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. 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). Datasets available for the United States allow greenhouse gas flux to be estimated for the following subset of the categories defined by IPCC (2003): (1) Forest Land Remaining Forest Land; (2) Cropland Remaining Cropland; (3) Land Converted to Cropland, (4) Grassland Remaining Grassland, (5) Land Converted to Grassland, and (6) Settlements Remaining Settlements. In addition, fluxes from some categories are reported under other categories because U.S. data are insufficient for separating these fluxes.

The greenhouse gas flux from Forest Land Remaining Forest Land is reported using estimates of changes in forest carbon stocks and the application of synthetic fertilizers to forest soils. The greenhouse gas flux from agricultural lands (i.e., cropland and grassland) includes changes in organic carbon 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). Fluxes are reported for four 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 landfilled yard trimmings and food scraps, urban trees, and soil fertilization.

Unlike the assessments in other sectors, which are based on annual activity data, the flux estimates in this chapter, with the exception of CO_2 fluxes from wood products, urban trees, and liming, and N_2O emissions from forest and settlement soils, are based on activity data collected at multiple-year intervals, which are in the form of forest, land-use, and municipal solid waste surveys. Carbon dioxide fluxes from forest carbon 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. The forest carbon stocks are based on state surveys, so the estimated CO_2 fluxes at the national level differ from year to year. Agricultural mineral and organic soil carbon 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, land-use, and municipal solid waste surveys were completed prior to 2004, the estimates of CO_2 flux from forests, agricultural soils, and landfilled yard trimmings and food scraps are based in part on extrapolation. Carbon dioxide flux from urban trees is based on neither annual data nor periodic survey data, but instead

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

Table 7-1: Net CO$_2$ Flux from Land Use, Land-Use Change, and Forestry (Tg CO$_2$ Eq.)

Land-Use Category	1990		1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land	**(773.4)**		**(618.8)**	**(637.9)**	**(631.0)**	**(634.0)**	**(634.6)**	**(635.8)**	**(637.2)**
Changes in Forest Carbon Stocks[a]	(773.4)		(618.8)	(637.9)	(631.0)	(634.0)	(634.6)	(635.8)	(637.2)
Cropland Remaining Cropland	**(33.1)**		**(24.6)**	**(24.6)**	**(26.1)**	**(27.8)**	**(27.5)**	**(28.7)**	**(28.9)**
Changes in Agricultural Soil Carbon Stocks and Liming Emissions[b]	(33.1)		(24.6)	(24.6)	(26.1)	(27.8)	(27.5)	(28.7)	(28.9)
Land Converted to Cropland	**1.5**		**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**
Changes in Agricultural Soil Carbon Stocks[c]	1.5		(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)
Grassland Remaining Grassland	**(4.5)**		**7.5**	**7.5**	**7.4**	**7.4**	**7.4**	**7.3**	**7.3**
Changes in Agricultural Soil Carbon Stocks[d]	(4.5)		7.5	7.5	7.4	7.4	7.4	7.3	7.3
Land Converted to Grassland	**(17.6)**		**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**
Changes in Agricultural Soil Carbon Stocks[e]	(17.6)		(21.1)	(21.1)	(21.1)	(21.1)	(21.1)	(21.1)	(21.1)
Settlements Remaining Settlements[f]	**(83.2)**		**(84.2)**	**(86.8)**	**(85.9)**	**(89.7)**	**(89.9)**	**(93.8)**	**(97.3)**
Urban Trees	(58.7)		(73.3)	(77.0)	(77.0)	(80.7)	(80.7)	(84.3)	(88.0)
Landfilled Yard Trimmings and Food Scraps	(24.5)		(10.9)	(9.8)	(8.9)	(9.0)	(9.3)	(9.4)	(9.3)
Total	**(910.4)**		**(744.0)**	**(765.7)**	**(759.5)**	**(768.0)**	**(768.6)**	**(774.8)**	**(780.1)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.
[a] Estimates include carbon stock changes on both Forest Land Remaining Forest Land, and Land Converted to Forest Land.
[b] Estimates include carbon stock changes in mineral soils and organic soils on Cropland Remaining Cropland, carbon stock changes in organic soils on Land Converted to Cropland, and liming emissions from all managed land.
[c] Estimates includes carbon stock changes in mineral soils only; organic soil carbon stock changes and liming emissions for this land use/land-use change category are reported under Cropland Remaining Cropland.
[d] Estimates include carbon stock changes in mineral soils and organic soils on Grassland Remaining Grassland, and carbon stock changes in organic soils on Land Converted to Grassland. Liming emissions for this land use/land-use change category are reported under Cropland Remaining Cropland.
[e] Estimates include carbon stock changes in mineral soils only; organic soil carbon stock changes and liming emissions for this land use/land-use change category are reported under Grassland Remaining Grassland and Cropland Remaining Cropland, respectively.
[f] Estimates include carbon stock changes on both Settlements Remaining Settlements, and Land Converted to Settlements. Liming emissions for this land use/land-use change category are reported under Cropland Remaining Cropland.

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 2004 resulted in a net carbon sequestration of 780.1 Tg CO$_2$ Eq. (212.8 Tg C) (Table 7-1 and Table 7-2). This represents an offset of approximately 13 percent of total U.S. CO$_2$ emissions. Total land use, land-use change, and forestry net carbon sequestration declined by approximately 14 percent between 1990 and 2004. This decline was primarily due to a decline in the rate of net carbon accumulation in forest carbon stocks. Net carbon accumulation in landfilled yard trimmings and food scraps, cropland, and grassland also slowed over this period. Net carbon accumulation in urban trees increased.

The application of synthetic fertilizers to forest and settlement soils in 2004 resulted in direct N$_2$O emissions of 6.8 Tg CO$_2$ Eq. (22 Gg) (Table 7-3 and Table 7-4). Direct N$_2$O emissions from fertilizer application increased by approximately 20 percent between 1990 and 2004.

7.1. Forest Land Remaining Forest Land

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

For estimating carbon (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.

