff fractions, calculated according to the IPCC default factors of 10 percent and 30 percent, respectively, were included with all sources of indirect emissions in the Agricultural Soil Management source category of the Agriculture chapter.

Uncertainty

The amount of N_2O emitted from forests depends not only on N inputs, but also on a large number of variables, including organic C availability, O_2 partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. IPCC (2006) does not incorporate any of these variables into the default methodology and only accounts for variations in estimated fertilizer application rates and estimated areas of forested land receiving N fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic N fertilizers are captured, so applications of organic N fertilizers are not estimated. However, the total quantity of organic N inputs to soils is included in the Agricultural Soil Management and *Settlements Remaining Settlements* sections.

Uncertainties exist in the fertilization rates, annual area of forest lands receiving fertilizer, and the emission factors. Fertilization rates were assigned a default level[26] of uncertainty at ±50 percent, and area receiving fertilizer was assigned a ±20 percent according to expert knowledge (Binkley 2004). IPCC (2006) provided estimates for the uncertainty associated with direct N_2O emission factor for synthetic N fertilizer application to soils. Quantitative uncertainty of this source category was estimated through the IPCC-recommended Tier 2 uncertainty estimation methodology. The uncertainty ranges around the 2005 activity data and emission factor input variables were directly applied to the 2006 emissions estimates. The results of the quantitative uncertainty analysis are summarized in Table 7-16. N_2O fluxes from soils were estimated to be between 0.1 and 1.1 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 59 percent below and 211 percent above the 2006 emission estimate of 0.3 Tg CO_2 Eq.

Table 7-16: Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in *Forest Land Remaining Forest Land* (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2006 Emission Estimate**	**Uncertainty Range Relative to Emission Estimate**

---

[26] Uncertainty is unknown for the fertilization rates so a conservative value of ±50% was used in the analysis.

		(Tg CO_2 Eq.)	(Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Forest Land Remaining Forest Land: N_2O Fluxes from Soils	N_2O	0.3	0.1	1.1	-59%	+211%

Note: This estimate includes direct N_2O emissions from N fertilizer additions to both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

Recalculations Discussion

No recalculations were performed for the time series.

Planned Improvements

State-level area data will be acquired for southeastern pine plantations receiving fertilizer to estimate soil N_2O emission by state and provide information about regional variation in emission patterns.

7.3. Land Converted to Forest Land (IPCC Source Category 5A2)

Land-use change is constantly occurring, and areas under a number of differing land-use types are converted to forest each year, just as forest land is converted to other uses. However, the magnitude of these changes is not currently known. Given the paucity of available land-use information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Forest Land* from fluxes on *Forest Land Remaining Forest Land* at this time.

7.4. Cropland Remaining Cropland (IPCC Source Category 5B1)

Mineral and Organic Soil Carbon Stock Changes

Soils contain both organic and inorganic forms of C, but soil organic C (SOC) stocks are the main source or sink for atmospheric CO_2 in most soils. Changes in inorganic C stocks are typically minor. Soil organic C is the dominant organic C pool in cropland ecosystems, because biomass and dead organic matter have considerably less C and those pools are relatively ephemeral. IPCC/UNEP/OECD/IEA (1997) and IPCC (2006) recommends reporting changes in soil organic C stocks due to agricultural land-use and management activities on mineral soils and organic soils.[27]

Typical well-drained mineral soils contain from 1 to 6 percent organic C by weight, although some mineral soils that are saturated with water for substantial periods during the year may contain significantly more C (NRCS 1999). When mineral soils undergo conversion from their native state to agricultural uses, as much as half the SOC can be lost to the atmosphere. The rate and ultimate magnitude of C loss will depend on pre-conversion conditions, conversion method and subsequent management practices, climate, and soil type. In the tropics, 40 to 60 percent of the C loss generally occurs within the first 10 years following conversion; C stocks continue to decline in subsequent decades but at a much slower rate. In temperate regions, C loss can continue for several decades, reducing stocks by 20 to 40 percent of native C levels. Eventually, the soil can reach a new equilibrium that reflects a balance between C inputs (e.g., decayed plant matter, roots, and organic amendments such as manure and crop residues) and C loss through microbial decomposition of organic matter. However, land use, management, and other conditions may change before the new equilibrium is reached. The quantity and quality of organic matter inputs and their rate of decomposition are determined by the combined interaction of climate, soil properties, and land use. Land use and agricultural practices such as clearing, drainage, tillage, planting, grazing, crop residue

---

[27] CO_2 emissions associated with liming are also estimated but included in a separate section of the report.

management, fertilization, and flooding, can modify both organic matter inputs and decomposition and thereby result in a net flux of C to or from the pool of soil C.

Organic soils, also referred to as histosols, include all soils with more than 12 to 20 percent organic C by weight, depending on clay content (NRCS 1999, Brady and Weil 1999). The organic layer of these soils can be very deep (i.e., several meters), forming under inundated conditions, in which minimal decomposition of plant residue occurs. When organic soils are prepared for crop production, they are drained and tilled, leading to aeration of the soil, which accelerates the rate of decomposition and CO_2 emissions. Because of the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time. The rate of CO_2 emissions varies depending on climate and composition (i.e., decomposability) of the organic matter. Also, the use of organic soils for annual crop production leads to higher C loss rates than drainage of organic soils in grassland or forests, due to deeper drainage and more intensive management practices in cropland (Armentano and Verhoeven 1990, as cited in IPCC/UNEP/OECD/IEA 1997). C losses are estimated from drained organic soils under both grassland and cropland management in this inventory.

Cropland Remaining Cropland includes all cropland in a year of the inventory that had been cropland for the last 20 years[28] according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area of *Cropland Remaining Cropland* changes through time with land-use change. For this area, CO_2 emissions and removals[29] due to changes in mineral soil C stocks are estimated using a Tier 3 approach for the majority of annual crops. A Tier 2 IPCC method is used for the remaining crops (vegetables, tobacco, perennial/horticultural crops, and rice) not included in the Tier 3 method. In addition, a Tier 2 method is used for very gravelly, cobbly or shaley soils (i.e., classified as soils that have greater than 35 percent of soil volume comprised of gravel, cobbles or shale) and for additional changes in mineral soil C stocks that were not addressed with the Tier 2 or 3 approaches (i.e., change in C stocks after 1997 due to Conservation Reserve Program enrollment). Emissions from organic soils are estimated using a Tier 2 IPCC method.

Of the two sub-source categories, land-use and land management of mineral soils was the most important component of total net C stock change between 1990 and 2006 (see Table 7-17 and Table 7-18). In 2006, mineral soils were estimated to remove about 69.5 Tg CO_2 Eq. (19.0 Tg C). This rate of C storage in mineral soils represented about a 20 percent increase in the rate since the initial reporting year of 1990. Emissions from organic soils were about 27.7 Tg CO_2 Eq. (7.5 Tg C) in 2006. In total, U.S. agricultural soils in *Cropland Remaining Cropland* removed approximately 41.8 Tg CO_2 Eq. (11.4 Tg C) in 2006.

Table 7-17: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (Tg CO_2 Eq.)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils	(57.5)	(67.0)	(66.1)	(67.7)	(68.0)	(68.1)	(68.5)	(68.7)	(69.5)
Organic Soils	27.4	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7
Total Net Flux	**(30.1)**	**(39.4)**	**(38.4)**	**(40.0)**	**(40.3)**	**(40.5)**	**(40.9)**	**(41.0)**	**(41.8)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

Table 7-18: Net CO_2 Flux from Soil C Stock Changes in *Cropland Remaining Cropland* (Tg C)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils	(15.7)	(18.3)	(18.0)	(18.5)	(18.5)	(18.6)	(18.7)	(18.7)	(19.0)
Organic Soils	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Total Net Flux	**(8.2)**	**(10.7)**	**(10.5)**	**(10.9)**	**(11.0)**	**(11.0)**	**(11.1)**	**(11.2)**	**(11.4)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and

---

[28] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

[29] Note that removals occur through crop and forage uptake of CO_2 into biomass C that is later incorporated into soils pools.

projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

The net increase in soil C stocks (39 percent for 2006, relative to 1990) was largely due to an increase in annual cropland enrolled in the Conservation Reserve Program, intensification of crop production by limiting the use of bare-summer fallow in semi-arid regions, increased hay production, and adoption of conservation tillage (i.e., reduced- and no-till practices). At present (2006), cropland enrolled in the Conservation Reserve Program accounts for 32 percent of the increase of C stocks for *Cropland Remaining Cropland* on mineral soils (Table 7-18).

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils is displayed in Figure 7-5 and Figure 7-6. The highest rates of sequestration in mineral soils occurred in the Midwest, where there were the largest amounts of cropland managed with conservation tillage. Rates were also high in the Great Plains due to enrollment in the Conservation Reserve Program. Emission rates from drained organic soils were highest along the southeastern coastal region, in the northeast central United States surrounding the Great Lakes, and along the central and northern portions of the west coast.

Figure 7-5: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 1993-2006 *Cropland Remaining Cropland*

Figure 7-6: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 1993-2006 *Cropland Remaining Cropland*

The estimates presented here are restricted to C stock changes in agricultural soils. Agricultural soils are also important sources of other greenhouse gases, particularly N_2O from application of fertilizers, manure, and crop residues and from cultivation of legumes, as well as CH_4 from flooded rice cultivation. These emissions are accounted for in the Agriculture chapter, along with non-CO_2 greenhouse gas emissions from field burning of crop residues and CH_4 and N_2O emissions from livestock digestion and manure management.

Methodology

The following section includes a description of the methodology used to estimate changes in soil C stocks due to: (1) agricultural land-use and management activities on mineral soils; and (2) agricultural land-use and management activities on organic soils for *Cropland Remaining Cropland*.

Soil C stock changes were estimated for *Cropland Remaining Cropland* (as well as agricultural land falling into the IPCC categories *Land Converted to Cropland*, *Grassland Remaining Grassland*, and *Land Converted to Grassland*) according to land-use histories recorded in the USDA National Resources Inventory (NRI) survey (USDA-NRCS 2000). The NRI is a statistically-based sample of all non-federal land, and includes ca. 400,000 points in agricultural land of the conterminous United States and Hawaii.[30] Each point is associated with an "expansion factor" that allows scaling of C stock changes from NRI points to the entire country (i.e., each expansion factor represents the amount of area with the same land-use/management history as the sample point). Land-use and some management information (e.g., crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning in 1982, and were subdivided into four inventory time periods, 1980 through 1984, 1985 through 1989, 1990 through 1994, and 1995 through 2000.

---

[30] NRI points were classified as agricultural if under grassland or cropland management in 1992 and/or 1997.

NRI points were classified as *Cropland Remaining Cropland* for an inventory time period (e.g., 1990 through 1994 and 1995 through 2000) if the land use had been cropland for 20 years.[31] Cropland includes all land used to produce food or fiber, as well as forage that is harvested and used as feed (e.g., hay and silage).

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach was used to estimate C stock changes for mineral soils used to produce a majority of annual crops in the United States   The remaining crops on mineral soils were estimated using an IPCC Tier 2 method (Ogle et al. 2003), including vegetables, tobacco, perennial/horticultural crops, rice, and crops rotated with these crops. The Tier 2 method was also used for very gravelly, cobbly or shaley soils (greater than 35 percent by volume). Mineral SOC stocks were estimated using a Tier 2 method for these areas, because the Century model used for the Tier 3 method has not been fully tested to address its adequacy for estimating C stock changes associated with certain crops and rotations, as well as cobbly, gravelly or shaley soils. An additional stock change calculation was made for mineral soils using Tier 2 emission factors, accounting for enrollment patterns in the Conservation Reserve Program after 1997, which was not addressed by the Tier 3 methods.

Further elaboration on the methodology and data used to estimate stock changes from mineral soils are described below and in Annex 3.13.

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993), which simulates the dynamics of C and other elements in cropland, grassland, forest, and savanna ecosystems. It uses monthly weather data as input, along with information about soil physical properties. Input data on land use and management can be specified at monthly resolution and include land-use type, crop/forage type and management activities (e.g., planting, harvesting, fertilization, manure amendments, tillage, irrigation, residue removal, grazing, and fire). The model computes net primary productivity and C additions to soil, soil temperature, and water dynamics, in addition to turnover, stabilization, and mineralization of soil organic matter C and nutrient (N, K, S) elements. This method is more accurate than the Tier 1 and 2 approaches provided by the IPCC, because the simulation model treats changes as continuous over time rather than the simplified discrete changes represented in the default method (see Box 7-2 for additional information). National estimates were obtained by simulating historical land-use and management patterns as recorded in the USDA National Resources Inventory (NRI) survey. Land-use and management activities were grouped into inventory time periods (i.e., time “blocks”) for 1980 through 1984, 1985 through 1989, 1990 through 1994, and 1995 through 2000, using NRI data from 1982, 1987, 1992, and 1997, respectively.

[BEGIN BOX]

Box 7-2: Tier 3 Inventory for Soil C Stocks compared to Tier 1 or 2 Approaches

A Tier 3 model-based approach is used to inventory soil C stock changes on the majority of agricultural land with mineral soils. This approach entails several fundamental differences compared to the IPCC Tier 1 or 2 methods,

---

[31] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

which are based on a classification of land areas into a number of discrete states based on a highly aggregated classification of climate, soil, and management (i.e., only six climate regions, seven soil types and eleven management systems occur in U.S. agricultural land under the IPCC categorization scheme). Input variables to the Tier 3 model, including climate, soils, and management activities (e.g., fertilization, crop species, tillage, etc.), are represented in considerably more detail both temporally and spatially, and exhibit multi-dimensional interactions through the more complex model structure compared with the IPCC Tier 1 or 2 approach. The spatial resolution of the analysis is also finer in the Tier 3 method compared to the lower tier methods as implemented in the United States for previous inventories (e.g., 3,037 counties versus 181 Major Land Resource Areas (MLRAs), respectively).

In the Century model, soil C dynamics (and CO_2 emissions and uptake) are treated as continuous variables, which change on a monthly time step. C emissions and removals are an outcome of plant production and decomposition processes, which are simulated in the model structure. Thus, changes in soil C stocks are influenced by not only changes in land use and management but also inter-annual climate variability and secondary feedbacks between management activities, climate and soils as they affect primary production and decomposition. This latter characteristic constitutes one of the greatest differences between the methods, and forms the basis for a more complete accounting of soil C stock changes in the Tier 3 approach compared with Tier 2 methodology.

Because the Tier 3 model simulates a continuous time period rather than as an equilibrium step change used in the IPCC methodology (Tier 1 and 2), the Tier 3 model addresses the delayed response of the soil to management and land-use changes, which can occur due to variable weather patterns and other environmental constraints that interact with land use and management and affect the time frame over which stock changes occur. Moreover, the Tier 3 method also accounts for the overall effect of increasing yields and, hence, C input to soils that have taken place across management systems and crop types within the United States. Productivity has increased by 1 to 2 percent annually over the past 4 to 5 decades for most major crops in the United States (Reilly and Fuglie 1998), which is believed to have led to increases in cropland soil C stocks (e.g., Allmaras et al. 2000). This is a major difference from the IPCC-based Tier 1 and 2 approaches, in which soil C stocks change only with discrete changes in management and/or land use, rather than a longer term trend such as gradual increases in crop productivity.

[END BOX]

Additional sources of activity data were used to supplement the land-use information from NRI. The Conservation Technology Information Center (CTIC 1998) provided annual data on tillage activity at the county level since 1989, with adjustments for long-term adoption of no-till agriculture (Towery 2001). Information on fertilizer use and rates by crop type for different regions of the United States were obtained primarily from the USDA Economic Research Service Cropping Practices Survey (ERS 1997) with additional data from other sources, including the National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to cropland during 1997 were estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds et al. 2003), and then adjusted using county-level estimates of manure available for application in other years of the inventory. Specifically, county-scale ratios of manure available in other years relative to 1997 were used to adjust the area amended with manure (see Annex 3.13 for further details). Greater availability of managed manure N relative to 1997 was, thus, assumed to increase the amount of area amended with manure, while reduced availability of manure N relative to 1997 was assumed to reduce the amended area.

The amount of manure produced by each livestock type was calculated for managed and unmanaged waste management systems. Managed systems include feedlots or other housing (which requires manure to be collected and managed); unmanaged systems include daily spread, pasture, range, and paddock systems. Annual animal population data for all livestock types, except horses and goats, were obtained for all years from the U.S. Department of Agriculture-National Agricultural Statistics Service. Population data used for cattle, swine, and sheep were downloaded from the USDA NASS Population Estimates Database (USDA 2007a). Poultry population data were obtained from USDA NASS reports (USDA 1995a, 1995b, 1998a, 1999, 2004a, 2004b, 2006a, 2006b, 2007b, 2007c). Horse population data were obtained from the FAOSTAT database (FAO 2007). Goat population data for 1992, 1997, and 2002 were obtained from the *Census of Agriculture* (USDA 2005); these data were interpolated and extrapolated to derive estimates for the other years. Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the 1992, 1997, and 2002 *Census of Agriculture* (USDA 2005).