Table 7-2: Net CO$_2$ Flux from Land Use, Land-Use Change, and Forestry (Tg C)

Land-Use Category	1990	1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land	**(210.9)**	**(168.8)**	**(174.0)**	**(172.1)**	**(172.9)**	**(173.1)**	**(173.4)**	**(173.8)**
Changes in Forest Carbon Stocks[a]	(210.9)	(168.8)	(174.0)	(172.1)	(172.9)	(173.1)	(173.4)	(173.8)
Cropland Remaining Cropland	**(9.0)**	**(6.7)**	**(6.7)**	**(7.1)**	**(7.6)**	**(7.5)**	**(7.8)**	**(7.9)**
Changes in Agricultural Soil Carbon Stocks and Liming Emissions[b]	(9.0)	(6.7)	(6.7)	(7.1)	(7.6)	(7.5)	(7.8)	(7.9)
Land Converted to Cropland	**0.4**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**
Changes in Agricultural Soil Carbon Stocks[c]	0.4	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Grassland Remaining Grassland	**(1.2)**	**2.1**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Changes in Agricultural Soil Carbon Stocks[d]	(1.2)	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Land Converted to Grassland	**(4.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**
Changes in Agricultural Soil Carbon Stocks[e]	(4.8)	(5.8)	(5.8)	(5.8)	(5.8)	(5.8)	(5.8)	(5.8)
Settlements Remaining Settlements[f]	**(22.7)**	**(23.0)**	**(23.7)**	**(23.4)**	**(24.5)**	**(24.5)**	**(25.6)**	**(26.5)**
Urban Trees	(16.0)	(20.0)	(21.0)	(21.0)	(22.0)	(22.0)	(23.0)	(24.0)
Landfilled Yard Trimmings and Food Scraps	(6.7)	(3.0)	(2.7)	(2.4)	(2.5)	(2.5)	(2.6)	(2.5)
Total	**(248.3)**	**(202.9)**	**(208.8)**	**(207.1)**	**(209.5)**	**(209.6)**	**(211.3)**	**(212.8)**

Note: 1 Tg C = 1 teragram carbon = 1 million metric tons carbon. Parentheses indicate net sequestration. Totals may not sum due to independent rounding.
[a] Estimates include carbon stock changes on both Forest Land Remaining Forest Land, and Land Converted to Forest Land.
[b] Estimates include carbon stock changes in mineral soils and organic soils on Cropland Remaining Cropland, carbon stock changes in organic soils on Land Converted to Cropland, and liming emissions from all managed land.
[c] Estimates includes carbon stock changes in mineral soils only; organic soil carbon stock changes and liming emissions for this land use/land-use change category are reported under Cropland Remaining Cropland.
[d] Estimates include carbon stock changes in mineral soils and organic soils on Grassland Remaining Grassland, and carbon stock changes in organic soils on Land Converted to Grassland. Liming emissions for this land use/land-use change category are reported under Cropland Remaining Cropland.
[e] Estimates include carbon stock changes in mineral soils only; organic soil carbon stock changes and liming emissions for this land use/land-use change category are reported under Grassland Remaining Grassland and Cropland Remaining Cropland, respectively.
[f] Estimates include carbon stock changes on both Settlements Remaining Settlements, and Land Converted to Settlements. Liming emissions for this land use/land-use change category are reported under Cropland Remaining Cropland.

Table 7-3: N$_2$O Emissions from Land Use, Land-Use Change, and Forestry (Tg CO$_2$ Eq.)

Land-Use Category	1990	1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land	**0.1**	**0.4**	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
N$_2$O Emissions from Soils[a]	0.1	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Settlements Remaining Settlements	**5.6**	**6.2**	**6.2**	**6.0**	**5.8**	**6.0**	**6.2**	**6.4**
N$_2$O Emissions from Soils[b]	5.6	6.2	6.2	6.0	5.8	6.0	6.2	6.4
Total	**5.7**	**6.5**	**6.7**	**6.4**	**6.2**	**6.4**	**6.6**	**6.8**

Note: These estimates include direct emissions only. Indirect N$_2$O emissions are reported in section 6.4 of the Agriculture chapter. Totals may not sum due to independent rounding.
[a] 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.
[b] Estimates include emissions from N fertilizer additions on both Settlements Remaining Settlements, and Land Converted to Settlements, but not from land-use conversion.

- 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 carbon (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 also necessary for estimating C flux, which are:

- Harvested wood products in use.

- Harvested wood products in landfills.

Carbon 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, growth, mortality, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, clearing, and replanting). As trees

Table 7-4: N$_2$O Emissions from Land Use, Land-Use Change, and Forestry (Gg)

Land-Use Category	1990		1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land	<1		1	2	1	1	1	1	1
N$_2$O Emissions from Soils[a]	<1		1	2	1	1	1	1	1
Settlements Remaining Settlements	18		20	20	19	19	19	20	21
N$_2$O Emissions from Soils[b]	18		20	20	19	19	19	20	21
Total	**18**		**21**	**22**	**21**	**20**	**21**	**21**	**22**

Note: These estimates include direct emissions only. Indirect N$_2$O emissions are reported in section 6.4 of the Agriculture chapter. Totals may not sum due to independent rounding.
[a] 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.
[b] Estimates include emissions from N fertilizer additions on both Settlements Remaining Settlements, and Land Converted to Settlements, but not from land-use conversion.

photosynthesize and grow, C is removed from the atmosphere and stored in living tree biomass. As trees age, they continue to accumulate C until they reach maturity, at which point they store a relatively constant amount of C. 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 landfills, the C contained in the wood may be released many years or decades later, or may be stored almost permanently in the landfills.
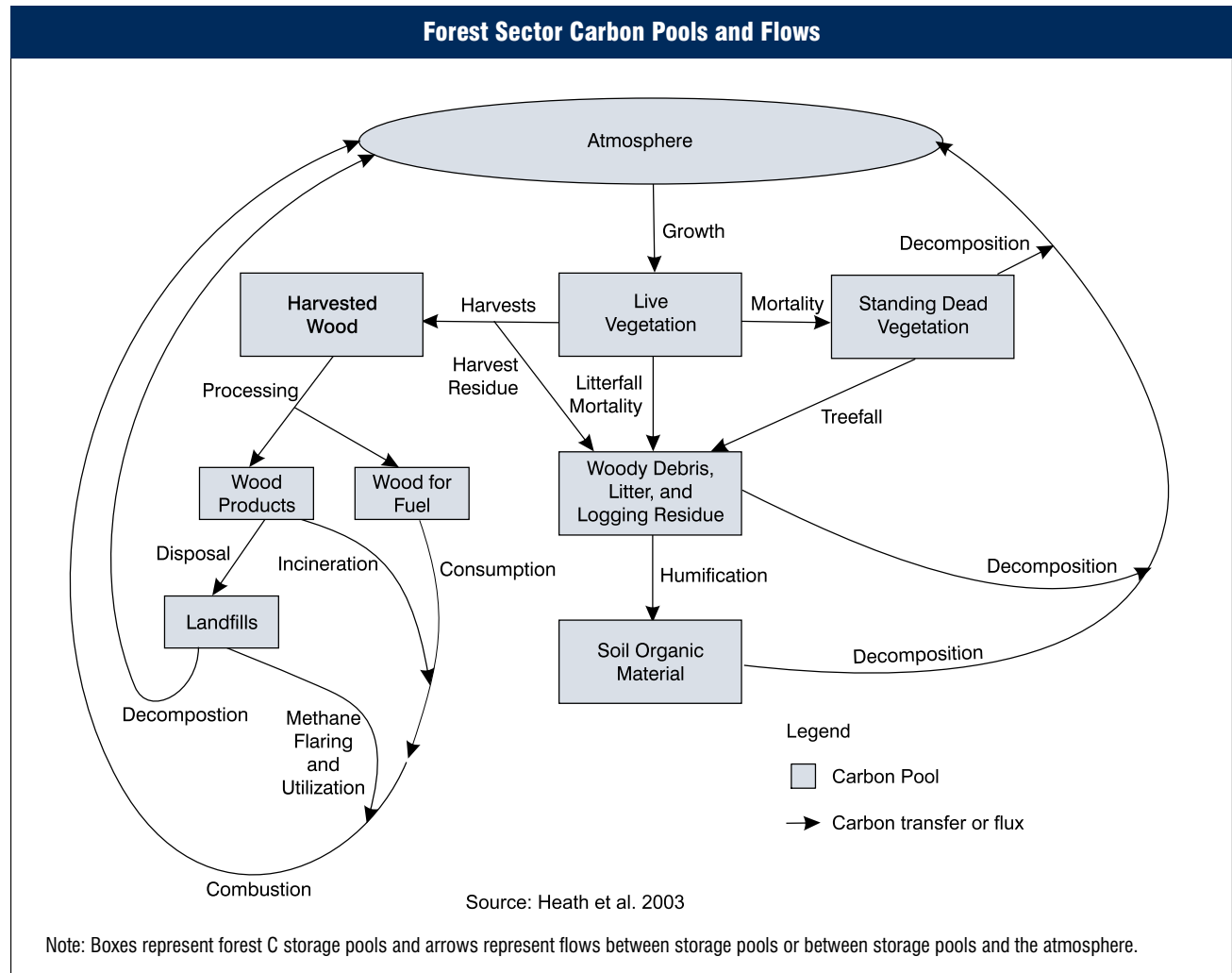
This section quantifies the net changes in C stocks in the five forest C pools and two harvested wood pools. The net change in stocks for each pool is estimated, and then the changes in stocks are summed over all pools to estimate total net flux. Thus, the focus on C implies that all C-based greenhouse gases are included, and the focus on stock change suggests that specific ecosystem fluxes are not 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 counts the carbon changes due to fires; however, it may not be possible to attribute the changes to the disturbance specifically. The IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (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.

Approximately 33 percent (303 million hectares) of the U.S. land area is forested. Approximately 250 million hectares are located in the conterminous 48 states and form the basis for the estimates provided in this chapter. Seventy-nine percent of the 250 million hectares are classified as timberland, meaning they meet minimum levels of productivity and are available for timber harvest. Historically, the timberlands in the conterminous 48 states have been more frequently or intensively surveyed than other forestlands. Of the remaining 51 million hectares, 16 million hectares are

Figure 7-1

Forest Sector Carbon Pools and Flows

Note: Boxes represent forest C storage pools and arrows represent flows between storage pools or between storage pools and the atmosphere.

Source: Heath et al. 2003

reserved forestlands (withdrawn by law from management for production of wood products) and 35 million hectares are lower productivity forestlands (Smith et al. 2004b). From the early 1970s to the early 1980s, forest land declined by approximately 2.4 million hectares. During the 1980s and 1990s, forest area increased by about 3.7 million hectares. These net changes in forest area represent average annual fluctuations of only about 0.1 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 can increase both the rate of growth and the eventual biomass density[2] of the forest, thereby increasing the uptake of C. Harvesting forests removes much of the aboveground C, but trees can grow on this area again and sequester C. 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 2004. Due to improvements in U.S. agricultural productivity, the rate of forest clearing for crop cultivation and pasture slowed in the late 19th century, and by 1920,

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

this practice had all but ceased. As farming expanded in the Midwest and West, large areas of previously cultivated land in the East were taken out of crop production, primarily between 1920 and 1950, and were allowed to revert to forests or were actively reforested. The impacts of these land-use changes still affect C fluxes from forests in the East. In addition, C fluxes from eastern forests have been affected by a trend toward managed growth on private land. Collectively, these changes have nearly doubled the biomass density in eastern forests since the early 1950s. 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 landfills rather than by incineration, significant quantities of C in harvested wood are transferred to long-term storage pools rather than being released rapidly to the atmosphere (Skog and Nicholson 1998). 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 an average annual net sequestration of 627 Tg CO_2 Eq. (171 Tg C) over the period 1990 through 2004 (Table 7-5, Table 7-6, 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, particularly before 1997. The increase in forest sequestration is due more to an increasing C density per area than to the increase in area of forestland. Forestland in the conterminous United States was approximately 246, 250, and 251 million hectares for