Manure amendments were an input to the Century Model based on manure N available for application from all managed or unmanaged systems except Pasture/Range/Paddock.[32] Data on the county-level N available for application were estimated for managed systems based on the total amount of N excreted in manure minus N losses and including the addition of N from bedding materials. N losses include direct nitrous oxide emissions, volatilization of ammonia and NOx, and runoff and leaching. More information on these losses is available in the description of the Manure Management source category. Animal-specific bedding factors were set equal to IPCC default factors (IPCC 2006). For unmanaged systems, it is assumed that no N losses or additions occur.

Monthly weather data, aggregated to county-scale from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database (Daly et al. 1994), were used as an input in the model simulations. Soil attributes, which were obtained from an NRI database, were assigned based on field visits and soil series descriptions. Where more than one inventory point was located in the same county (i.e., same weather) and had the same land-use/management histories and soil type, data inputs to the model were identical and, therefore, these points were clustered for simulation purposes. For the 370,738 NRI points representing non-federal cropland and grassland, there were a total of 170,279 clustered points that represent the unique combinations of climate, soils, land use, and management in the modeled data set. Each NRI cluster point was run 100 times as part of the uncertainty assessment, yielding a total of over 14 million simulation runs for the analysis. C stock estimates from Century were adjusted using a structural uncertainty estimator accounting for uncertainty in model algorithms and parameter values (Ogle et al. 2007). Mean changes in C stocks and 95 percent confidence intervals were estimated for 1990 to 1994 and 1995 to 2000 (see Uncertainty section for more details). C stock changes from 2001 to 2006 were assumed to be similar to the 1995 to 2000 block, because no additional activity data are currently available from the NRI for the latter years.

Tier 2 Approach

In the IPCC Tier 2 method, data on climate, soil types, land-use, and land management activity were used to classify land area to apply appropriate stock change factors. MLRAs formed the base spatial unit for mapping climate regions in the United States; each MLRA represents a geographic unit with relatively similar soils, climate, water resources, and land uses (NRCS 1981).[33] MLRAs were classified into climate regions according to the IPCC categories using the PRISM climate database of Daly et al. (1994).

Reference C stocks were estimated using the National Soil Survey Characterization Database (NRCS 1997) with cultivated cropland as the reference condition, rather than native vegetation as used in IPCC (2003, 2006). Changing the reference condition was necessary because soil measurements under agricultural management are much more common and easily identified in the National Soil Survey Characterization Database (NRCS 1997) than those that are not considered cultivated cropland.

U.S.-specific stock change factors were derived from published literature to determine the impact of management practices on SOC storage, including changes in tillage, cropping rotations and intensification, and land-use change between cultivated and uncultivated conditions (Ogle et al. 2003, Ogle et al. 2006).[34] U.S. factors associated with

---

[32] Pasture/Range/Paddock manure additions to soils are addressed in the *Grassland Remaining Grassland* and *Land Converted to Grassland* categories.

[33] The polygons displayed in Figure 7-5 through Figure 7-6 are the Major Land Resource Areas.

[34] Stock change factors have been derived from published literature to reflect changes in tillage, cropping rotations and intensification, land-use change between cultivated and uncultivated conditions, and drainage of organic soils.

organic matter amendments were not estimated because of an insufficient number of studies to analyze those impacts. Instead, factors from IPCC (2003) were used to estimate the effect of those activities. Euliss and Gleason (2002) provided the data for computing the change in SOC storage resulting from restoration of wetland enrolled in the Conservation Reserve Program.

Similar to the Tier 3 Century method, activity data were primarily based on the historical land-use/management patterns recorded in the NRI. Each NRI point was classified by land use, soil type, climate region (using PRISM data, Daly et al. 1994) and management condition. Classification of cropland area by tillage practice was based on data from the Conservation Tillage Information Center (CTIC 1998, Towery 2001) as described above. Activity data on wetland restoration of Conservation Reserve Program land were obtained from Euliss and Gleason (2002). Manure N amendments over the inventory time period were based on application rates and areas amended with manure N from Edmonds et al. (2003), in addition to the managed manure production data discussed in the previous methodology subsection on the Tier 3 analysis for mineral soils.

Combining information from these data sources, SOC stocks for mineral soils were estimated 50,000 times for 1982, 1992, and 1997, using a Monte Carlo simulation approach and the probability distribution functions for U.S.-specific stock change factors, reference C stocks, and land-use activity data (Ogle et al. 2002, Ogle et al. 2003). The annual C flux for 1990 through 1992 was determined by calculating the average annual change in stocks between 1982 and 1992; annual C flux for 1993 through 2006 was determined by calculating the average annual change in stocks between 1992 and 1997.

Additional Mineral C Stock Change

Annual C flux estimates for mineral soils between 1990 and 2006 were adjusted to account for additional C stock changes associated with gains or losses in soil C after 1997 due to changes in Conservation Reserve Program enrollment. The change in enrollment acreage relative to 1997 was based on data from USDA-FSA (2007) for 1998 through 2006, and the differences in mineral soil areas were multiplied by 0.5 metric tons C per hectare per year to estimate the net effect on soil C stocks. The stock change rate is based on estimations using the IPCC method (see Annex 3.13 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Cropland Remaining Cropland* were estimated using the Tier 2 method provided in IPCC (2003, 2006), with U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. Similar to the Tier 2 analysis for mineral soils, the final estimates included a measure of uncertainty as determined from the Monte Carlo simulation with 50,000 iterations. Emissions were based on the 1992 and 1997 *Cropland Remaining Cropland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2006.

Uncertainty

Uncertainty associated with the *Cropland Remaining Cropland* land-use category was addressed for changes in agricultural soil C stocks (including both mineral and organic soils). Uncertainty estimates are presented in Table 7-19 for mineral soil C stocks and organic soil C stocks disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in soil C stocks occurring within *Cropland Remaining Cropland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006). The combined uncertainty was calculated by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. More details on how the individual uncertainties were developed appear later in this section. The combined uncertainty for soil C stocks in *Cropland Remaining Cropland* ranged from 38 percent below and 35 percent above the 2006 stock change estimate of -41.8 Tg CO_2 Eq.

Table 7-19: Quantitative Uncertainty Estimates for C Stock Changes occurring within *Cropland Remaining*

Cropland (Tg CO_2 Eq. and Percent)

Source	2006 Flux Estimate[1] (Tg CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[1] (Tg CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: *Cropland Remaining Cropland*, Tier 3 Inventory Methodology	(64.0)	(74.1)	(53.5)	-16%	+16%
Mineral Soil C Stocks: *Cropland Remaining Cropland*, Tier 2 Inventory Methodology	(3.0)	(6.9)	0.8	-127%	+128%
Mineral Soil C Stocks: *Cropland Remaining Cropland* (Change in CRP enrollment relative to 1997)	(2.5)	(3.7)	(1.2)	-50%	+50%
Organic Soil C Stocks: *Cropland Remaining Cropland*, Tier 2 Inventory Methodology	27.7	15.8	36.9	-43%	+33%
Combined Uncertainty for Flux associated with Agricultural Soil Carbon Stock Change in *Cropland Remaining Cropland*	**(41.8)**	**(57.9)**	**(27.3)**	**-38%**	**+35%**

[1] Flux estimates based on soil C stock changes.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data were properly handled through the inventory process. The manure amendment records were not recorded correctly in a subset of the Century model output; corrective actions were taken to resolve this error. As discussed in the uncertainty sections, results were compared to field measurements, and a statistical relationship was developed to assess uncertainties in the model's predictive capability. The comparisons included over 40 long-term experiments, representing about 800 combinations of management treatments across all of the sites (Ogle et al. 2007). Inventory reporting forms and text were reviewed and revised as needed to correct transcription errors.

Recalculations Discussion

Two changes were implemented in the current inventory that led to a change in the time series. First, there was a modification in the land use classification. The classification is based on the land use in a specific year of the inventory and the previous 20 years. However, in the 1990 through 2005 inventory, each point was only classified once based on the entire NRI time series of the land-use history. This approach led to incorrect classifications for the early 1990s. For example, a NRI point may have been cropland in 1982, 1987 and 1992, but converted to grassland in 1997. In the previous inventory, the NRI point would be classified as *Land Converted to Grassland* for the entire inventory from 1990 through 2005. This is incorrect for the early 1990s because the point was *Cropland Remaining Cropland* during those years. Second, the time series for manure N between 1990 and 2006, which was used to adjust manure applications relative to 1997, was based on manure N available for application rather than manure N production. Overall, the recalculations resulted in an average annual decrease of 1.9 Tg CO_2 Eq. for the period 1990 through 2005, compared to the previous inventory.

Planned Improvements

Several improvements are planned for the agricultural soil C inventory. The first improvement is to incorporate new land-use and management activity data from the NRI. In the current inventory, NRI data only provide land-use and management statistics through 1997, but it is anticipated that new statistics will be released in the coming year for 2000 through 2003. The new data will greatly improve the accuracy of land-use and management influences on soil C in the latter part of the time series.

The second improvement is to incorporate additional crops into the Tier 3 approach. Currently, crops such as vegetables, rice, perennial and horticultural crops have not been fully implemented in the Century model application. However, efforts are currently underway to further develop the model application for simulating soil C dynamics in land managed for production of these crops. This improvement is expected to reduce uncertainties in the inventory results.

The third improvement is to incorporate remote sensing in the analysis for estimation of crop and forage production. Specifically, the Enhanced Vegetation Index (EVI) product that is derived from MODIS satellite imagery is being used to refine the production estimation for the Tier 3 assessment framework. EVI reflects changes in plant "greenness" over the growing season and can be used to compute production based on the light use efficiency of the crop or forage (Potter et al. 1993). In the current framework, production is simulated based on the weather data, soil characteristics, and the genetic potential of the crop. While this method produces reasonable results, remote sensing can be used to refine the productivity estimates and reduce biases in crop production and subsequent C input to soil systems. It is anticipated that precision in the Tier 3 assessment framework will be increased by 25 percent or more with the new method.

The fourth improvement is to develop an automated quality control system to evaluate the results from Century model simulations. Currently, there are over 14 million simulations, and it is not possible to manually review each simulation. Results are aggregated and evaluated at larger scales such as MLRAs and States. QA/QC at these larger scales may not uncover errors at the scale of individual NRI points, which is the scale at which the Century model is used to simulate soil C dynamics. An automated system would greatly improve QA/QC, performing checks on the results from each simulation and identifying errors for further refinements.

The final improvement is to further develop the uncertainty analysis for the Tier 3 method by addressing the uncertainty inherent in the Century model results for other agricultural land (i.e., *Grassland Remaining Grassland*, *Land Converted to Grassland*, and *Land Converted to Cropland*). In addition, uncertainties need to be addressed in the simulation of soil C stocks for the pre-NRI time period (i.e., before 1979). In the current analysis, inventory development focused on uncertainties in the last two decades because the management activity during the most recent time periods will likely have the largest impact on current trends in soil C storage. However, legacy effects of past management can also have a significant effect on current C stock trends, as well as trajectories of those C stocks in the near future. Therefore, a planned improvement is to revise the inventory to address uncertainties in management activity prior to 1979, providing a more rigorous accounting of uncertainties associated with the Tier 3 method.

CO_2 Emissions from Agricultural Liming

IPCC (2006) recommends reporting CO_2 emissions from lime additions (in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils. Limestone and dolomite are added by land managers to ameliorate acidification. When these compounds come in contact with acid soils, they degrade, thereby generating CO_2. The rate and ultimate magnitude of degradation of applied limestone and dolomite depends on the soil conditions, climate regime, and the type of mineral applied. Emissions from liming have fluctuated over the past sixteen years, ranging from 3.9 Tg CO_2 Eq. to 5.0 Tg CO_2 Eq. In 2006, liming of agricultural soils in the United States resulted in emissions of 4.4 Tg CO_2 Eq. (1.2 Tg C), representing about a 6 percent decrease in emissions since 1990 (see Table 7-17 and Table 7-18).

Table 7-20: Emissions from Liming of Agricultural Soils (Tg CO_2 Eq.)

Source	**1990**		**1995**		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Liming of Soils[1]	4.7		4.4		4.3	4.4	5.0	4.6	3.9	4.3	4.4

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

[1] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

Table 7-21: Emissions from Liming of Agricultural Soils (Tg C)

Source	**1990**		**1995**		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Liming of Soils[1]	1.3		1.2		1.2	1.2	1.4	1.2	1.1	1.2	1.2

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on

historical data only.
[1] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

Methodology

CO_2 emissions from degradation of limestone and dolomite applied to agricultural soils were estimated using a Tier 2 methodology consistent with IPCC (2006). The annual amounts of limestone and dolomite applied (see Table 7-22) were multiplied by CO_2 emission factors from West and McBride (2005). These emission factors (0.059 metric ton C/metric ton limestone, 0.064 metric ton C/metric ton dolomite) are lower than the IPCC default emission factors, because they account for the portion of agricultural lime that may leach through the soil and travel by rivers to the ocean (West and McBride 2005). The annual application rates of limestone and dolomite were derived from estimates and industry statistics provided in the *Minerals Yearbook* and *Mineral Industry Surveys* (Tepordei 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006; Willett 2007; USGS 2007). To develop these data, the U.S. Geological Survey (USGS; U.S. Bureau of Mines prior to 1997) obtained production and use information by surveying crushed stone manufacturers. Because some manufacturers were reluctant to provide information, the estimates of total crushed limestone and dolomite production and use were divided into three components: (1) production by end-use, as reported by manufacturers (i.e., “specified” production); (2) production reported by manufacturers without end-uses specified (i.e., “unspecified” production); and (3) estimated additional production by manufacturers who did not respond to the survey (i.e., “estimated” production).

The “unspecified” and “estimated” amounts of crushed limestone and dolomite applied to agricultural soils were calculated by multiplying the percentage of total “specified” limestone and dolomite production applied to agricultural soils by the total amounts of “unspecified” and “estimated” limestone and dolomite production. In other words, the proportion of total “unspecified” and “estimated” crushed limestone and dolomite that was applied to agricultural soils (as opposed to other uses of the stone) was assumed to be proportionate to the amount of “specified” crushed limestone and dolomite that was applied to agricultural soils. In addition, data were not available for 1990, 1992, and 2006 on the fractions of total crushed stone production that were limestone and dolomite, and on the fractions of limestone and dolomite production that were applied to soils. To estimate the 1990 and 1992 data, a set of average fractions were calculated using the 1991 and 1993 data. These average fractions were applied to the quantity of "total crushed stone produced or used" reported for 1990 and 1992 in the 1994 *Minerals Yearbook* (Tepordei 1996). To estimate 2006 data, the previous year’s fractions were applied to a 2006 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2007* (USGS 2007).

The primary source for limestone and dolomite activity data is the *Minerals Yearbook*, published by the Bureau of Mines through 1994 and by the USGS from 1995 to the present. In 1994, the “Crushed Stone” chapter in the *Minerals Yearbook* began rounding (to the nearest thousand) quantities for total crushed stone produced or used. It then reported revised (rounded) quantities for each of the years from 1990 to 1993. In order to minimize the inconsistencies in the activity data, these revised production numbers have been used in all of the subsequent calculations. Since limestone and dolomite activity data are also available at the state level, the national-level estimates reported here were broken out by state for the first time this year, but are not reported here.

Table 7-22: Applied Minerals (Million Metric Tons)

Mineral	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Limestone	19.01	17.30	15.86	16.10	20.45	18.71	15.50	18.09	18.20
Dolomite	2.36	2.77	3.81	3.95	2.35	2.25	2.33	1.85	1.87

Note: These numbers represent amounts applied to all agricultural land, including *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

Uncertainty

Uncertainty regarding limestone and dolomite activity data inputs was estimated at ±15 percent and assumed to be uniformly distributed around the inventory estimate (Tepordei 2003b). Analysis of the uncertainty associated with the emission factors included the following: the fraction of agricultural lime dissolved by nitric acid versus the fraction that reacts with carbonic acid, and the portion of bicarbonate that leaches through the soil and is transported to the ocean. Uncertainty regarding the time associated with leaching and transport was not accounted for, but should not change the uncertainty associated with CO_2 emissions (West 2005). The uncertainty associated with the fraction of agricultural lime dissolved by nitric acid and the portion of bicarbonate that leaches through the soil were each modeled as a smoothed triangular distribution between ranges of 0 percent to 100 percent. The uncertainty surrounding these two components largely drives the overall uncertainty estimates reported below. More information on the uncertainty estimates for Liming of Agricultural Soils is contained within the Uncertainty Annex.

A Monte Carlo (Tier 2) uncertainty analysis was applied to estimate the uncertainty of CO_2 emissions from liming. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-23. CO_2 emissions from Liming of Agricultural Soils in 2006 were estimated to be between 0.2 and 8.5 Tg CO_2 Eq. at the 95 percent confidence level. This indicates a range of 95 percent below to 95 percent above the 2006 emission estimate of 4.4 Tg CO_2 Eq.