Table 7-5. Net Annual Changes in Carbon Stocks (Tg CO_2/yr) in Forest and Harvested Wood Pools

| Carbon Pool	1990	1998	1999	2000	2001	2002	2003	2004
Forest	**(563.3)**	**(412.7)**	**(423.2)**	**(420.2)**	**(420.2)**	**(420.2)**	**(420.2)**	**(420.2)**
Aboveground Biomass	(338.5)	(287.5)	(306.6)	(310.3)	(310.3)	(310.3)	(310.3)	(310.3)
Belowground Biomass	(64.8)	(55.1)	(59.5)	(60.3)	(60.3)	(60.3)	(60.3)	(60.3)
Dead Wood	(43.5)	(41.6)	(35.5)	(33.2)	(33.2)	(33.2)	(33.2)	(33.2)
Litter	(82.9)	(12.4)	(24.9)	(26.6)	(26.6)	(26.6)	(26.6)	(26.6)
Soil Organic Carbon	(33.6)	(16.0)	3.2	10.1	10.1	10.1	10.1	10.1
Harvested Wood	**(210.1)**	**(206.1)**	**(214.7)**	**(210.8)**	**(213.8)**	**(214.4)**	**(215.6)**	**(217.0)**
Wood Products	(47.6)	(51.9)	(61.5)	(58.7)	(59.0)	(59.2)	(60.4)	(60.8)
Landfilled Wood	(162.4)	(154.2)	(153.1)	(152.1)	(154.8)	(155.3)	(155.1)	(156.2)
Total Net Flux	**(773.4)**	**(618.8)**	**(637.9)**	**(631.0)**	**(634.0)**	**(634.6)**	**(635.8)**	**(637.2)**

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

Carbon Pool	1990	1998	1999	2000	2001	2002	2003	2004
Forest	**(153.6)**	**(112.6)**	**(115.4)**	**(114.6)**	**(114.6)**	**(114.6)**	**(114.6)**	**(114.6)**
Aboveground Biomass	(92.3)	(78.4)	(83.6)	(84.6)	(84.6)	(84.6)	(84.6)	(84.6)
Belowground Biomass	(17.7)	(15.0)	(16.2)	(16.4)	(16.4)	(16.4)	(16.4)	(16.4)
Dead Wood	(11.9)	(11.4)	(9.7)	(9.1)	(9.1)	(9.1)	(9.1)	(9.1)
Litter	(22.6)	(3.4)	(6.8)	(7.2)	(7.2)	(7.2)	(7.2)	(7.2)
Soil Organic Carbon	(9.2)	(4.4)	0.9	2.8	2.8	2.8	2.8	2.8
Harvested Wood	**(57.3)**	**(56.2)**	**(58.5)**	**(57.5)**	**(58.3)**	**(58.5)**	**(58.8)**	**(59.2)**
Wood Products	(13.0)	(14.2)	(16.8)	(16.0)	(16.1)	(16.1)	(16.5)	(16.6)
Landfilled Wood	(44.3)	(42.1)	(41.8)	(41.5)	(42.2)	(42.3)	(42.3)	(42.6)
Total Net Flux	**(210.9)**	**(168.8)**	**(174.0)**	**(172.1)**	**(172.9)**	**(173.1)**	**(173.4)**	**(173.8)**

Note: 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 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.

Figure 7-2

Estimates of Net Annual Changes in Carbon Stocks for Major Carbon Pools
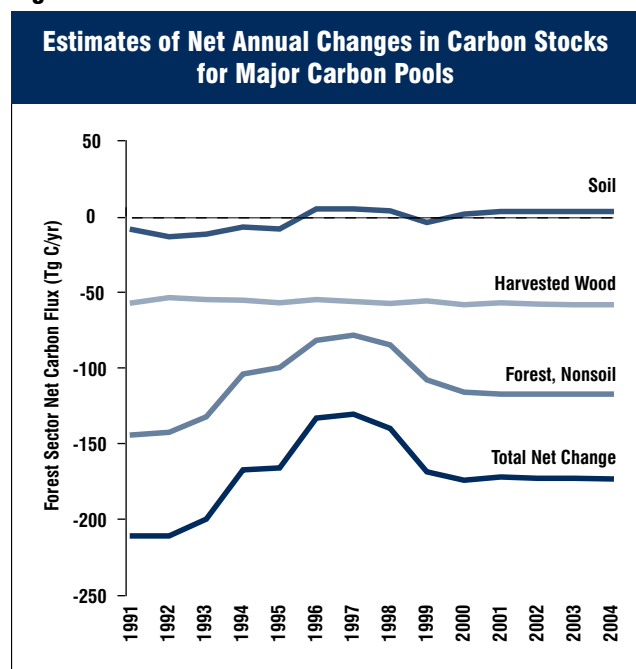
1987, 1997, and 2002, respectively, only a 2 percent increase over the period (Smith et al. 2004b). Continuous, regular annual surveys are not available over the period for each state; therefore, estimates for non-survey years were derived by interpolation between known data points. Survey years vary from state to state. National estimates are a composite of individual state surveys. Total sequestration declined by 18 percent between 1990 and 2004. Estimated sequestration

in the litter carbon pool had the greatest effect on total change; the net rate of accumulation in litter decreased by 56 Tg CO_2 Eq. Aboveground biomass and soil carbon had the next largest effects on total change; the net rate of accumulation in these pools decreased by 28 and 24 Tg CO_2 Eq., respectively.

Stock estimates for forest and harvested wood C storage pools are presented in Table 7-7. 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 7-3 shows county-average carbon densities for live trees on forestland, including both above- and belowground biomass.

Methodology

The methodology described herein is consistent with IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003) and the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). Estimates of net C flux from forest pools were derived from periodic and annualized inventories of forest stocks. Net changes in C stocks were interpolated between survey years. Carbon emissions from harvested wood were determined by accounting for the variable rate of decay of harvested wood according to its disposition (e.g., product pool, landfill, combustion).[3]
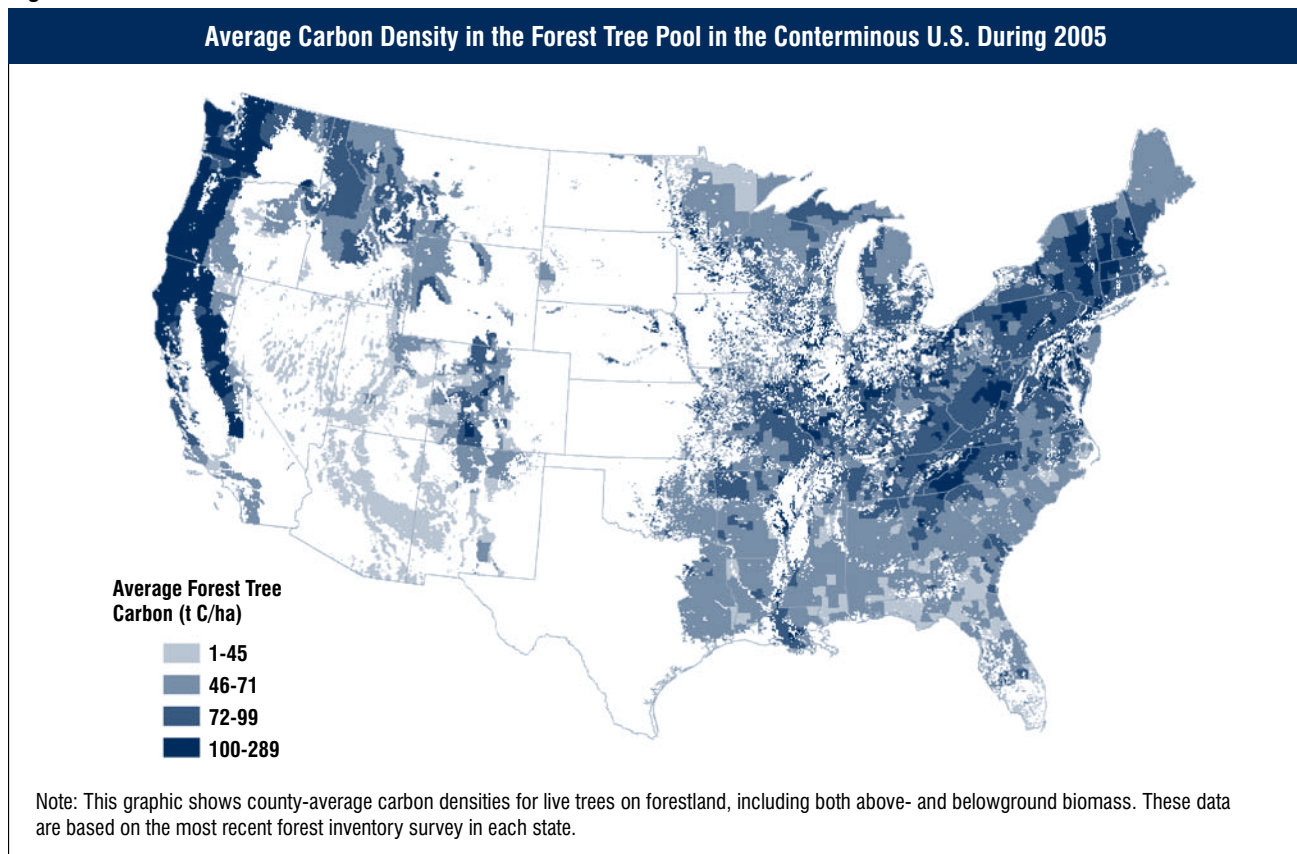
Table 7-7. Carbon Stocks (Tg C) in Forest and Harvested Wood Pools

Carbon Pool	1990		1998	1999	2000	2001	2002	2003	2004	2005
Forest	**39,508**		**40,417**	**40,529**	**40,645**	**40,760**	**40,874**	**40,989**	**41,103**	**41,218**
Aboveground Biomass	14,334		14,938	15,016	15,100	15,184	15,269	15,354	15,438	15,523
Belowground Biomass	2,853		2,967	2,982	2,998	3,014	3,031	3,047	3,064	3,080
Dead Wood	2,409		2,488	2,499	2,509	2,518	2,527	2,536	2,545	2,554
Litter	4,492		4,565	4,569	4,575	4,583	4,590	4,597	4,604	4,612
Soil Organic Carbon	15,420		15,460	15,464	15,463	15,460	15,458	15,455	15,452	15,449
Harvested Wood	**1,915**		**2,365**	**2,421**	**2,480**	**2,537**	**2,595**	**2,654**	**2,713**	**2,772**
Wood Products	1,134		1,248	1,262	1,279	1,295	1,311	1,327	1,344	1,360
Landfilled Wood	781		1,117	1,159	1,200	1,242	1,284	1,327	1,369	1,411
Total Carbon Stock	**41,423**		**42,782**	**42,951**	**43,125**	**43,297**	**43,470**	**43,643**	**43,816**	**43,990**

Note: Forest C stocks do not include forest stocks in Alaska, Hawaii, or U.S. territories, or trees on non-forest land (e.g., urban trees). Wood product stocks include exports, even if the logs are processed in other countries, and exclude imports. Forest 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. 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 2004 requires estimates of C stocks for 2004 and 2005.

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[3] The wood product stock and flux estimates presented here use the production approach, meaning that they do not account for C stored in imported wood products, but do include C stored in exports, even if the logs are processed in other countries. This approach is used because it follows the precedent established in previous reports (Heath et al. 1996).

Figure 7-3

Average Carbon Density in the Forest Tree Pool in the Conterminous U.S. During 2005

Average Forest Tree
Carbon (t C/ha)

- 1-45
- 46-71
- 72-99
- 100-289

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.

Different data sources were used to estimate the C stocks and stock change in: (1) forests (aboveground and belowground biomass, dead wood, and litter); (2) forest soils; and (3) harvested wood products. Therefore, these pools are described separately below.

Live Biomass, Dead Wood, and Litter Carbon

The estimates of non-soil forest C stocks are based on data derived from forest surveys. Forest survey data were obtained from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (Frayer and Furnival 1999, Smith et al. 2001). Surveys provide estimates of the merchantable volume of wood and other variables that are used to estimate C stocks. Estimates of temporal change such as growth, mortality, harvests, or area change are derived from repeated surveys, which were conducted every 5 to 14 years, depending on the state. Historically, the FIA program did not conduct detailed surveys of all forest land,

but instead focused on land capable of supporting timber production (timberland).[4] Over time, however, individual state surveys gradually started to include reserved and less productive forest land. The C stock estimates provided here include all forest land. See Annex 3.12 for discussion of how past data gaps on these lands were filled.

Temporal and spatial gaps in surveys were addressed with the new national plot design and annualized sampling (Alerich et al. 2005), which were recently introduced by FIA. 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. Sampling is designed such that partial inventory cycles provide usable, unbiased samples of forest inventory. Thus, many states have relatively recent partial inventories, yet not all states are currently surveyed this way. All annualized surveys initiated since 1998 have followed the new national plot

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[4] 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. Productivity is at a minimum rate of 20 cubic feet of industrial wood per acre per year. The remaining portion of forest land is classified as either reserved forest land, which is forest land withdrawn from timber use by statute or regulation, or other forest land, which includes less productive forests on which timber is growing at a rate less than 20 cubic feet per acre per year. In 2002, there were about 199 million hectares of timberland in the conterminous United States, which represented 79 percent of all forest land over the same area (Smith et al. 2004b).

design for all forestland, including reserved and less productive land.