Table 7-23: Tier 2 Quantitative Uncertainty Estimates for CO_2 Emissions from Liming of Agricultural Soils (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2006 Emissions Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emissions Estimate**[a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Liming of Agricultural Soils[1]	CO_2	4.4	0.2	8.5	-95%	95%

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

[1] Also includes emissions from liming on *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. The QA/QC analysis did not reveal any inaccuracies or incorrect input values.

Recalculations Discussion

Several adjustments were made in the current inventory to improve the results. The quantity of applied minerals reported in the previous inventory for 2005 has been revised. Consequently, the reported emissions resulting from liming in 2005 have also changed. In the previous inventory, to estimate 2005 data, the previous year's fractions were applied to a 2005 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2006* (USGS 2006). Since publication of the previous inventory, the *Minerals Yearbook* has published actual quantities of crushed stone sold or used by producers in the United States in 2005. These values have replaced those used in the previous inventory to calculate the quantity of minerals applied to soil and the emissions from liming.

CO_2 Emissions from Urea Fertilization

The use of urea ($CO(NH_2)_2$) as fertilizer leads to emissions of CO_2 that was fixed during the industrial production process. Urea in the presence of water and urease enzymes is converted into ammonium (NH_4^+), hydroxyl ion (OH^-), and bicarbonate (HCO_3^-). The bicarbonate then evolves into CO_2 and water. Emissions from urea fertilization in the US totaled 3.6 Tg CO_2 Eq. (1.0 Tg C) in 2006 (Table 7-24 and Table 7-25). Emissions from urea fertilization have fluctuated over the past sixteen years, ranging from 2.3 Tg CO_2 Eq. to 3.7 Tg CO_2 Eq.

Table 7-24: CO_2 Emissions from Urea Fertilization in *Cropland Remaining Cropland* (Tg CO_2 Eq.)

Source	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Urea Fertilization[1]	2.4	2.7	3.2	3.4	3.6	3.7	3.7	3.5	3.6

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

[1] Also includes emissions from urea fertilization on *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

Table 7-25: CO_2 Emissions from Urea Fertilization in *Cropland Remaining Cropland* (Tg C)

Source	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Urea Fertilization[1]	0.7	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

[1] Also includes emissions from urea fertilization on *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland.*

Methodology

Carbon dioxide emissions from the application of urea to agricultural soils were estimated using the IPCC (2006) Tier 1 methodology. The annual amounts of urea fertilizer applied (see Table 7-26) were derived from state-level fertilizer sales data provided in *Commercial Fertilizers* (TVA 1991, 1992, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006) and were multiplied by the default IPCC (2006) emission factor of 0.20, which is equal to the C content of urea on an atomic weight basis. Because fertilizer sales data are reported in fertilizer years (July through June), a calculation was performed to convert the data to calendar years (January through December). According to historic monthly fertilizer use data (TVA 1992b), 65 percent of total fertilizer used in any fertilizer year is applied between January through June of that calendar year, and 35 percent of total fertilizer used in any fertilizer year is applied between July through December of the previous calendar year. Fertilizer use data for the 2007 fertilizer year were not available in time for publication, so July through December 2006 fertilizer use was estimated by calculating the percent change (increase or decrease) in fertilizer use from January through June 2005 to July through December 2005. This percent change was then multiplied by the January through June 2006 data to estimate July through December 2006 fertilizer use. State-level estimates of CO_2 emissions from the application of urea to agricultural soils were summed to estimate total emissions for the entire United States.

Table 7-26: Applied Urea (Million Metric Tons)

	1990	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Urea Fertilizer[1]	3.30	3.62	4.38	4.66	4.87	5.02	4.98	4.78	4.96

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

[1] These numbers represent amounts applied to all agricultural land, including *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland*.

Uncertainty

Uncertainty estimates are presented in Table 7-27 for Urea Fertilization. A Tier 2 Monte Carlo analysis was completed. The largest source of uncertainty was the default emission factor, which assumes that 100 percent of the C applied to soils is ultimately emitted into the environment as CO_2. This factor does not incorporate the possibility that some of the C may be retained in the soil. The emission estimate is, thus, likely to be high. In addition, each urea consumption data point has an associated uncertainty. Urea for non-fertilizer use may be included in consumption totals; it was determined through personal communication with Fertilizer Regulatory Program Coordinator David L. Terry (2007), however, that amount is most likely very small. Lastly, there is uncertainty surrounding the assumptions behind the calculation that converts fertilizer years to calendar years. CO_2 emissions from Urea Fertilization of Agricultural Soils in 2006 were estimated to be between 2.1 and 3.8 Tg CO_2 Eq. at the 95 percent confidence level. This indicates a range of 43 percent below to 3 percent above the 2006 emission estimate of 3.6 Tg CO_2 Eq.

Table 7-27: Quantitative Uncertainty Estimates for CO_2 Emissions from Urea Fertilization (Tg CO_2 Eq. and Percent)

Source	**Gas**	**2006 Emissions Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Emissions Estimate[a]**			
			(Tg CO_2 Eq.)		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Urea Fertilization	CO_2	3.6	2.1	3.8	-43%	3%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: These numbers represent amounts applied to all agricultural land, including *Land Converted to Cropland, Grassland Remaining Grassland,* and *Land Converted to Grassland*.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. Minor errors were found in these steps and corrective actions were taken, including a data point that was incorrectly transcribed. Inventory reporting forms and text were reviewed and revised as needed to correct transcription errors.

Recalculations Discussion

Emissions from Urea production and application were previously included in the Industrial Processes Chapter. That chapter has been modified to only include emissions from Urea production.

Planned Improvements

Several improvements are planned for the urea fertilization inventory. The first improvement is to investigate using a Tier 2 or Tier 3 approach, which would utilize country-specific information to estimate a more precise emission factor. The second improvement is to investigate and quantify, if possible, the amount of urea that is currently included in urea consumption totals, but is used for non-agricultural practices such as deicing.

7.5. Land Converted to Cropland (IPCC Source Category 5B2)

Land Converted to Cropland includes all cropland in an inventory year that had been another land use in the past 20 years[35] according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area considered in *Land Converted to Cropland* changes through time with land-use change. Lands are retained in this category for 20 years as recommended by the IPCC guidelines (IPCC 2006) unless there is another land-use change. Background on agricultural C stock changes is provided in *Cropland Remaining Cropland* and will only be summarized here for *Land Converted to Cropland*. Soils are the largest pool of C in agricultural land, and also have the greatest potential for storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared with soils. The IPCC/UNEP/OECD/IEA (1997) and the IPCC (2003, 2006) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[36]

Land-use and management of mineral soils in *Land Converted to Cropland* led to losses of soil C during the early 1990s but losses declined slightly through the latter part of the time series (Table 7-28 and Table 7-29). The total rate of change in soil C stocks was 9.4 Tg CO_2 Eq. (2.6 Tg C) in 2006. Emissions from mineral soils were

---

[35] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

[36] CO_2 emissions associated with liming are also estimated but included in a separate section of the report.

estimated at 6.7 Tg CO_2 Eq. (1.8 Tg C) in 2006, while drainage and cultivation of organic soils led to annual losses of 2.6 Tg CO_2 Eq. (0.7 Tg C) in 2006.

Table 7-28: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Cropland* (Tg CO_2 Eq.)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils	12.3	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Organic Soils	2.4	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Total Net Flux	**14.7**	**9.4**	**9.4**	**9.4**	**9.4**	**9.4**	**9.4**	**9.4**	**9.4**

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

Table 7-29: Net CO_2 Flux from Soil C Stock Changes in *Land Converted to Cropland* (Tg C)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils	3.4	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Organic Soils	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Total Net Flux	**4.0**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**	**2.6**

Note: Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils for *Land Converted to Cropland* is displayed in Figure 7-7 and Figure 7-8. While a large portion of the United States had net losses in soil C for *Land Converted to Cropland*, there were some notable areas with sequestration in the Intermountain West and Central United States. These areas were gaining C following conversion, because croplands were irrigated or receiving higher fertilizer inputs relative to the previous land use. Emissions from organic soils were largest in California, Florida and the upper Midwest, which coincided with largest concentrations of cultivated organic soils in the United States.

Figure 7-7: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 1993-2006
Land Converted to Cropland

Figure 7-8: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 1993-2006
Land Converted to Cropland

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks due to agricultural land-use and management activities on mineral and organic soils for *Land Converted to Cropland*.

Soil C stock changes were estimated for *Land Converted to Cropland* according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2000).[37] Land use and some management information (e.g., crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning in 1982, and were subdivided into four inventory time periods, 1980 through 1984, 1985 through 1989, 1990 through 1994 and 1995 through 2000. NRI points were classified as *Land Converted to Cropland* for an inventory time period (e.g., 1990 through 1994 and 1995 through 2000) if the land use was cropland in the respective inventory time period but had

---

[37] More recent NRI land use survey data are available and will be incorporated by the public review.

been another use during the previous 20 years.[38] Cropland includes all land used to produce food or fiber, as well as forage that is harvested and used as feed (e.g., hay and silage). Further elaboration on the methodologies and data used to estimate stock changes for mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.13.

Mineral Soil Carbon Stock Changes

A Tier 3 model-based approach was used to estimate C stock changes for soils on *Land Converted to Cropland* used to produce a majority of all crops. Soil C stock changes on the remaining soils were estimated with the IPCC Tier 2 method (Ogle et al. 2003), including land used to produce vegetable, tobacco, perennial/horticultural crops, and rice; land on very gravelly, cobbly or shaley soils (greater than 35 percent by volume); and land converted from forest or federal ownership.[39]

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model for the Tier 3 methods. National estimates were obtained by using the model to simulate historical land-use change patterns as recorded in the USDA National Resources Inventory (USDA-NRCS 2000). The methods used for *Land Converted to Cropland* are the same as those described in the Tier 3 portion of *Cropland Remaining Cropland* Section for mineral soils (see *Cropland Remaining Cropland* Tier 3 methods section for additional information).

Tier 2 Approach

For the mineral soils not included in the Tier 3 analysis, SOC stock changes were estimated using a Tier 2 Approach for *Land Converted to Cropland* as described in the Tier 2 portion of *Cropland Remaining Cropland* Section for mineral soils (see *Cropland Remaining Cropland* Tier 2 methods section for additional information).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Cropland* were estimated using the Tier 2 method provided in IPCC (2003, 2006), with U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. The final estimates included a measure of uncertainty as determined from the Monte Carlo simulation with 50,000 iterations. Emissions were based on the 1992 and 1997 *Land Converted to Cropland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2006.

Uncertainty

Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 approaches were based on the same method described for *Cropland Remaining Cropland*, except that the uncertainty inherent in the structure of the Century model was not addressed. The uncertainty for annual C emission estimates from drained organic soils in *Land Converted to Cropland* was estimated using the Tier 2 approach, as described in the *Cropland Remaining Cropland* Section.

Uncertainty estimates are presented in Table 7-30 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). A combined

---

[38] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

[39] Federal land is not a land use, but rather an ownership designation that is treated as forest or nominal grassland for purposes of these calculations. The specific use for federal lands is not identified in the NRI survey (USDA-NRCS 2000).

uncertainty estimate for changes in agricultural soil C stocks occurring within *Land Converted to Cropland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Land Converted to Cropland* was estimated to be 25 percent below and 22 percent above the inventory estimate of 9.4 Tg CO_2 Eq.

Table 7-30: Quantitative Uncertainty Estimates[1] for C Stock Changes occurring within *Land Converted to Cropland* (Tg CO_2 Eq. and Percent)

Source	**2006 Flux Estimate[1] (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Flux Estimate[1] (Tg CO_2 Eq.)**		**(%)**	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Mineral Soil C Stocks: *Land Converted to Cropland*, Tier 3 Inventory Methodology	2.6	2.0	3.1	-21%	21%
Mineral Soil C Stocks: *Land Converted to Cropland*, Tier 2 Inventory Methodology	4.1	2.3	5.8	-44%	41%
Organic Soil C Stocks: *Land Converted to Cropland*, Tier 2 Inventory Methodology	2.6	1.2	3.7	-53%	41%
Combined Uncertainty for Flux associated with Soil Carbon Stock Change in *Land Converted to Cropland*	**9.4**	**7.0**	**11.4**	**-25%**	**22%**

[1] Flux estimates based on soil C stock change.

QA/QC and Verification

See QA/QC and Verification Section under *Cropland Remaining Cropland*.

Recalculations Discussion

Two changes were implemented in the current inventory that led to a change in the time series. First, there was a modification in the land use classification. The classification is based on the land use in a specific year of the inventory and the previous 20 years. However, in the 1990 through 2005 inventory, each point was only classified once based on the entire NRI time series of the land-use history. This approach led to incorrect classifications for the early 1990s. For example, a NRI point may have been grassland in 1982, 1987 and 1992, but converted to cropland in 1997. In the previous inventory, the NRI point would be classified as *Land Converted to Cropland* for the entire inventory from 1990 through 2005. This is incorrect for the early 1990s because the point was *Grassland Remaining Grassland* during those years. Second, the time series for manure N between 1990 through 2006, which was used to adjust manure applications relative to 1997, was based on manure N available for application rather than manure N production. Overall, these recalculations resulted in an average annual increase in emissions of 3.3 Tg CO_2 Eq. for soil C stock changes in *Land Converted to Cropland* over the time series from 1990 through 2005, compared to the previous inventory.

Planned Improvements

The empirically-based uncertainty estimator described in the *Cropland Remaining Cropland* section for the Tier 3 approach has not been developed to estimate uncertainties related to the structure of Century model for *Land Converted to Cropland*, but this is a planned improvement. This improvement will produce a more rigorous assessment of uncertainty. See Planned Improvements section under *Cropland Remaining Cropland* for additional planned improvements.

7.6. Grassland Remaining Grassland (IPCC Source Category 5C1)

Grassland Remaining Grassland includes all grassland in an inventory year that had been grassland for the previous

20 years[40] according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area considered in *Grassland Remaining Grassland* changes through time with land-use change. Background on agricultural C stock changes is provided in the *Cropland Remaining Cropland* section and will only be summarized here for *Grassland Remaining Grassland*. Soils are the largest pool of C in agricultural land, and also have the greatest potential for storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared to soils. The IPCC/UNEP/OECD/IEA (1997) and IPCC (2003, 2006) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[41]

Land-use and management of mineral soils in *Grassland Remaining Grassland* increased soil C during the early 1990s, but this trend was reversed over the decade, with small losses of C prevailing during the latter part of the time series. Organic soils lost about the same amount of C in each year of the inventory. Due to the pattern for mineral soils, the overall trend shifted from small increases in soil C during 1990 to decreases in soil C during the latter years of the inventory, estimated at 16.2 Tg CO_2 Eq. (4.4 Tg C) in 2006. Overall, flux rates changed by 18.1 Tg CO_2 Eq. (4.9 Tg C) from 1990 to 2006.

Table 7-31: Net CO_2 Flux from Soil C Stock Changes in *Grassland Remaining Grassland* (Tg CO_2 Eq.)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils	(5.7)	12.9	12.8	12.7	12.7	12.7	12.6	12.6	12.5
Organic Soils	3.9	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Total Net Flux	**(1.9)**	**16.6**	**16.4**	**16.4**	**16.4**	**16.4**	**16.3**	**16.3**	**16.2**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

Table 7-32: Net CO2 Flux from Soil C Stock Changes in Grassland Remaining Grassland (Tg C)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils	(1.6)	3.5	3.5	3.5	3.5	3.5	3.4	3.4	3.4
Organic Soils	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total Net Flux	**(0.5)**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**	**4.4**	**4.4**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils is displayed in Figure 7-9 and Figure 7-10. Grassland is losing soil organic C in the United States largely due to droughts that are causing small losses of C on a per hectare basis, but are occurring over a large land base. In areas with net gains in soil organic C, sequestration was driven by irrigation and seeding legumes. Similar to *Cropland Remaining Cropland*, emission rates from drained organic soils were highest along the southeastern coastal region, in the northeast central United States surrounding the Great Lakes, and along the central and northern portions of the west coast.

Figure 7-9: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 1993-2006
Grassland Remaining Grassland

---

[40] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

[41] CO_2 emissions associated with liming are also estimated but included in a separate section of the report.

Figure 7-10: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 1993-2006 *Grassland Remaining Grassland*

Methodology

The following section includes a brief description of the methodology used to estimate changes in soil C stocks due to agricultural land-use and management activities on mineral and organic soils for *Grassland Remaining Grassland*.

Soil C stock changes were estimated for *Grassland Remaining Grassland* according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2000).[42] Land use and some management information (e.g., irrigation, legume pastures) were collected for each NRI point on a 5-year cycle beginning in 1982, 1980 through 1984, 1985 through 1989, 1990 through 1994 and 1995 through 2000. NRI points were classified as *Grassland Remaining Grassland* for an inventory time period (e.g., 1990 through 1994 and 1995 through 2000) if the land use was grassland in the inventory time period and had been grassland for the previous 20 years.[43] Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are often seeded grassland, possibly following tree removal, that may or may not be improved with practices such as irrigation and interseeding legumes. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.13.

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach was used to estimate C stock changes for most mineral soils in *Grassland Remaining Grassland*. The C stock changes for the remaining soils were estimated with an IPCC Tier 2 method (Ogle et al. 2003), including gravelly, cobbly or shaley soils (greater than 35 percent by volume) and additional stock changes associated with sewage sludge amendments.

Tier 3 Approach

Mineral soil organic C stocks and stock changes for *Grassland Remaining Grassland* were estimated using the Century biogeochemical model, as described in *Cropland Remaining Cropland*. Historical land-use and management patterns were used in the Century simulations as recorded in the USDA National Resources Inventory (NRI) survey, with supplemental information on fertilizer use and rates from the USDA Economic Research Service Cropping Practices Survey (ERS 1997) and National Agricultural Statistics Service (NASS 1992, 1999, 2004). Frequency and rates of manure application to grassland during 1997 were estimated from data compiled by the USDA Natural Resources Conservation Service (Edmonds, et al. 2003), and then adjusted using county-level estimates of manure available for application in other years of the inventory. Specifically, county-scale ratios of manure available in other years relative to 1997 were used to adjust the area amended with manure (see Annex 3.13 for further details). Greater availability of managed manure N relative to 1997 was, thus, assumed to increase the urea amended with manure, while reduced availability of manure N relative to 1997 was assumed to reduce the amended area.

The amount of manure produced by each livestock type was calculated for managed and unmanaged waste management systems. Managed systems include feedlots or other housing (which requires manure to be collected and managed); unmanaged systems include daily spread, pasture, range, and paddock systems. Annual animal

---

[42] More recent NRI land use survey data are available and will be incorporated by the public review.

[43] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

population data for all livestock types, except horses and goats, were obtained for all years from the U.S. Department of Agriculture-National Agricultural Statistics Service. Population data used for cattle, swine, and sheep were downloaded from the USDA NASS Population Estimates Database (USDA 2007a). Poultry population data were obtained from USDA NASS reports (USDA 1995a, 1995b, 1998a, 1999, 2004a, 2004b, 2006a, 2006b, 2007b, 2007c). Horse population data were obtained from the FAOSTAT database (FAO 2007). Goat population data for 1992, 1997, and 2002 were obtained from the *Census of Agriculture* (USDA 2005); these data were interpolated and extrapolated to derive estimates for the other years. Information regarding poultry turnover (i.e., slaughter) rate was obtained from state Natural Resource Conservation Service personnel (Lange 2000). Additional population data for different farm size categories for dairy and swine were obtained from the 1992, 1997, and 2002 *Census of Agriculture* (USDA 2005).

Pasture/Range/Paddock (PRP) manure N deposition was estimated internally in the Century model, as part of the grassland system simulations (i.e., PRP manure deposition was not an external input into the model). Manure amendments were an input to the Century Model based on manure N available for application from all other managed or unmanaged systems. Data on the county-level N available for application were estimated for managed systems based on the total amount of N excreted in manure minus N losses and including the addition of N from bedding materials. Nitrogen losses include direct nitrous oxide emissions, volatilization of ammonia and NOx, and runoff and leaching. More information on these losses is available in the description of the Manure Management source category. Animal-specific bedding factors were set equal to IPCC default factors (IPCC 2006). For unmanaged systems, it is assumed that no N losses or additions occur. See the Tier 3 methods in *Cropland Remaining Cropland* section for additional discussion on the Tier 3 methodology for mineral soils.

Tier 2 Approach

The Tier 2 approach is based on the same methods described in the Tier 2 portion of *Cropland Remaining Cropland* Section for mineral soils (see *Cropland Remaining Cropland* Tier 2 methods section for additional information).

Additional Mineral C Stock Change Calculations

Annual C flux estimates for mineral soils between 1990 and 2006 were adjusted to account for additional C stock changes associated with sewage sludge amendments using a Tier 2 method. Estimates of the amounts of sewage sludge N applied to agricultural land were derived from national data on sewage sludge generation, disposition, and nitrogen content. Total sewage sludge generation data for 1988, 1996, and 1998, in dry mass units, were obtained from an EPA report (EPA 1999) and estimates for 2004 were obtained from an independent national biosolids survey (NEBRA 2007). These values were linearly interpolated to estimate values for the intervening years. N application rates from Kellogg et al. (2000) were used to determine the amount of area receiving sludge amendments. Although sewage sludge can be added to land managed for other land uses, it was assumed that agricultural amendments occur in grassland. Cropland is assumed to rarely be amended with sewage sludge due to the high metal content and other pollutants in human waste. The soil C storage rate was estimated at 0.38 metric tons C per hectare per year for sewage sludge amendments to grassland. The stock change rate is based on country-specific factors and the IPCC default method (see Annex 3.13 for further discussion).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Grassland Remaining Grassland* were estimated using the Tier 2 method provided in IPCC (2003, 2006), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. Emissions were based on the 1992 and 1997 *Grassland Remaining Grassland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2006.

Uncertainty

Uncertainty estimates are presented in Table 7-33 for each subsource (i.e., mineral soil C stocks and organic soil C stocks) disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in agricultural soil C stocks occurring within *Grassland Remaining Grassland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC Guidelines (2006), i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities. The combined uncertainty for soil C stocks in *Grassland Remaining Grassland* was estimated to be 18 percent below and 15 percent above the inventory estimate of 16.2 Tg CO_2 Eq.

Table 7-33: Quantitative Uncertainty Estimates[1] for C Stock Changes occurring within *Grassland Remaining Grassland* (Tg CO2 Eq. and Percent)

Source	**2006 Flux Estimate[1] (Tg CO_2 Eq.)**	**Uncertainty Range Relative to Flux Estimate[1] (Tg CO_2 Eq.)**		**(%)**	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Mineral Soil C Stocks *Grassland Remaining Grassland*, Tier 3 Inventory Methodology	13.9	12.5	15.3	-10%	10%
Mineral Soil C Stocks: *Grassland Remaining Grassland*, Tier 2 Inventory Methodology	(0.2)	(0.3)	0.0	-89%	127%
Mineral Soil C Stocks: *Grassland Remaining Grassland* (Change in Soil C due to Sewage Sludge Amendments)	(1.2)	(1.7)	(0.6)	-50%	50%
Organic Soil C Stocks: *Grassland Remaining Grassland*, Tier 2 Inventory Methodology	3.7	1.2	5.5	-66%	49%
Combined Uncertainty for Flux Associated with Agricultural Soil Carbon Stock Change in *Grassland Remaining Grassland*	**16.2**	**13.4**	**18.6**	**-18%**	**15%**

[1] Flux estimates based on soil C stock changes.

Uncertainties in Mineral Soil Carbon Stock Changes

The uncertainty analysis for *Grassland Remaining Grassland* using the Tier 3 approach and Tier 2 approach were based on the same method described for *Cropland Remaining Cropland*, except that the uncertainty inherent in the structure of the Century model was not addressed. See the Tier 3 approach for mineral soils under the *Cropland Remaining Cropland* section for additional discussion.

A ±50 percent uncertainty was assumed for additional adjustments to the soil C stocks between 1990 and 2006 to account for additional C stock changes associated with amending grassland soils with sewage sludge.

Uncertainties in Soil Carbon Stock Changes for Organic Soils

Uncertainty in C emissions from organic soils was estimated using country-specific factors and a Monte Carlo analysis. Probability distribution functions for emission factors were derived from a synthesis of 10 studies, and combined with uncertainties in the NRI land use and management data for organic soils in the Monte Carlo analysis. See the Tier 2 section under minerals soils of *Cropland Remaining Cropland* for additional discussion.

QA/QC and Verification

Quality control measures included checking input data, model scripts, and results to ensure data were properly handled through the inventory process. The manure amendment records were not recorded correctly in a subset of the Century model output; corrective actions were taken to resolve this error.

Recalculations Discussion

Two changes were implemented in the current inventory that led to a change in the time series. First, there was a modification in the land use classification. The classification is based on the land use in a specific year of the inventory and the previous 20 years. However, in the previous inventory, each point was only classified once based on the entire NRI time series of the land-use history. This approach led to incorrect classifications for the early 1990s. For example, a NRI point may have been grassland in 1982, 1987 and 1992, but converted to cropland in 1997. In the previous inventory, the NRI point would be classified as *Land Converted to Cropland* for the entire inventory from 1990 through 2005. This is incorrect for the early 1990s because the point was *Grassland Remaining Grassland* during those years. Second, the time series for manure N between 1990 through 2006, which was used to adjust manure applications relative to 1997, was based on manure N available for application rather than manure N production. Overall, the recalculations resulted in an average annual decrease in emissions of 0.5 Tg CO_2 Eq. for the time series over the period from 1990 through 2005, compared to the previous inventory.

Planned Improvements

The empirically-based uncertainty estimator described in the *Cropland Remaining Cropland* section for the Tier 3 approach has not been developed to estimate uncertainties in Century model results for *Grassland Remaining Grassland*, but this is a planned improvement for the inventory. This improvement will produce a more rigorous assessment of uncertainty. See Planned Improvements section under *Cropland Remaining Cropland* for additional planned improvements.

7.7. Land Converted to Grassland (IPCC Source Category 5C2)

Land Converted to Grassland includes all grassland in an inventory year that had been in another land use during the previous 20 years[44] according to the USDA NRI land use survey (USDA-NRCS 2000). Consequently, the area of *Land Converted to Grassland* changes through time with land-use change. Lands are retained in this category for 20 years as recommended by IPCC (2006) unless there is another land use change. Background on agricultural C stock changes is provided in *Cropland Remaining Cropland* and will only be summarized here for *Land Converted to Grassland*. Soils are the largest pool of C in agricultural land, and also have the greatest potential for storage or release of C, because biomass and dead organic matter C pools are relatively small and ephemeral compared with soils. IPCC/UNEP/OECD/IEA (1997) and IPCC (2003, 2006) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.[45]

Land-use and management of mineral soils in *Land Converted to Grassland* led to an increase in soil C stocks from 1990 through 2006, which was largely caused by annual cropland converted into pasture (see Table 7-34 and Table 7-35). Stock change rates over the time series varied from -14.7 to -17.2 Tg CO_2 Eq./yr (4 to 5 Tg C). Drainage of organic soils for grazing management led to losses varying from 0.5 to 0.9 Tg CO_2 Eq./yr (0.1 to 0.2 Tg C).

Table 7-34: Net CO2 Flux from Soil C Stock Changes for *Land Converted to Grassland* (Tg CO2 Eq.)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils[1]	(14.7)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)	(17.2)
Organic Soils	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Total Net Flux	**(14.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**	**(16.3)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.
[1] Stock changes due to application of sewage sludge are reported in *Grassland Remaining Grassland*.

Table 7-35: Net CO2 Flux from Soil C Stock Changes for *Land Converted to Grassland* (Tg C)

Soil Type	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mineral Soils[1]	(4.0)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)	(4.7)

---

[44] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

[45] CO_2 emissions associated with liming are also estimated but included in a separate section of the report.

Organic Soils	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total Net Flux	**(3.9)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**	**(4.5)**

Note: Parentheses indicate net sequestration. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only. Totals may not sum due to independent rounding.

[1] Stock changes due to application of sewage sludge in *Land Converted to Grassland* are reported in *Grassland Remaining Grassland*.

The spatial variability in annual CO_2 flux associated with C stock changes in mineral soils is displayed in Figure 7-11 and Figure 7-12. Soil C stock increased in most states for *Land Converted to Grassland*. The largest gains were in the southeast and northwest, and the amount of sequestration increased through the 1990s. The patterns were driven by conversion of annual cropland into continuous pasture. Emissions from organic soils were largest in California, Florida and the upper Midwest, which coincides with largest concentrations of organic soils in the United States that are used for agricultural production.

Figure 7-11: Total Net Annual CO_2 Flux for Mineral Soils under Agricultural Management within States, 1993-2006 *Land Converted to Grassland*

Figure 7-12: Total Net Annual CO_2 Flux for Organic Soils under Agricultural Management within States, 1993-2006 *Land Converted to Grassland*

Methodology

This section includes a brief description of the methodology used to estimate changes in soil C stocks due to agricultural land-use and management activities on mineral soils for *Land Converted to Grassland*.

Soil C stock changes were estimated for *Land Converted to Grassland* according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2000).[46] Land use and some management information (e.g., legume pastures, crop type, soil attributes, and irrigation) was collected for each NRI point on a 5-year cycle beginning in 1982, and was subdivided into four inventory time periods, 1980 through 1984, 1985 through 1989, 1990 through 1994 and 1995 through 2000. NRI points were classified as *Land Converted to Grassland* for an inventory time period (e.g., 1990 through 1994 and 1995 through 2000) if the land use was grassland at the end of the respective inventory time period but had been another use in the previous 20 years.[47] Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangeland typically includes extensive areas of native grassland that are not intensively managed, while pastures are often seeded grassland, possibly following tree removal, that may or may not be improved with practices such as irrigation and interseeding legumes. Further elaboration on the methodologies and data used to estimate stock changes from mineral and organic soils are provided in the *Cropland Remaining Cropland* section and Annex 3.13.

Mineral Soil Carbon Stock Changes

An IPCC Tier 3 model-based approach was used to estimate C stock changes for *Land Converted to Grassland* on most mineral soils. C stock changes on the remaining soils were estimated with an IPCC Tier 2 approach (Ogle et

---

[46] More recent NRI land use survey data are available and will be incorporated by the public review.

[47] NRI points were classified according to land-use history records starting in 1982 when the NRI survey began. Therefore, the classification was based on less than 20 years of recorded land-use history for the time series from 1982 to 2001.

al. 2003), including prior cropland used to produce vegetables, tobacco, perennial/horticultural crops, and rice; land areas with very gravelly, cobbly or shaley soils (greater than 35 percent by volume); and land converted from forest or federal ownership.[48] A Tier 2 approach was also used to estimate additional changes in mineral soil C stocks due to sewage sludge amendments. However, stock changes associated with sewage sludge amendments are reported in the *Grassland Remaining Grassland* section.

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model as described for *Grassland Remaining Grassland*. Historical land-use and management patterns were used in the Century simulations as recorded in the NRI survey, with supplemental information on fertilizer use and rates from the USDA Economic Research Service Cropping Practices Survey (ERS 1997) and the National Agricultural Statistics Service (NASS 1992, 1999, 2004) (see *Grassland Remaining Grassland* Tier 3 methods section for additional information).

Tier 2 Approach

The Tier 2 approach used for *Land Converted to Grassland* on mineral soils is the same as described for *Cropland Remaining Cropland* (See *Cropland Remaining Cropland* Tier 2 Approach for additional information).

Organic Soil Carbon Stock Changes

Annual C emissions from drained organic soils in *Land Converted to Grassland* were estimated using the Tier 2 method provided in IPCC (2003, 2006), which utilizes U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates. Emissions were based on the 1992 and 1997 *Land Converted to Grassland* areas from the *1997 National Resources Inventory* (USDA-NRCS 2000). The annual flux estimated for 1992 was applied to 1990 through 1992, and the annual flux estimated for 1997 was applied to 1993 through 2006.

Uncertainty

Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 approaches were based on the same method described in *Cropland Remaining Cropland*, except that the uncertainty inherent in the structure of the Century model was not addressed. The uncertainty or annual C emission estimates from drained organic soils in *Land Converted to Grassland* was estimated using the Tier 2 approach, as described in the *Cropland Remaining Cropland* section.

Uncertainty estimates are presented in Table 7-36 for each subsource (i.e., mineral soil C stocks and organic soil C stocks), disaggregated to the level of the inventory methodology employed (i.e., Tier 2 and Tier 3). A combined uncertainty estimate for changes in agricultural soil C stocks occurring within *Land Converted to Grassland* is also included. Uncertainty estimates from each component were combined using the error propagation equation in accordance with IPCC (2006), (i.e., by taking the square root of the sum of the squares of the standard deviations of the uncertain quantities). The combined uncertainty for soil C stocks in *Land Converted to Grassland* ranged from 13 percent below and 14 percent above the 2006 estimate of 16.3 Tg CO_2 Eq.

Table 7-36: Quantitative Uncertainty Estimates[1] for C Stock Changes occurring within *Land Converted to Grassland* (Tg CO_2 Eq. and Percent)

Source	2006 Flux Estimate[1] (Tg CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[1]

---

[48] Federal land is not a land use, but rather an ownership designation that is treated as forest or nominal grassland for purposes of these calculations. The specific use for federal lands is not identified in the NRI survey (USDA-NRCS 2000).

		(Tg CO$_2$ Eq.)		**(%)**	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Mineral Soil C Stocks: *Land Converted to Grassland*, Tier 3 Inventory Methodology	(12.2)	(12.5)	(11.9)	-2%	2%
Mineral Soil C Stocks: *Land Converted to Grassland*, Tier 2 Inventory Methodology	(5.0)	(7.0)	(2.8)	-39%	43%
Organic Soil C Stocks: *Land Converted to Grassland*, Tier 2 Inventory Methodology	0.9	0.2	1.8	-76%	104%
Combined Uncertainty for Flux associated with Agricultural Soil Carbon Stocks in *Land Converted to Grassland*	**(16.3)**	**(18.4)**	**(14.0)**	**-13%**	**14%**

[1] Flux estimates based on soil C stock changes.