For each periodic or annualized inventory in each state, each C pool was estimated using coefficients from the FORCARB2 model (Birdsey and Heath 1995, Birdsey and Heath 2001, Heath et al. 2003, Smith et al. 2004a). Estimates of C stocks made by the FORCARB2 coefficients at the plot level are organized somewhat differently than the standard IPCC pools reported in Table 7-7. However, the estimators are compatible with reorganizing the pools following IPCC *LULUCF Good Practice Guidance* (2003). For example, the biomass pools here include the FORCARB2 pools of live trees and understory vegetation, each of which are divided into aboveground versus belowground portions. Calculations for the tree portion of the aboveground biomass C pool were made using individual-tree or volume-to-biomass conversion factors for different types of forests, depending on the data available for each survey (Jenkins et al. 2003, Smith et al. 2003). Biomass was converted to C mass by dividing by two because dry biomass is approximately 50 percent C (IPCC/UNEP/OECD/IEA 1997). The other portion of aboveground biomass, live understory C, was estimated from inventory data using tables presented in Birdsey (1996). Litter C was estimated from inventory data using the equations presented in Smith and Heath (2002). Down dead wood was estimated using a FORCARB2 simulation and U.S. forest statistics (Smith et al. 2001).

Forest Soil Carbon

Estimates of soil organic carbon stocks are based solely on forest area and on average soil C density for each broad forest type group. Thus, any changes in soil C stocks are due to changes in total forest area or the distribution of forest types within that area. Estimates of the organic C content of soils are based on the national STATSGO spatial database (USDA 1991) and follow methods of Amichev and Galbraith (2004). These data were overlaid with FIA survey data to estimate soil C on forest land by broad forest type group.

Forest Carbon Stocks and Fluxes

The overall approach for determining forest C stock change was to estimate forest C stocks based on data from two forest surveys conducted several years apart. Carbon stocks were calculated separately for each state based on inventories available since 1990 and for the most recent inventory prior to 1990. For each pool in each state in each year, C stocks were estimated by linear interpolation between survey years. Similarly, fluxes were estimated for each pool in each state by dividing the difference between two successive stocks by the number of intervening years between surveys. Stocks and fluxes since the most recent survey were based on extrapolating estimates from the last two surveys. C stock and flux estimates for each pool were summed over all states to form estimates for the conterminous United States. Data sources and methods for estimating individual C pools are described more fully in Annex 3.12.

Harvested Wood Carbon

Estimates of C stock changes in wood products and wood discarded in landfills were based on the methods described by Skog and Nicholson (1998). Carbon stocks in wood products in use and wood products stored in landfills were estimated from 1910 onward based on historical data from the USDA Forest Service (USDA 1964, Ulrich 1989, Howard 2001), and historical data as implemented in the framework underlying the North American Pulp and Paper (NAPAP, Ince 1994), the Timber Assessment Market, and the Aggregate Timberland Assessment System Timber Inventory models (TAMM/ATLAS, Haynes 2003, Mills and Kincaid 1992). Beginning with data on annual wood and paper production, the fate of C in harvested wood was tracked for each year from 1910 through 2004, and included the change in C stocks in wood products, the change in C in landfills, and the amount of C emitted to the atmosphere (CO_2 and CH_4) both with and without energy recovery. To account for imports and exports, the production approach was used, meaning that C in exported wood was counted as if it remained in the United States, and C in imported wood was not counted.

Uncertainty

The forest survey data that underlie the forest C estimates are based on a statistical sample designed to represent the wide variety of growth conditions present over large territories. However, forest survey data that are currently available generally exclude timber stocks on most forest land in Alaska, Hawaii, and U.S. territories. For this reason, estimates have been developed only for the conterminous United States. Within the conterminous United States, the USDA Forest Service mandates that forest area data are accurate within 3 percent at the 67 percent confidence level (one standard error) per 405,000 ha (10^6

acres) of timberland (Aldrich et al. 2005). For larger areas, the uncertainty in area is concomitantly smaller. For growing stock volume data on timberland, the accuracy is targeted to be 5 or 10 percent for each 28.3 million m^3 (10^9 cubic feet) at the same confidence level. An analysis of uncertainty in growing stock volume data for timber producing land in the Southeast by Phillips et al. (2000) found that nearly all of the uncertainty in their analysis was due to sampling rather than the regression equations used to estimate volume from tree height and diameter. Standard errors for growing stock volume ranged from 1 to 2 percent for individual states and less than 1 percent for the 5-state region. However, the total standard error for the change in growing stock volume was estimated to be 12 to 139 percent for individual states, and 20 percent for the 5-state region. The high relative uncertainty for growing stock volume change in some states was due to small net changes in growing stock volume. However, the uncertainty in volume change may be smaller than was found in this study because estimates from samples taken at different times on permanent survey plots are correlated, and such correlation reduces the uncertainty in estimates of changes in volume or C over time (Smith and Heath 2000).

In addition to uncertainty in data summarized for inventory surveys, there is uncertainty associated with the estimates of specific C stocks in those forest ecosystems. Estimates for these pools are derived from extrapolations of site-specific studies to all forest land since survey data on these pools are not generally available. Such extrapolation introduces uncertainty because available studies may not adequately represent regional or national averages. Uncertainty may also arise due to: (1) modeling errors (e.g., relying on coefficients or relationships that are not well known); and (2) errors in converting estimates from one reporting unit to another (Birdsey and Heath 1995). An important source of uncertainty is that there is little consensus from available data sets on the effect of land-use change and forest management activities (such as harvest) on soil C stocks. For example, while Johnson and Curtis (2001) found little or no net change in soil C following harvest, on average, across a number of studies, many of the individual studies did exhibit differences. Heath and Smith (2000a) noted that the experimental design in a number of soil studies limited their usefulness for determining effects of harvesting on soil C. Because soil C stocks are large, estimates need to be very precise, since even small relative changes in soil C sum to large differences when integrated over large areas. The soil C stock and stock change estimates presented herein are based on the assumption that soil C density for each broad forest type group stays constant over time. As more information becomes available, the effects of land use and of changes in land use and forest management will be better accounted for in estimates of soil C (see "Planned Improvements" below).