QA/QC and Verification

See the QA/QC and Verification section under *Grassland Remaining Grassland*.

Recalculations Discussion

Two changes were implemented in the current inventory that led to a change in the time series. First, there was a modification in the land use classification. The classification is based on the land use in a specific year of the inventory and the previous 20 years. However, in the 1990 through 2005 inventory, each point was only classified once based on the entire NRI time series of the land-use history. This approach led to incorrect classifications for the early 1990s. For example, a NRI point may have been cropland in 1982, 1987 and 1992, but converted to grassland in 1997. In the previous inventory, the NRI point would be classified as *Land Converted to Grassland* for the entire inventory from 1990 through 2005. This is incorrect for the early 1990s because the point was *Cropland Remaining Cropland* during those years. Second, the time series for manure N between 1990 through 2006, which was used to adjust manure applications relative to 1997, was based on manure N available for application rather than manure N production. Overall, the recalculations resulted in an average annual decrease in emissions of 0.1 Tg CO$_2$ Eq. for the time series from 1990 through 2005, compared to the previous inventory.

Planned Improvements

The empirically-based uncertainty estimator described in the *Cropland Remaining Cropland* section for the Tier 3 approach has not been developed to estimate uncertainties in Century model results for *Land Converted to Grassland*, but this is a planned improvement for the inventory. This improvement will produce a more rigorous assessment of uncertainty. See Planned Improvements section under *Cropland Remaining Cropland* for additional planned improvements.

7.8. Settlements Remaining Settlements

Changes in Carbon Stocks in Urban Trees (IPCC Source Category 5E1)

Urban forests constitute a significant portion of the total U.S. tree canopy cover (Dwyer et al. 2000). Urban areas (cities, towns, and villages) are estimated to cover over 4.4 percent of the United States (Nowak et al. 2005). With an average tree canopy cover of 27 percent, urban areas account for approximately 3 percent of total tree cover in the continental United States (Nowak et al. 2001). Trees in urban areas of the United States were estimated to account for an average annual net sequestration of 78.1 Tg CO$_2$ Eq. (21 Tg C) over the period from 1990 through 2006. Total sequestration increased by 57 percent between 1990 and 2006 due to increases in urban land area. Data on C storage and urban tree coverage were collected since the early 1990s and have been applied to the entire time series in this report. Annual estimates of CO$_2$ flux were developed based on periodic U.S. Census data on urban area (Table 7-37). Net C flux from urban trees in 2006 was estimated to be -95.5 Tg CO$_2$ Eq. (-26 Tg C).

Net C flux from urban trees is proportionately greater on an area basis than that of forests. This trend is primarily the result of different net growth rates in urban areas versus forests—urban trees often grow faster than forest trees because of the relatively open structure of the urban forest (Nowak and Crane 2002). Also, areas in each case are accounted for differently. Because urban areas contain less tree coverage than forest areas, the C storage per hectare of land is in fact smaller for urban areas. However, urban tree reporting occurs on a per unit tree cover basis (tree canopy area), rather than total land area. Urban trees, therefore, appear to have a greater C density than forested areas (Nowak and Crane 2002).

Table 7-37: Net C Flux from Urban Trees (Tg CO_2 Eq. and Tg C)

Year	Tg CO_2 Eq.	Tg C
1990	(60.6)	(16.5)
1995	(71.5)	(19.5)
2000	(82.4)	(22.5)
2001	(84.6)	(23.1)
2002	(86.8)	(23.7)
2003	(88.9)	(24.3)
2004	(91.1)	(24.9)
2005	(93.3)	(25.4)
2006	(95.5)	(26.0)

Note: Parentheses indicate net sequestration.

Methodology

The methodology used by Nowak and Crane (2002) is based on average annual estimates of urban tree growth and decomposition, which were derived from field measurements and data from the scientific literature, urban area estimates from U.S. Census data, and urban tree cover estimates from remote sensing data. This approach is consistent with the default IPCC methodology in IPCC (2006), although sufficient data are not yet available to determine interannual gains and losses in C stocks in the living biomass of urban trees. Annual changes in net C flux from urban trees are based solely on changes in total urban area in the United States.

Most of the field data were analyzed using the U.S. Forest Service's Urban Forest Effects (UFORE) model.[49] The UFORE model is a computer model that uses standardized field data from random plots and local air pollution and meteorological data to quantify urban forest structure, values of the urban forest, and environmental effects, including total C stored and annual C sequestration (Nowak et al. 2007a).

Nowak and Crane (2002) developed estimates of annual gross C sequestration from tree growth and annual gross C emissions from decomposition for 15 U.S. cities: Atlanta, GA; Baltimore, MD; Boston, MA; Chicago, IL; Freehold, NJ; Jersey City, NJ; Minneapolis, MN; Moorestown, NJ; New York, NY; Oakland, CA; Philadelphia, PA; San Francisco, CA; Syracuse, NY; Washington, DC; and Woodbridge, NJ. The gross C sequestration estimates were derived from field data that were collected in these 15 cities during the period from 1989 through 2006, including tree measurements of stem diameter, tree height, crown height, and crown width, and information on location, species, and canopy condition. The field data were converted to annual gross C sequestration rates for each species (or genus), diameter class, and land-use condition (forested, park-like, and open growth) by applying allometric equations, a root-to-shoot ratio, moisture contents, a C content of 50 percent (dry weight basis), an adjustment factor to account for smaller aboveground biomass volumes (given a particular diameter) in urban conditions compared to forests, an adjustment factor to account for tree condition (fair to excellent, poor, critical, dying, or dead), and annual diameter and height growth rates. The annual gross C sequestration rates for each species (or genus),

---

[49] Oakland and Chicago estimates were based on prototypes to the UFORE model.

diameter class, and land-use condition were then scaled up to city estimates using tree population information. The field data from the 15 cities, some of which are unpublished (Nowak 2007c), are described in Nowak and Crane (2002), Nowak et al. (2007a), and references cited therein. The allometric equations were taken from the scientific literature (see Nowak 1994, Nowak et al. 2002), and the adjustments to account for smaller volumes in urban conditions were based on information in Nowak (1994). A root-to-shoot ratio of 0.26 was taken from Cairns et al. (1997), and species- or genus-specific moisture contents were taken from various literature sources (see Nowak 1994). Tree growth rates were taken from existing literature. Average diameter growth was based on the following sources: estimates for trees in forest stands came from Smith and Shifley (1984); estimates for trees on land uses with a park-like structure came from deVries (1987); and estimates for more open-grown trees came from Nowak (1994). Formulas from Fleming (1988) formed the basis for average height growth calculations. Growth rates were adjusted to account for tree condition. Growth factors for Atlanta, Boston, Chicago, Freehold, Jersey City, Moorestown, New York, Oakland, Philadelphia, and Woodbridge were adjusted based on the typical growth conditions of different land-use categories (e.g., forest stands, park-like stands). Growth factors for the more recent studies in Baltimore, Minneapolis, San Francisco, Syracuse, and Washington were adjusted using an updated methodology based on the condition of each individual tree, which is determined using tree competition factors (depending on whether it is open grown or suppressed) (Nowak 2007b).

Annual gross C emission estimates were derived by applying estimates of annual mortality and condition, and assumptions about whether dead trees were removed from the site, to C stock estimates. These values were derived as intermediate steps in the sequestration calculations, and different decomposition rates were applied to dead trees left standing compared with those removed from the site. The annual gross C emission rates for each species (or genus), diameter class, and condition class were then scaled up to city estimates using tree population information. Estimates of annual mortality rates by diameter class and condition class were derived from a study of street-tree mortality (Nowak 1986). Assumptions about whether dead trees would be removed from the site were based on expert judgment of the authors. Decomposition rates were based on literature estimates (Nowak and Crane 2002).

National annual net C sequestration by urban trees was calculated based on estimates of gross and net sequestration from 13 of the 15 cities (Table 7-38), and urban area and urban tree cover data for the United States. Annual net C sequestration estimates were derived for 13 cities by subtracting the annual gross emission estimates from the annual gross sequestration estimates.[50] The urban areas are based on 1990 and 2000 U.S. Census data. The 1990 U.S. Census defined urban land as “urbanized areas,” which included land with a population density greater than 1,000 people per square mile, and adjacent “urban places,” which had predefined political boundaries and a population total greater than 2,500. In 2000, the U.S. Census replaced the “urban places” category with a new category of urban land called an “urban cluster,” which included areas with more than 500 people per square mile. Urban land area has increased by approximately 36 percent from 1990 to 2000; Nowak et al. (2005) estimate that the changes in the definition of urban land have resulted in approximately 20 percent of the total reported increase in urban land area from 1990 to 2000. Under both 1990 and 2000 definitions, urban encompasses most cities, towns, and villages (i.e., it includes both urban and suburban areas). The gross and net C sequestration values for each city were divided by each city’s area of tree cover to determine the average annual sequestration rates per unit of tree area for each city. The median value for gross sequestration (0.31 kg C/m^2-year) was then multiplied by the estimate of national urban tree cover area to estimate national annual gross sequestration. To estimate national annual net sequestration, the estimate of national annual gross sequestration was multiplied by the average of the ratios of net to gross sequestration for those cities that had both estimates (0.72). The urban tree cover estimates for each of the 15 cities and the United States were obtained from Dwyer et al. (2000), Nowak et al. (2002), and Nowak (2007a). The urban area estimates were taken from Nowak et al. (2005).

Table 7-38: C Stocks (Metric Tons C), Annual C Sequestration (Metric Tons C/yr), Tree Cover (Percent), and Annual C Sequestration per Area of Tree Cover (kg C/m^{2}cover-yr) for 15 U.S. Cities

City	**Carbon**	**Gross Annual**	**Net Annual**	**Tree**	**Gross Annual**	**Net Annual**

---

[50] Two cities did not have net estimates.

	Stocks	Sequestration	Sequestration	Cover	Sequestration per Area of Tree Cover	Sequestration per Area of Tree Cover
Atlanta, GA	1,219,256	42,093	32,169	36.7%	0.34	0.26
Baltimore, MD	541,589	14,696	9,261	21.0%	0.35	0.22
Boston, MA	289,392	9,525	6,966	22.3%	0.30	0.22
Chicago, IL	NA	NA	NA	11.0%	0.61	NA
Freehold, NJ	18,144	494	318	34.4%	0.28	0.18
Jersey City, NJ	19,051	807	577	11.5%	0.18	0.13
Minneapolis, MN	226,796	8,074	4,265	26.4%	0.20	0.11
Moorestown, NJ	106,141	3,411	2,577	28.0%	0.32	0.24
New York, NY	1,224,699	38,374	20,786	20.9%	0.23	0.12
Oakland, CA	NA	NA	NA	21.0%	NA	NA
Philadelphia, PA	480,808	14,606	10,530	15.7%	0.27	0.20
San Francisco, CA	175,994	4,627	4,152	11.9%	0.33	0.29
Syracuse, NY	156,943	4,917	4,270	23.1%	0.33	0.29
Washington, DC	477,179	14,696	11,661	28.6%	0.32	0.26
Woodbridge, NJ	145,150	5,044	3,663	29.5%	0.28	0.21

NA = not analyzed.

Sources: Nowak and Crane (2002) and Nowak (2007a,c).

Uncertainty

Uncertainty associated with changes in C stocks in urban trees includes the uncertainty associated with urban area, percent urban tree coverage, and estimates of gross and net C sequestration for the 15 U.S. cities. A 10 percent uncertainty was associated with urban area estimates while a 5 percent uncertainty was associated with percent urban tree coverage. Both of these uncertainty estimates were based on expert judgment. Uncertainty associated with estimates of gross and net C sequestration for the 15 U.S. cities was based on standard error estimates for each of the city-level sequestration estimates reported by Nowak (2007c). These estimates are based on field data collected in 15 U.S. cities, and uncertainty in these estimates increases as they are scaled up to the national level.

Additional uncertainty is associated with the biomass equations, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there may be some overlap between the urban tree C estimates and the forest tree C estimates. Due to data limitations, urban soil flux is not quantified as part of this analysis, while reconciliation of urban tree and forest tree estimates will be addressed through the land representation effort described at the beginning of this chapter.

A Monte Carlo (Tier 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-39. The net C flux from changes in C stocks in urban trees was estimated to be between -112.1 and -76.5 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 17 percent below and 20 percent above the 2006 flux estimate of -95.5 Tg CO_2 Eq.

Table 7-39: Tier 2 Quantitative Uncertainty Estimates for Net C Flux from Changes in C Stocks in Urban Trees (Tg CO_2 Eq. and Percent)

Source	Gas	2006 Flux Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate			
			(Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Changes in C Stocks in Urban Trees	CO_2	(95.5)	(112.1)	(76.5)	-17%	20%

Note: Parentheses indicate negative values or net sequestration.

QA/QC and Verification

The net C flux resulting from urban trees was calculated using estimates of gross and net C sequestration estimates for urban trees and urban tree coverage area found in literature. The validity of these data for their use in this section of the inventory was evaluated through correspondence established with an author of the papers. Through this correspondence, the methods used to collect the urban tree sequestration and area data were further clarified and the use of these data in the inventory was reviewed and validated (Nowak 2002a, 2007b).

Recalculations Discussion

New data was added for six U.S. cities: Freehold, NJ; Minneapolis, MN; Moorestown, NJ; San Francisco, CA; Washington, DC; and Woodbridge, NJ. Data for Sacramento, CA was removed from the urban trees estimates because it was analyzed using a different methodology. These changes brought the total number of included cities to 15, providing a better median estimate of net and gross sequestration than the previous inventory estimate based on data from 10 U.S. cities.

There was also a slight change in the methodology for adjusting urban tree growth rates to account for tree condition. Some of the older studies used average growth rates based on the typical growth conditions of different land-use categories. In contrast, some of the newer studies adjust growth factors based on the condition of the tree, which is determined using tree competition factors (depending on whether it is open grown or suppressed) for each individual tree. The cities that use each of these methodologies are identified above in the Methodology section. The difference that resulted from this change in methodological approach is very small and likely washes out on average (Nowak 2007b).

These changes resulted in changes in the estimates of net annual C sequestration by urban trees for the time period 1990 through 2005. On average, estimates of net annual C sequestration by urban trees increased by 5.3 percent over the period from 1990 to 2005 relative to the previous report.

Planned Improvements

A consistent representation of the managed land base in the United States is being developed. A component of this effort, which is discussed at the beginning of the LULUCF chapter, will involve reconciling the overlap between urban forest and non-urban forest greenhouse gas inventories. It is highly likely that urban forest inventories are including areas considered non-urban under the Forest Inventory and Analysis (FIA) program of the USDA Forest Service, resulting in "double-counting" of these land areas in estimates of C stocks and fluxes for the inventory. Planned improvements to the FIA program include the development of a long-term dataset that will define urban area boundaries and make it possible to identify what area is forested. Once those data become available, they will be incorporated into estimates of net C flux resulting from urban trees.

Urban forest data for additional cities is expected in the near term, and the use of this data will further refine the estimated median sequestration value. It may also be possible to report C losses and gains separately in the future. It is currently not possible, since existing studies estimate rather than measure natality or mortality; net sequestration estimates are based on assumptions about whether dead trees are being removed, burned, or chipped. There is an effort underway to develop long-term data on permanent plots in at least two cities, which would allow for direct calculation of C losses and gains from observed rather than estimated natality and mortality of trees.

Direct N_2O Fluxes from Settlement Soils (IPCC Source Category 5E1)

Of the synthetic N fertilizers applied to soils in the United States, approximately 2.5 percent are currently applied to lawns, golf courses, and other landscaping occurring within settlement areas. Application rates are less than those occurring on cropped soils, and, therefore, account for a smaller proportion of total U.S. soil N_2O emissions per unit area. In addition to synthetic N fertilizers, a portion of surface applied sewage sludge is applied to settlement areas. In 2006, N_2O emissions from this source were 1.5 Tg CO_2 Eq. (4.7 Gg). There was an overall increase of 48 percent over the period from 1990 through 2006 due to a general increase in the application of synthetic N fertilizers to an expanding settlement area. Interannual variability in these emissions is directly attributable to interannual variability in total synthetic fertilizer consumption and sewage sludge applications in the United States. Emissions from this source are summarized in Table 7-40.

Table 7-40: N_2O Fluxes from Soils in *Settlements Remaining Settlements* (Tg CO_2 Eq. and Gg)

Year	**Tg CO_2 Eq.**	**G**
1990	1.0	3.2
1995	1.2	3.9
2000	1.2	4.0
2001	1.4	4.6
2002	1.5	4.7
2003	1.5	4.9
2004	1.6	5.0
2005	1.5	4.8
2006	1.5	4.7

Note: These estimates include direct N_2O emissions from N fertilizer additions only. Indirect N_2O emissions from fertilizer additions are reported in the Agriculture chapter. These estimates include emissions from both *Settlements Remaining Settlements* and from *Land Converted to Settlements.*

Methodology

For soils within *Settlements Remaining Settlements*, the IPCC Tier 1 approach was used to estimate soil N_2O emissions from synthetic N fertilizer and sewage sludge additions. Estimates of direct N_2O emissions from soils in settlements were based on the amount of N in synthetic commercial fertilizers applied to settlement soils and the amount of N in sewage sludge applied to non-agricultural land and in surface disposal of sewage sludge.

Nitrogen applications to settlement soils are estimated using data compiled by the USGS (Ruddy et al. 2006). The USGS estimated on-farm and non-farm fertilizer use based on sales records at the county level from 1982 through 2001 (Ruddy et al. 2006). Non-farm N fertilizer was assumed to be applied to settlements and forests and values for 2001 were used for 2002 through 2006. Settlement application was calculated by subtracting forest application from total non-farm fertilizer use. Sewage sludge applications were derived from national data on sewage sludge generation, disposition, and N content (see Annex 3.11 for further detail). The total amount of N resulting from these sources was multiplied by the IPCC default emission factor for applied N (1 percent) to estimate direct N_2O emissions (IPCC 2006). The volatilized and leached/runoff proportions, calculated with the IPCC default volatilization factors (10 or 20 percent, respectively, for synthetic or organic N fertilizers) and leaching/runoff factor for wet areas (30 percent), were included with the total N contributions to indirect emissions, as reported in the N_2O Emissions from Agricultural Soil Management source category of the Agriculture chapter.

Uncertainty

The amount of N_2O emitted from settlements depends not only on N inputs, but also on a large number of variables, including organic C availability, O_2 partial pressure, soil moisture content, pH, temperature, and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology does not incorporate any of these variables and only accounts for variations in fertilizer N and sewage sludge application rates. All settlement soils are treated equivalently under this methodology.

Uncertainties exist in both the fertilizer N and sewage sludge application rates in addition to the emission factors.

Uncertainty in fertilizer N application was assigned a default level[51] of ±50 percent. Uncertainty in the amounts of sewage sludge applied to non-agricultural lands and used in surface disposal was derived from variability in several factors, including: (1) N content of sewage sludge; (2) total sludge applied in 2000; (3) wastewater existing flow in 1996 and 2000; and (4) the sewage sludge disposal practice distributions to non-agricultural land application and surface disposal. Uncertainty in the emission factors was provided by the IPCC (2006).

Quantitative uncertainty of this source category was estimated through the IPCC-recommended Tier 2 uncertainty estimation methodology. The uncertainty ranges around the 2005 activity data and emission factor input variables were directly applied to the 2006 emissions estimates. The results of the quantitative uncertainty analysis are summarized in Table 7-41. N_2O emissions from soils in *Settlements Remaining Settlements* in 2006 were estimated to be between 0.8 and 3.9 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 49 percent below to 163 percent above the 2006 emission estimate of 1.5 Tg CO_2 Eq.

Table 7-41: Quantitative Uncertainty Estimates of N_2O Emissions from Soils in *Settlements Remaining Settlements* (Tg CO_2 Eq. and Percent)

Source	Gas	2006 Emissions (Tg CO_2 Eq.)	Uncertainty Range Relative to 2006 Emission Estimate			
			(Tg CO_2 Eq.)		(%)	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Settlements Remaining Settlements:						
N_2O Fluxes from Soils	N_2O	1.5	0.8	3.9	-49%	163%

Note: This estimate includes direct N_2O emissions from N fertilizer additions to both *Settlements Remaining Settlements* and from *Land Converted to Settlements*.

Recalculations Discussion

A new data source was used for N fertilization in the current inventory. Instead of assuming settlement soils receive 10 percent of total synthetic N fertilizer applied in the United States, fertilization data were based on county-scale non-farm application amounts from a database compiled by the USGS (Ruddy et al. 2006). According to the USGS data, approximately 1.7 percent of synthetic fertilizer N sold was for non-farm use in 1990 and this gradually increased to 3.1 percent in 2001. After subtracting forest application from non-farm fertilizer use, this change resulted in a 75 percent decrease in the emission estimates for 2005 and an average decrease of about 78 percent over the period from 1990 to 2005.

Planned Improvements

The key planned improvement is to estimate emissions using the process-based DAYCENT model instead of the IPCC default methodology. DAYCENT has been used to estimate N_2O emissions from agricultural soils, reducing bias and improving precision in estimates for the cropland and grassland soils. Applying the DAYCENT model is also anticipated to reduce uncertainties in the estimated emissions from settlement soils. In addition, this planned improvement would incorporate state-level settlement area data from the National Resource Inventory. Another minor improvement is to update the uncertainty analysis for direct emissions from settlements to be consistent with the most recent activity data for this source.

7.9. Land Converted to Settlements (Source Category 5E2)

Land-use change is constantly occurring, and land under a number of uses undergoes urbanization in the United

---

[51] No uncertainty is provided with the USGS application data (Ruddy et al. 2006) so a conservative ±50% was used in the analysis.

States each year. However, data on the amount of land converted to settlements is currently lacking. Given the lack of available information relevant to this particular IPCC source category, it is not possible to separate CO_2 or N_2O fluxes on *Land Converted to Settlements* from fluxes on *Settlements Remaining Settlements* at this time.

7.10. Other (IPCC Source Category 5G)

Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills

In the United States, a significant change in C stocks results from the removal of yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps from settlements to be disposed in landfills. Yard trimmings and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are discarded in landfills. C contained in landfilled yard trimmings and food scraps can be stored for very long periods.

Carbon storage estimates are associated with particular land uses. For example, harvested wood products are accounted for under *Forest Land Remaining Forest Land* because these wood products are a component of the forest ecosystem. The wood products serve as reservoirs to which C resulting from photosynthesis in trees is transferred, but the removals in this case occur in the forest. C stock changes in yard trimmings and food scraps are associated with settlements, but removals in this case do not occur within settlements. To address this complexity, yard trimming and food scrap C storage is therefore reported under the “Other” source category.

Both the amount of yard trimmings and food scraps collected annually and the fraction that is landfilled have declined over the last decade. In 1990, over 51 million metric tons (wet weight) of yard trimmings and food scraps were generated (i.e., put at the curb for collection to be taken to disposal sites or to composting facilities) (EPA 2007; Schneider 2007, 2008). Since then, programs banning or discouraging disposal have led to an increase in backyard composting and the use of mulching mowers, and a consequent 7 percent decrease in the amount of yard trimmings generated (i.e., collected for composting or disposal). At the same time, a dramatic increase in the number of municipal composting facilities has reduced the proportion of collected yard trimmings that are discarded in landfills—from 72 percent in 1990 to 31 percent in 2006. The net effect of the reduction in generation and the increase in composting is a 60 percent decrease in the quantity of yard trimmings disposed in landfills since 1990. Food scraps generation has grown by 50 percent since 1990, but the proportion of food scraps discarded in landfills has decreased slightly from 81 percent in 1990 to 80 percent in 2006. Overall, the decrease in the yard trimmings landfill disposal rate has more than compensated for the increase in food scrap disposal in landfills, and the net result is a decrease in annual landfill C storage from 23.9 Tg CO_2 Eq. in 1990 to 10.5 Tg CO_2 Eq. in 2006 (Table 7-42 and Table 7-43).

Table 7-42: Net Changes in Yard Trimming and Food Scrap Stocks in Landfills (Tg CO_2 Eq.)

Carbon Pool	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Yard Trimmings	**(21.4)**	**(12.6)**	**(8.2)**	**(8.5)**	**(8.7)**	**(7.1)**	**(6.2)**	**(6.5)**	**(6.8)**
Grass	(1.9)	(0.8)	(0.4)	(0.5)	(0.6)	(0.4)	(0.3)	(0.4)	(0.5)
Leaves	(9.7)	(6.0)	(4.0)	(4.1)	(4.2)	(3.5)	(3.1)	(3.2)	(3.3)
Branches	(9.7)	(5.8)	(3.7)	(3.8)	(3.9)	(3.2)	(2.8)	(2.9)	(3.0)
Food Scraps	**(2.5)**	**(1.6)**	**(3.3)**	**(3.1)**	**(3.1)**	**(2.9)**	**(3.4)**	**(3.5)**	**(3.7)**
Total Net Flux	**(23.9)**	**(14.1)**	**(11.5)**	**(11.6)**	**(11.8)**	**(10.0)**	**(9.6)**	**(10.0)**	**(10.5)**

Note: Totals may not sum due to independent rounding.

Table 7-43: Net Changes in Yard Trimming and Food Scrap Stocks in Landfills (Tg C)

Carbon Pool	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Yard Trimmings	**(5.8)**	**(3.4)**	**(2.2)**	**(2.3)**	**(2.4)**	**(1.9)**	**(1.7)**	**(1.8)**	**(1.9)**
Grass	(0.5)	(0.2)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)
Leaves	(2.7)	(1.6)	(1.1)	(1.1)	(1.1)	(0.9)	(0.8)	(0.9)	(0.9)
Branches	(2.6)	(1.6)	(1.0)	(1.0)	(1.1)	(0.9)	(0.8)	(0.8)	(0.8)
Food Scraps	**(0.7)**	**(0.4)**	**(0.9)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.9)**	**(0.9)**	**(1.0)**

Total Net Flux	**(6.5)**		**(3.9)**		**(3.1)**	**(3.2)**	**(3.2)**	**(2.7)**	**(2.6)**	**(2.7)**	**(2.9)**

Note: Totals may not sum due to independent rounding.

Methodology

As empirical evidence shows, the removal of C from the natural cycling of C between the atmosphere and biogenic materials, which occurs when wastes of biogenic origin are deposited in landfills, sequesters C (Barlaz 1998, 2005, 2008). When wastes of sustainable, biogenic origin (such as yard trimming and food scraps) are landfilled and do not completely decompose, the C that remains is effectively removed from the global C cycle. Estimates of net C flux resulting from landfilled yard trimmings and food scraps were developed by estimating the change in landfilled C stocks between inventory years, based on methodologies presented for the Land Use, Land-Use Change and Forestry sector in IPCC (2003). C stock estimates were calculated by determining the mass of landfilled C resulting from yard trimmings or food scraps discarded in a given year; adding the accumulated landfilled C from previous years; and subtracting the portion of C landfilled in previous years that decomposed.

To determine the total landfilled C stocks for a given year, the following were estimated: 1) the composition of the yard trimmings; 2) the mass of yard trimmings and food scraps discarded in landfills; 3) the C storage factor of the landfilled yard trimmings and food scraps adjusted by mass balance; and 4) the rate of decomposition of the degradable C. The composition of yard trimmings was assumed to be 30 percent grass clippings, 40 percent leaves, and 30 percent branches on a wet weight basis (Oshins and Block 2000). The yard trimmings were subdivided, because each component has its own unique adjusted C storage factor and rate of decomposition. The mass of yard trimmings and food scraps disposed of in landfills was estimated by multiplying the quantity of yard trimmings and food scraps discarded by the proportion of discards managed in landfills. Data on discards (i.e., the amount generated minus the amount diverted to centralized composting facilities) for both yard trimmings and food scraps were taken primarily from *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: 2006 Facts and Figures* (EPA 2007), which provides data for 1960, 1970, 1980, 1990, 2000, 2002, and 2004 through 2006. To provide data for some of the missing years, detailed backup data was obtained from Schneider (2007, 2008). Remaining years in the time series for which data were not provided were estimated using linear interpolation. The report does not subdivide discards of individual materials into volumes landfilled and combusted, although it provides an estimate of the proportion of overall waste stream discards managed in landfills and combustors (i.e., ranging from 90 percent and 10 percent respectively in 1980, to 67 percent and 33 percent in 1960).

The amount of C disposed of in landfills each year, starting in 1960, was estimated by converting the discarded landfilled yard trimmings and food scraps from a wet weight to a dry weight basis, and then multiplying by the initial (i.e., pre-decomposition) C content (as a fraction of dry weight). The dry weight of landfilled material was calculated using dry weight to wet weight ratios (Tchobanoglous et al. 1993, cited by Barlaz 1998) and the initial C contents were determined by Barlaz (1998, 2005, 2008) (Table 7-44).

The amount of C remaining in the landfill for each subsequent year was tracked based on a simple model of C fate. As demonstrated by Barlaz (1998, 2005, 2008), a portion of the initial C resists decomposition and is essentially persistent in the landfill environment. Barlaz (1998, 2005, 2008) conducted a series of experiments designed to measure biodegradation of yard trimmings, food scraps, and other materials, in conditions designed to promote decomposition (i.e., by providing ample moisture and nutrients). After measuring the initial C content, the materials were placed in sealed containers along with a “seed” containing methanogenic microbes from a landfill. Once decomposition was complete, the yard trimmings and food scraps were re-analyzed for C content; the C remaining in the solid sample can be expressed as a proportion of initial C (shown in the row labeled “CS” in Table 7-44).

The modeling approach applied to simulate U.S. landfill C flows builds on the findings of Barlaz (1998, 2005, 2008). The proportion of C stored is assumed to persist in landfills. The remaining portion is assumed to degrade, resulting in emissions of CH_4 and CO_2 (the CH_4 emissions resulting from decomposition of yard trimmings and food scraps are accounted for in the *Waste* chapter). The degradable portion of the C is assumed to decay according to first order kinetics. Food scraps are assumed to have a half-life of 3.7 years; grass is assumed to have a half-life of 5 years; leaves are assumed to have a half-life of 20 years; and branches are assumed to have a half-life of 23.1 years. The half-life of food scraps is consistent with analysis for landfill CH_4 in the *Waste* chapter.

For each of the four materials (grass, leaves, branches, food scraps), the stock of C in landfills for any given year is calculated according to the following formula:

$$LFC_{i,t} = \sum_{n} W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k\,(t - n)}]\}$$

where,

t = Year for which C stocks are being estimated (year),
i = Waste type for which C stocks are being estimated (grass, leaves, branches, food scraps),
$LFC_{i,t}$ = Stock of C in landfills in year *t*, for waste *i* (metric tons),
$W_{i,n}$ = Mass of waste *i* disposed in landfills in year *n* (metric tons, wet weight),
n = Year in which the waste was disposed (year, where 1960 U$\leq$U n U$\leq$U t),
MC_i = Moisture content of waste *i* (percent of water),
CS_i = Proportion of initial C that is stored for waste *i* (percent),
ICC_i = Initial C content of waste *i* (percent),
e = Natural logarithm, and
k = First order rate constant for waste *i*, which is equal to 0.693 divided by the half-life for decomposition ($year^{-1}$).

For a given year *t*, the total stock of C in landfills ($TLFC_t$) is the sum of stocks across all four materials. The annual flux of C in landfills (F_t) for year *t* is calculated as the change in stock compared to the preceding year:

$$F_t = TLFC_t - TLFC_{t-1}$$

Thus, the C placed in a landfill in year *n* is tracked for each year *t* through the end of the inventory period (2006). For example, disposal of food scraps in 1960 resulted in depositing about 1,135,000 metric tons of C. Of this amount, 16 percent (179,000 metric tons) is persistent; the remaining 84 percent (956,000 metric tons) is degradable. By 1964, more than half of the degradable portion (500,000 metric tons) decomposes, leaving a total of 635,000 metric tons (the persistent portion, plus the remainder of the degradable portion).

Continuing the example, by 2006, the total food scraps C originally disposed in 1960 had declined to 179,000 metric tons (i.e., virtually all of the degradable C had decomposed). By summing the C remaining from 1960 with the C remaining from food scraps disposed in subsequent years (1961 through 2006), the total landfill C from food scraps in 2006 was 29.5 million metric tons. This value is then added to the C stock from grass, leaves, and branches to calculate the total landfill C stock in 2006, yielding a value of 234.4 million metric tons (as shown in Table 7-45). In exactly the same way total net flux is calculated for forest C and harvested wood products, the total net flux of landfill C for yard trimmings and food scraps for a given year (Table 7-43) is the difference in the landfill C stock for a given year and the stock in the preceding year. For example, the net change in 2006 shown in Table 7-43 (2.9 Tg C) is equal to the stock in 2006 (234.4 Tg C) minus the stock in 2005 (231.5 Tg C).

When applying the C storage data reported by Barlaz (1998, 2005, 2008), an adjustment was made to the reported values so that a perfect mass balance on total C could be attained for each of the materials. There are four principal elements in the mass balance:

- Initial C content (ICC, measured),
- C output as CH_4 (CH_4-C, measured),
- C output as CO_2 (CO_2-C, not measured), and
- Residual stored C (CS, measured).