A quantitative uncertainty analysis was developed for the estimates of C stock and flux presented here. The analysis incorporated the information discussed above as well as preliminary uncertainty analyses of previous C estimates developed according to the same or similar methodologies as applied here (Heath and Smith 2000b, Smith and Heath 2000, Skog et al. 2004). Some additional details on the analysis are provided in Annex 3.12. The uncertainty analysis was performed using the IPCC-recommended Tier 2 uncertainty estimation methodology—Monte Carlo Simulation technique. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-8. The 2004 flux estimate for forest C stocks is estimated to be between -794.7 and -476.3 Tg CO_2 Eq. at a 95 percent confidence level (i.e., 19 out of every 20 Monte Carlo stochastic simulations fall within this interval). This indicates a relative range of

Table 7-8: Tier 2 Quantitative Uncertainty Estimates for Net CO_2 Flux from Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks (Tg CO_2 Eq. and Percent)

Source	Gas	2004 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 Land Remaining Forest Land: Changes in Forest Carbon Stocks	CO_2	(637.2)	(794.7)	(476.3)	-25%	+25%

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.

24.7 percent below to 25.2 percent above the 2004 flux estimate of -637.2 Tg CO_2 Eq. The 95 percent confidence intervals for the two principal components of total flux are -546 to -294 Tg CO_2 Eq. for forest ecosystems and -297 to -136 Tg CO_2 Eq. for harvested wood.

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 since 1952. The main purpose of the Forest Inventory and Analysis 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 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 (FIA Database Retrieval System).

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 (FIA Database Retrieval System). 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).

Recalculations Discussion

The overall scheme for developing annualized estimates of C stocks based on the individual state surveys is similar to that presented in the previous Inventory (EPA 2005). The change from the previous year's methods involves the use of survey data. This year, the emphasis was on using all available state surveys in the FIADB, with RPA data used as necessary to estimate pre-1990 stocks. In the previous inventory, the FIADB was used to supplement the RPA datasets. Additionally, the FIADB has been updated over the last year.

The modifications and updates to the forest inventory data are detailed in Table A-180 in Annex 3.12 (the forest carbon methodology annex) and can be compared with forest inventories identified in a similar table in the previous U.S. Greenhouse Gas Inventory (EPA 2005). These changes are reflected in estimates of forest carbon stocks. Biomass stocks prior to 1996 were revised upward slightly, and biomass stocks after 1997 were revised downward. Stocks of dead wood were revised downward throughout, with greater changes in more recent years. The net effect is an average decrease in estimated forest carbon stocks of less than 1 percent for the period 1990 through 2003. These comparisons can be independently calculated by referring to Table A-183 in this Inventory and the analogous table in the previous Inventory (EPA 2005). Overall, these changes resulted in an average annual decrease of 206 Tg CO_2 Eq. (24 percent) in the net change in forest carbon stocks for the period 1990 through 2003.

Planned Improvements

The ongoing annualized surveys by the FIA Program will improve precision of forest C estimates as new state surveys become available (Gillespie 1999). In addition, the more intensive sampling of down dead wood, litter, and soil organic C on some of the permanent plots will substantially improve resolution of C pools at the plot level.

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). 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, many forests in the Eastern United States are re-growing on abandoned agricultural

land. During such regrowth, soil and forest floor C stocks often increase substantially over many years or even decades, especially on highly eroded agricultural land. In addition, with deforestation, soil C stocks often decrease over many years. A new methodology is being developed to account for these changes in soil C over time. This methodology includes estimates of area changes among land uses (especially forest and agriculture), estimates of the rate of soil C stock gain with afforestation, and estimates of the rate of soil C stock loss with deforestation over time. This topic is important because soil C stocks are large, and soil C flux estimates contribute substantially to total forest C flux, as shown in Table 7-6 and Figure 7-2.

The estimates of C stored in harvested wood products are currently being revised using more detailed wood products production and use data, and more detailed parameters on disposition and decay of products.

An additional planned improvement is to develop a consistent representation of the U.S. managed land base. Currently, the forest C and the agricultural soil C inventories are the two major analyses addressing land-use and management impacts on C stocks. The forest inventory relies on the activity data from the FIA Program to estimate anthropogenic impacts on forest land, while the agricultural soil C inventory relies on the USDA National Resources Inventory (NRI). Recent research has revealed that the classification of forest land is not consistent between the FIA and NRI, leading to some double-counting and gaps in the current forest C and agricultural soil C inventories (e.g., some areas classified as forest land in the FIA are considered rangeland in the NRI). Consequently, the land bases are in the process of being compared between the inventories to determine where overlap or gaps occur, and then ensure that the inventories are revised to have a consistent and complete accounting of land-use and management impacts across all managed land in the United States.

N$_2$O Fluxes from Soils (IPCC Source Category 5A1)

Of the 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 fertilizer. This is because forests are typically fertilized only twice during their approximately 40-year growth cycle (once at planting and once at approximately 20 years). Thus, although the rate of fertilizer application for the area of forests that receives fertilizer in any given year is relatively high, average annual applications, inferred by dividing all forest land by the amount of fertilizer added to forests in a given year, is quite low. Nitrous oxide (N$_2$O) emissions from forest soils for 2004 were almost 7 times higher than the baseline year (1990). The trend toward increasing N$_2$O emissions is a result of an increase in fertilized area of pine plantations in the southeastern United States. Total 2004 forest soil N$_2$O emissions are roughly equivalent to 3.9 percent of the total forest soil carbon flux, and 0.06 percent of the total sequestration in standing forests, and are summarized in Table 7-9.