In a simple system where the only C fates are CH_4, CO_2, and C storage, the following equation is used to attain a mass balance:

$$CH_4\text{-}C + CO_2\text{-}C + CS = ICC$$

The experiments by Barlaz and his colleagues (Barlaz 1998, 2005; Eleazer et al. 1997) did not measure CO_2 outputs in experiments. However, if the only decomposition is anaerobic, then CH_4-C = CO_2-C.[52] Thus, the system should be defined by:

$$2 \times CH_4\text{-C} + CS = ICC$$

The C outputs (= 2 × CH_4-C + CS) were less than 100 percent of the initial C mass for food scraps, leaves, grass, and branches (75, 94, 86, and 90 percent, respectively). For these materials, it was assumed that the unaccounted for C had exited the experiment as CH_4 and CO_2, and no adjustment was made to the measured value of CS. The resulting C stocks are shown in Table 7-45.

Table 7-44: Moisture Content (%), C Storage Factor, Proportion of Initial C Sequestered (%), Initial C Content (%), and Half-Life (years) for Landfilled Yard Trimmings and Food Scraps in Landfills

	Yard Trimmings			**Food Scraps**
Variable	**Grass**	**Leaves**	**Branches**	
Moisture Content (% H_2O)	70	30	10	70
CS, proportion of initial C stored (%)	53	85	77	16
Initial C Content (%)	45	46	49	51
Half-life (years)	5	20	23	4

Table 7-45: C Stocks in Yard Trimmings and Food Scraps in Landfills (Tg C)

Carbon Pool	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Yard Trimmings	**156.9**	**180.2**	**192.9**	**195.2**	**197.6**	**199.5**	**201.2**	**203.0**	**204.9**
Grass	15.8	17.7	18.3	18.5	18.6	18.8	18.8	19.0	19.1
Leaves	70.2	81.0	87.2	88.3	89.5	90.4	91.3	92.1	93.0
Branches	70.9	81.6	87.4	88.4	89.5	90.4	91.1	91.9	92.8
Food Scraps	**17.9**	**20.6**	**24.1**	**25.0**	**25.8**	**26.6**	**27.5**	**28.5**	**29.5**
Total Carbon Stocks	**174.8**	**200.8**	**217.1**	**220.2**	**223.4**	**226.2**	**228.8**	**231.5**	**234.4**

Note: Totals may not sum due to independent rounding.

Uncertainty

The uncertainty analysis for landfilled yard trimmings and food scraps includes an evaluation of the effects of uncertainty for the following data and factors: disposal in landfills per year (tons of C), initial C content, moisture content, decomposition rate (half-life), and proportion of C stored. The C storage landfill estimates are also a function of the composition of the yard trimmings (i.e., the proportions of grass, leaves and branches in the yard trimmings mixture). There are respective uncertainties associated with each of these factors.

A Monte Carlo (Tier 2) uncertainty analysis was applied to estimate the overall uncertainty of the sequestration estimate. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-46. Total yard trimmings and food scraps CO_2 flux in 2006 was estimated to be between -19.1 and -6.0 Tg CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo stochastic simulations). This indicates a range of -82 percent below to 43 percent above the 2006 flux estimate of -10.5 Tg CO_2 Eq. More information on the uncertainty estimates for Yard Trimmings and Food Scraps in Landfills is contained within the Uncertainty Annex.

Table 7-46: Tier 2 Quantitative Uncertainty Estimates for CO_2 Flux from Yard Trimmings and Food Scraps in Landfills (Tg CO_2 Eq. and Percent)

---

[52] The molar ratio of CH_4 to CO_2 is 1:1 for carbohydrates (e.g., cellulose, hemicellulose). For proteins as $C_{3.2}H_5ON_{0.86}$, the molar ratio is 1.65 CH_4 per 1.55 CO_2 (Barlaz et al. 1989). Given the predominance of carbohydrates, for all practical purposes, the overall ratio is 1:1.

Source	Gas	2006 Flux Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Flux Estimate[a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Yard Trimmings and Food Scraps	CO_2	(10.5)	(19.1)	(6.0)	-82%	+43%

[a] Range of flux estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Parentheses indicate negative values or net C sequestration.

QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation.

Recalculations Discussion

The half lives of branches and food scraps were updated to be consistent with recommended values for food scraps and woody materials provided in IPCC (2006) for analyzing landfill CH_4.

The current inventory uses detailed unpublished backup data (Schneider 2007, 2008) for some years not previously shown in the MSW Facts and Figures reports (EPA 1999, 2003, 2005, 2005a, 2006, 2007). This data included updated generation, materials recovery, composting, combustion, and discard data for 1960, 1970, 1980, and 1990 through 2006. This newly available data allowed several previous interpolations to be replaced with the complete time series of data used to create the MSW Facts and Figures reports (EPA 1999, 2003, 2005, 2005a, 2006, 2007).

Additionally, updated experimental results from Barlaz (2008) were incorporated. These data changed several estimates for leaves: the initial C content (from 42 percent to 46 percent), the proportion of initial C stored (from 72 percent to 85 percent), and the C output from CH_4, used as a check on the mass balance, The proportion of initial C stored for grass also changed (from 68 percent to 53 percent). These changes are the result of a re-interpretation of the experimental results, which combined a sample of the material being tested (e.g., leaves) with a sample of "seed" material—decomposed refuse—containing microorganisms capable of anaerobic decomposition. Because the seed material also contained some organic C, the mass balance had to be adjusted to net out the influence of the C from the seed. The re-interpretation of the results accounts for differences in the rates of decomposition of the seed along compared to the seed plus the material being tested.

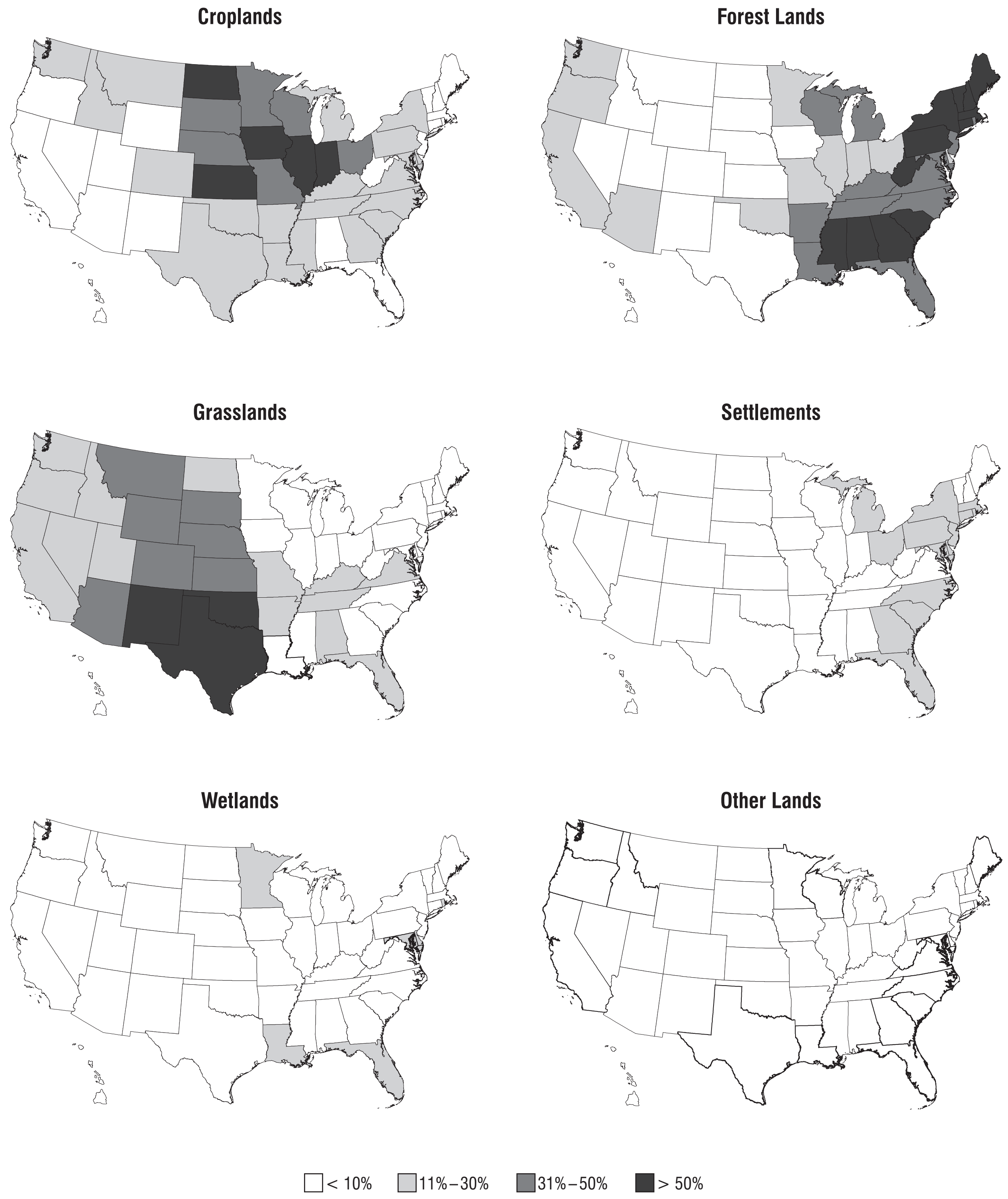
These changes resulted in an average 7 percent increase in stocks across the time series and a 13 percent change in the stocks for 2005 compared to the previous inventory.

Planned Improvements

Future work may evaluate the potential contribution of inorganic C, primarily in the form of carbonates, to landfill sequestration, as well as the consistency between the estimates of C storage described in this chapter and the estimates of landfill CH_4 emissions described in the *Waste* chapter.

Figure 7-1

Percent of Total Land Area in Each Land-Use Category by State



Croplands

Forest Lands

Grasslands

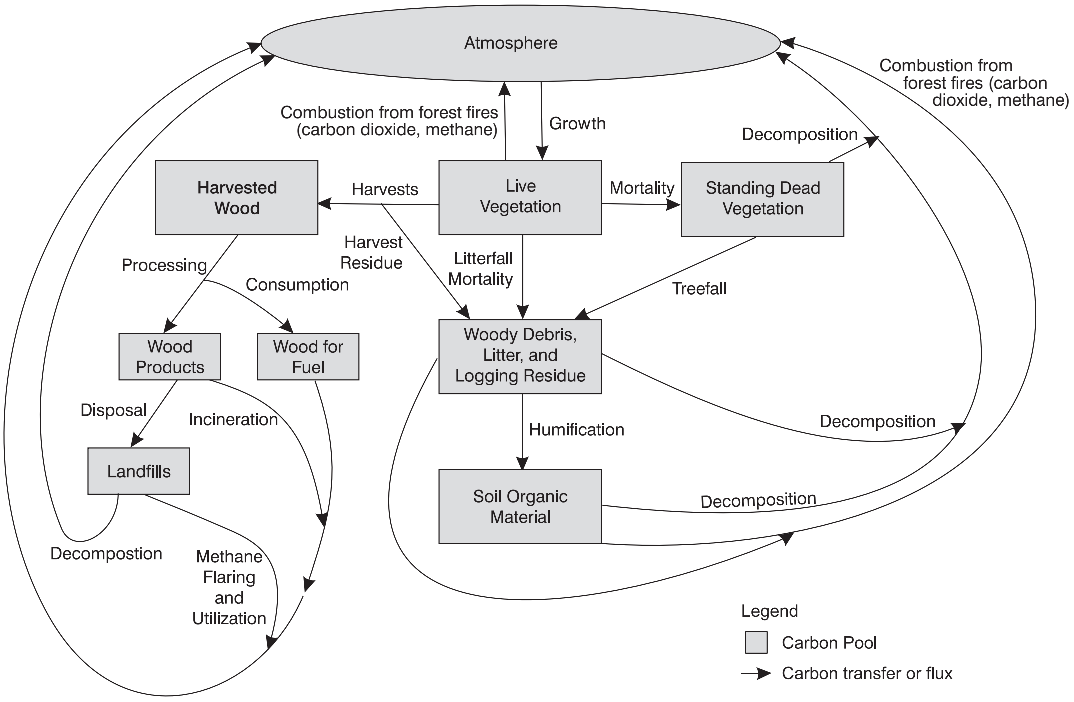
Settlements

Wetlands

Other Lands

Figure 7-2

Forest Sector Carbon Pools and Flows



Source: Heath et al. 2003

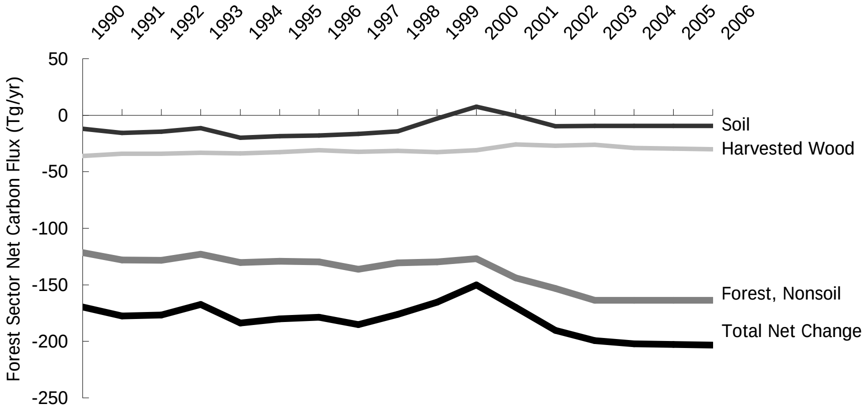
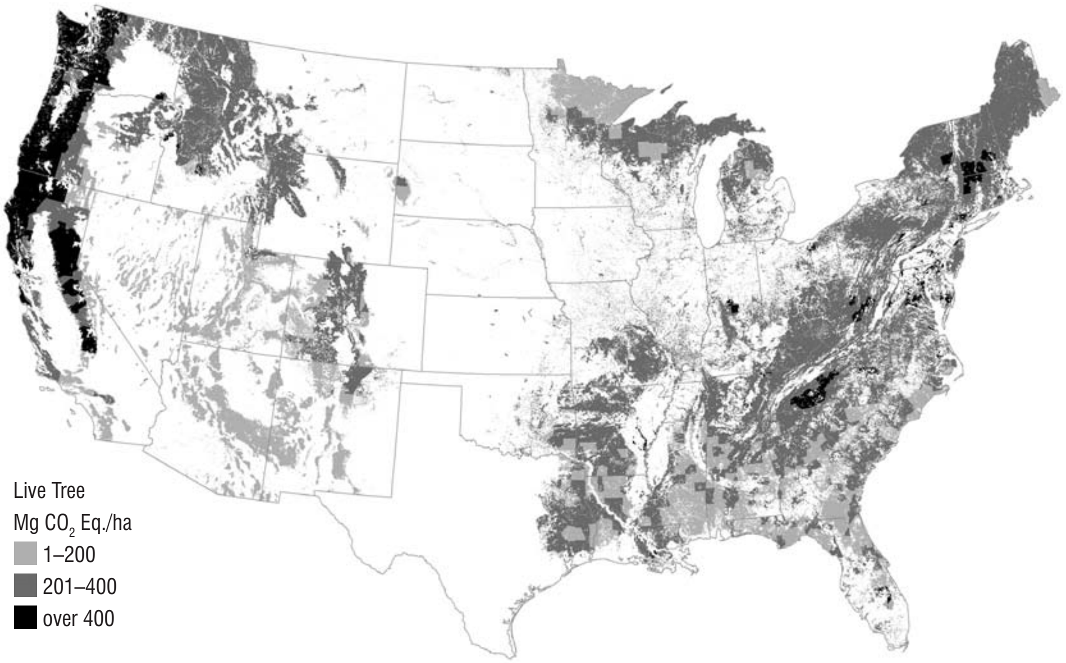


Figure 7-3: Estimates of Net Annual Changes in Carbon Stocks for Major Carbon Pools

Figure 7-4

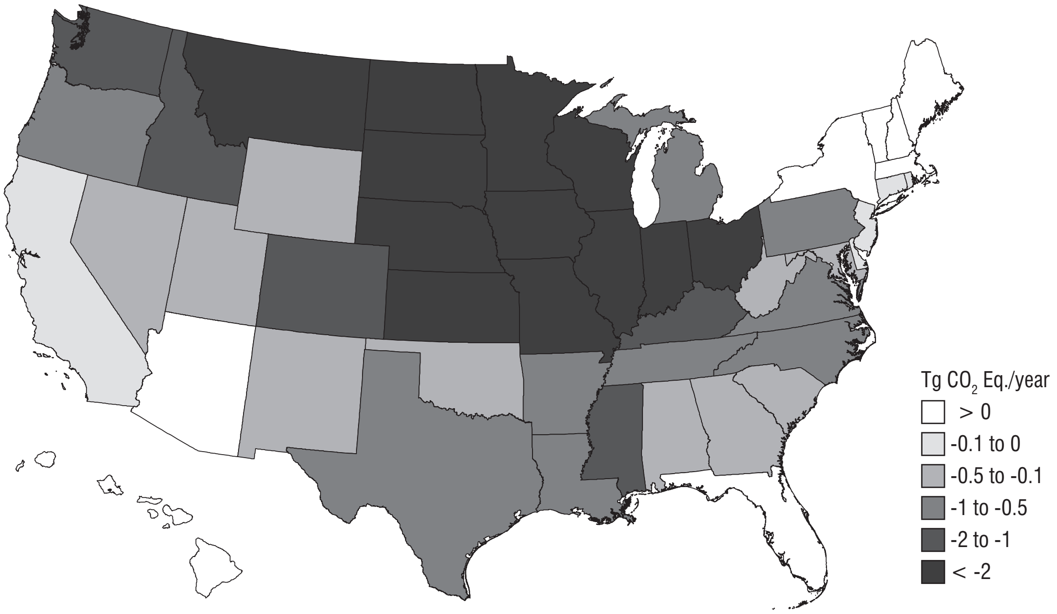
Average C Density in the Forest Tree Pool in the Conterminous U.S., 2007



Note: This graphic shows county-average carbon densities for live trees on forestland, including both above- and belowground biomass. These data are based on the most recent forest inventory survey in each state. (See Table A-3 for the most recent inventory year for each state or substate.)

Figure 7-5

Total Net Annual CO$_2$ Flux For Mineral Soils Under Agricultural Management within States, 1993–2006
Cropland Remaining Cropland

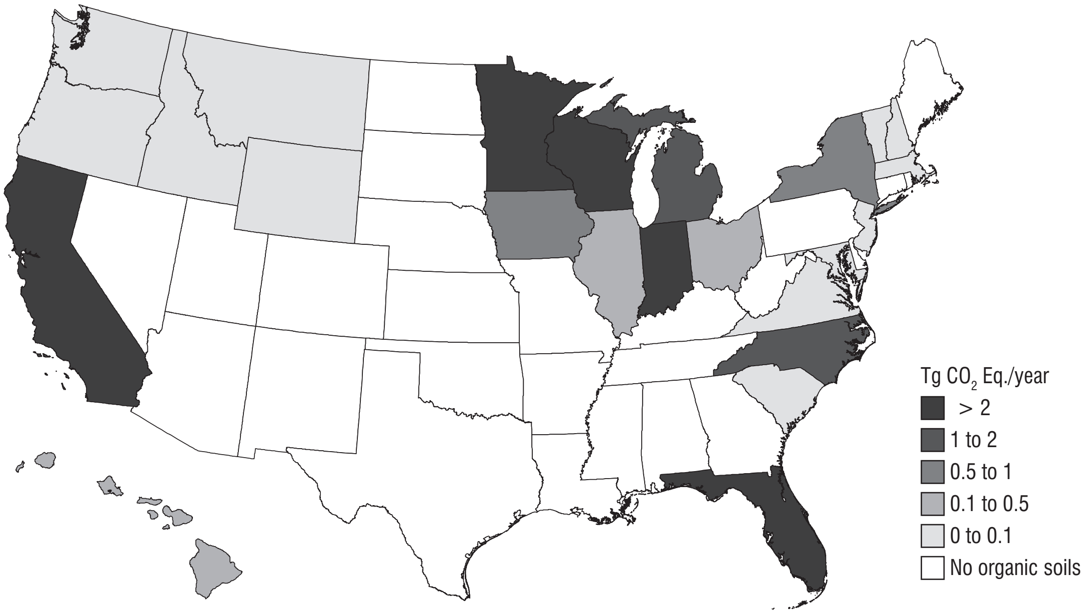


Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-6

Total Net Annual CO$_2$ Flux For Organic Soils Under Agricultural Management within States, 1993–2006

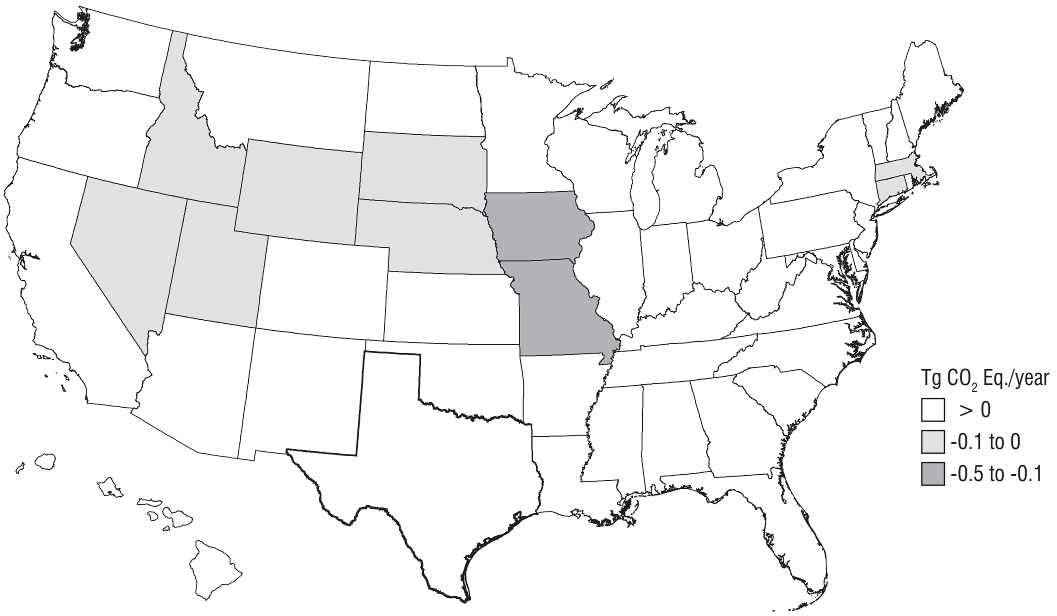
Cropland Remaining Cropland



Note: Values greater than zero represent emissions.

Figure 7-7

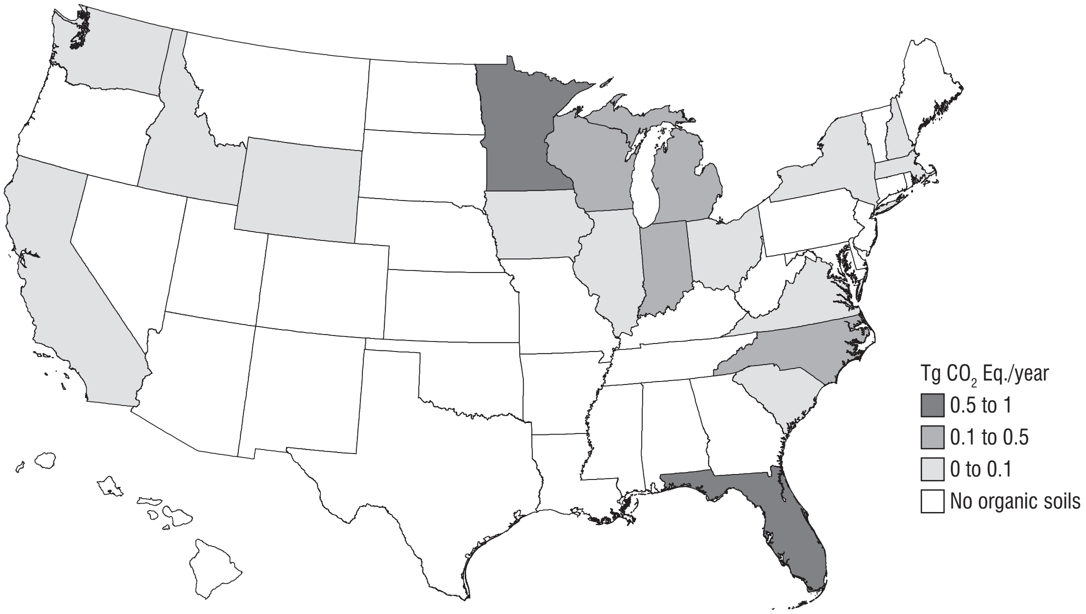
Total Net Annual CO_2 Flux For Mineral Soils Under Agricultural Management within States, 1993–2006
Land Converted to Cropland



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-8

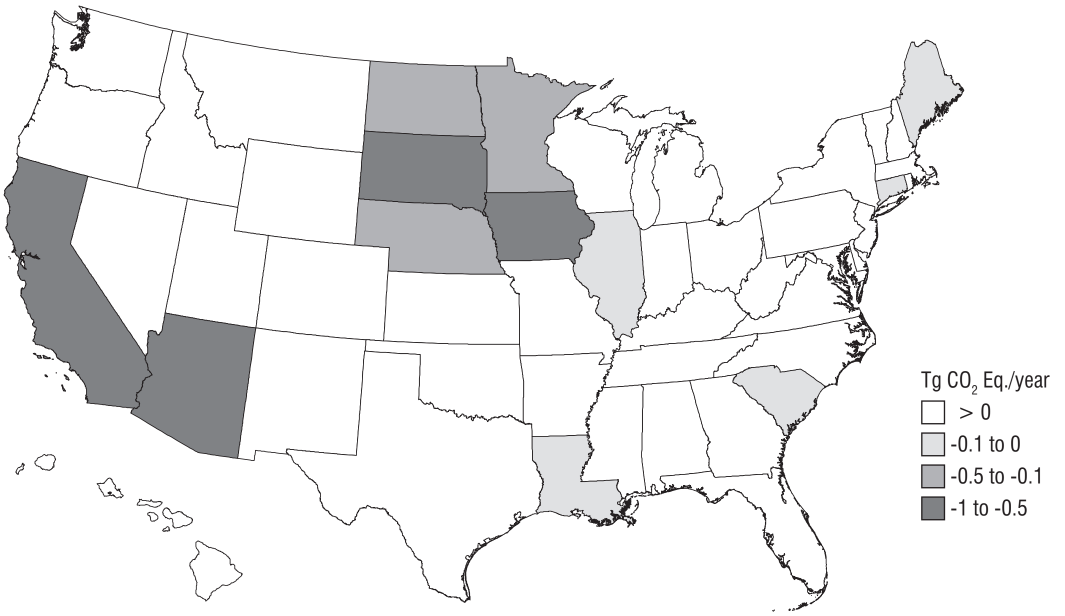
Total Net Annual CO_2 Flux For Organic Soils Under Agricultural Management within States, 1993–2006
Land Converted to Cropland



Note: Values greater than zero represent emissions.

Figure 7-9

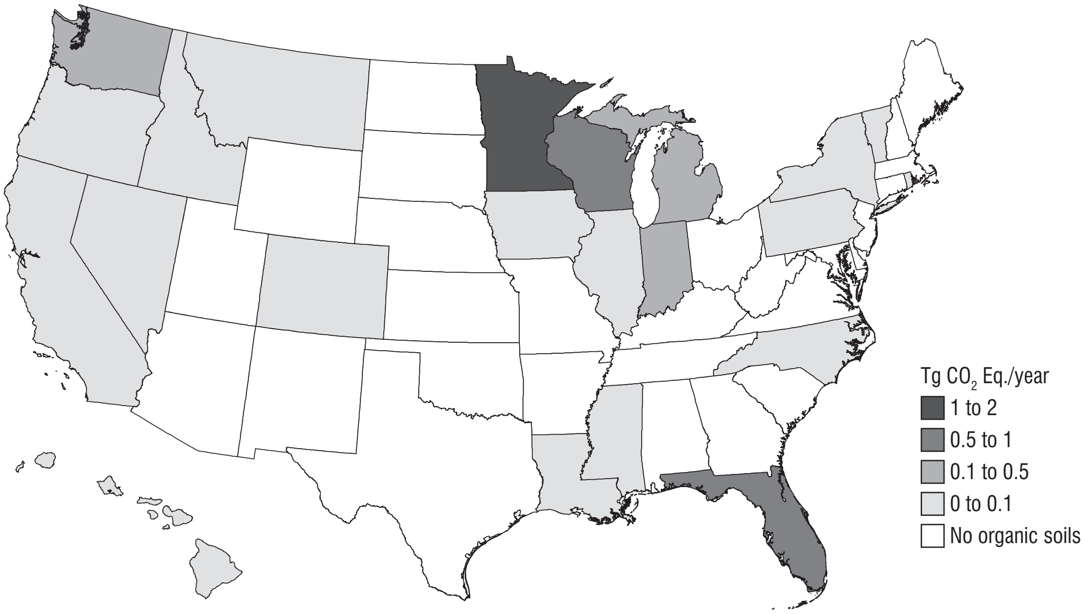
Total Net Annual CO_2 Flux For Mineral Soils Under Agricultural Management within States, 1993–2006
Grassland Remaining Grassland



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-10

Total Net Annual CO_2 Flux For Organic Soils Under Agricultural Management within States, 1993–2006
Grassland Remaining Grassland

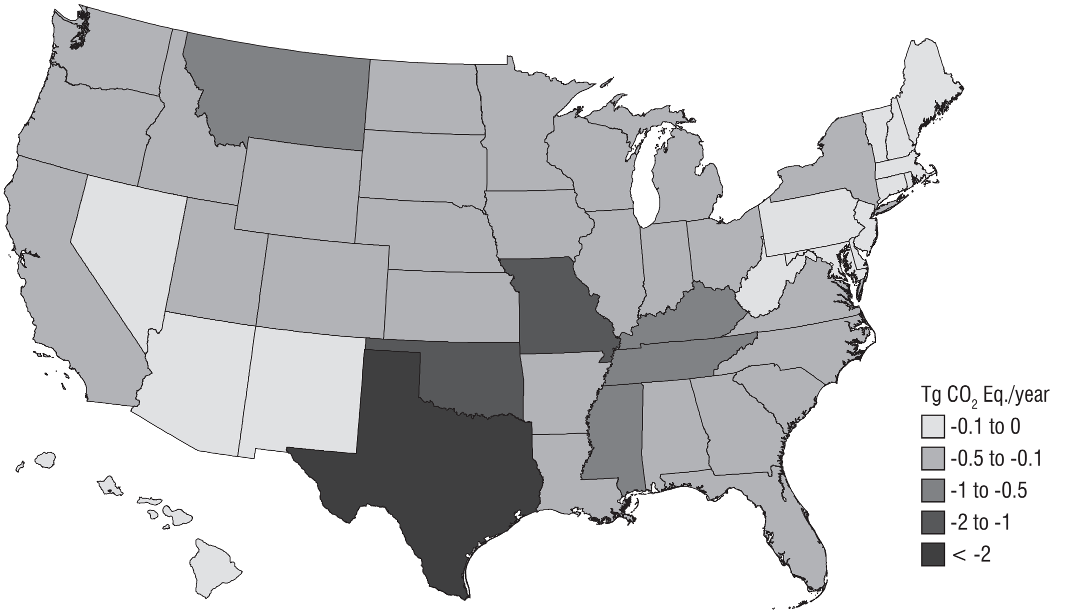


Note: Values greater than zero represent emissions.

Figure 7-11

Total Net Annual CO_2 Flux For Mineral Soils Under Agricultural Management within States, 1993–2006

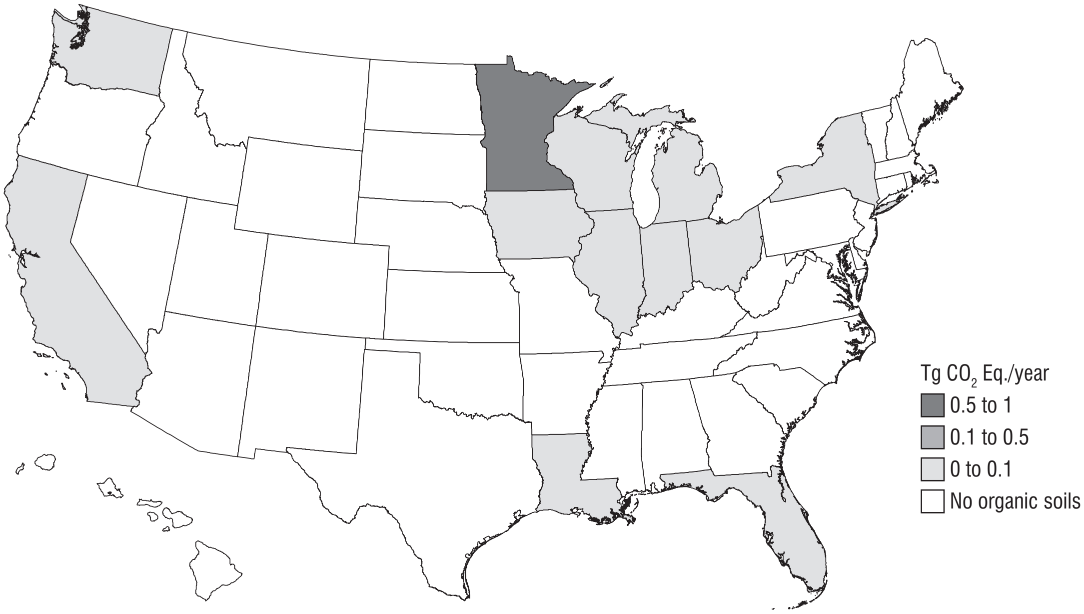
Land Converted to Grassland



Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 2 and 3 Inventory computations. See Methodology for additional details.

Figure 7-12

Total Net Annual CO_2 Flux For Organic Soils Under Agricultural Management within States, 1993–2006
Land Converted to Grassland



Note: Values greater than zero represent emissions.