Methodology

For soils within Forest Land Remaining Forest Land, the IPCC Tier 1 approach was used to estimate N$_2$O from soils. According to U.S. Forest Service statistics for 1996 (USDA Forest Service 2001), approximately 75 percent of trees planted for timber, and about 60 percent of national total harvested forest area are in the Southeastern United States. Consequently, it was assumed that southeastern pine plantations represent the vast majority of fertilized forests in the United States. Therefore, estimates of direct N$_2$O emissions from fertilizer applications to forests were based on the area of pine plantations receiving fertilizer in the

Table 7-9. N$_2$O Fluxes from Soils in Forest Land Remaining Forest Land (Tg CO$_2$ Eq. and Gg)

Forest Land Remaining Forest Land: N$_2$O Fluxes from Soils	1990		1998	1999	2000	2001	2002	2003	2004
Tg CO$_2$ Eq.	0.1		0.4	0.5	0.4	0.4	0.4	0.4	0.4
Gg	<1		1	2	1	1	1	1	1

Note: These estimates include direct N$_2$O emissions from N fertilizer additions only. Indirect N$_2$O emissions from fertilizer additions are reported in section 6.4 of the Agriculture chapter. These estimates include emissions from both Forest Land Remaining Forest Land, and from Land Converted to Forest Land.

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; however, it should be expected that emissions from the small areas of fertilized forests in other regions would be insubstantial 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, and 2004, so data from 2001 were substituted for these years. The proportion of N additions that volatilized from forest soils was assumed to be 10 percent of total amendments, according to the IPCC's default. The unvolatilized N applied to forests was then multiplied by the IPCC default emission factor of 1.25 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 sector.

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 carbon 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.

The IPCC default methodology used here does not incorporate any of these variables and only accounts for variations in estimated fertilizer application rates and estimated areas of forested land receiving fertilizer. All forest soils are treated equivalently under this methodology. Furthermore, only synthetic fertilizers are captured, so applications of organic fertilizers are not accounted for here.

Uncertainties exist in the fertilizer application rates, the area of forested land receiving fertilizer, and the emission factors used to derive emission estimates. Uncertainty was calculated according to a modified IPCC Tier 1 methodology. The 95 percent confidence interval of the IPCC default emission factor for synthetic fertilizer applied to soil, according to Chapter 4 of IPCC (2000), ranges from 0.25 to 6 percent. While a Tier 1 analysis should be generated from a symmetrical distribution of uncertainty around the emission factor, an asymmetrical distribution was imposed here to account for the fact that the emission factor used was not the mean of the range given by IPCC. Therefore, an upper bound of 480 percent and a lower bound of 80 percent were assigned to the emission factor. The higher uncertainty percentage is shown below, but the lower bound reflects a truncated distribution. The uncertainties in the area of forested land receiving fertilizer and fertilization rates were conservatively estimated to be ±54 percent (Binkley 2004). The results of the Tier 1 quantitative uncertainty analysis are summarized in Table 7-10. N_2O fluxes from soils were estimated to be between 0.01 and 2.3 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 96 percent below and 483 percent above the 2004 emission estimate of 0.4 Tg CO_2 Eq.

Planned Improvements

Area data for southeastern pine plantations receiving fertilizer will be updated with more recent datasets, and the indirect N_2O emissions from fertilization of forests, which

Table 7-10: Tier 1 Quantitative Uncertainty Estimates of N_2O Fluxes from Soils in Forest Land Remaining Forest Land (Tg CO_2 Eq. and Percent)

Source	Gas	2004 Emission Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate			
			(Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Forest Land Remaining Forest Land:						
N_2O Fluxes from Soils	N_2O	0.4	<0.1	2.3	-96%	+483%

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

are currently reported in the Agriculture chapter, will be reported here.

7.2. 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.

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

Soils contain both organic and inorganic forms of carbon (C), but soil organic carbon (SOC) stocks are the main source or sink for atmospheric CO_2 in most soils. Changes in inorganic carbon stocks are typically minor. In addition, soil organic carbon 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. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) recommends 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. In addition, the IPCC Guidelines recommends reporting CO_2 emissions that result from liming of soils with dolomite and limestone.

Typical well-drained mineral soils contain from 1 to 6 percent organic carbon by weight, although some mineral soils that experience long-term saturation 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; after that, C stocks continue to decline 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 will 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 oxidation. 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 management, fertilization, and flooding, can modify both organic matter inputs and decomposition, and thereby result in a net flux of C to or from soils.

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.

The last category of the IPCC methodology addresses emissions from lime additions (in the form of crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils. Lime 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.

For U.S. agricultural soils, CO_2 emissions and removals[5] due to changes in mineral soil C stocks are estimated using a Tier 3 approach employing a process-based model for the majority of annual crops, Tier 2 IPCC method for the remaining crops (vegetables, perennial/horticultural crops, tobacco and rice), and a Tier 1 method for additional changes in mineral soil C stocks that were not addressed with the Tier 2 or 3 approaches (i.e., variation in manure N production and thus areas amended with manure relative to 1997, as well as gains or losses in C sequestration after 1997 due to changes in Conservation Reserve Program enrollment). Emissions from organic soils are also estimated using a Tier 2 IPCC method. Emissions from liming are estimated using a Tier 2 IPCC method that relies on national aggregate statistics of lime application and newly published research on emissions from liming of agricultural soils (West and McBride 2005).

Of the three sub-source categories, land-use and land management of mineral soils was the most important component of total net C stock change between 1990 through 2004 (see Table 7-11 and Table 7-12). In 2004, mineral soils were estimated to remove about 63.2 Tg CO_2 Eq. (17 Tg C). However, this rate of C storage in mineral soils represented about a 7 percent decline since the initial reporting year of 1990. Emissions from organic soils had the second largest flux, emitting about 30.3 Tg CO_2 Eq. (8 Tg C) in 2004. Liming emitted another 4.0 Tg CO_2 Eq. (1 Tg C) in 2004. In total, U.S. agricultural soils in Cropland Remaining Cropland removed approximately 28.9 Tg CO_2 Eq. (8 Tg C) in 2004, which was the average rate of change per year over the 1990 through 2004 reporting period.

Net increase in soil carbon stocks was largely due to 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).

The spatial variability in annual CO_2 flux associated with C stock changes in mineral and organic soils is displayed in Figure 7-4 through Figure 7-7. The high rates of sequestration in mineral soils occurred in the Midwest, where there were the largest amounts of cropland managed with conservation tillage adoption. Rates were also high in Great Plains due to enrollment in the Conservation Reserve Program. Emission

Table 7-11: Net Soil C Stock Changes and Liming Emissions in Cropland Remaining Cropland (Tg CO_2 Eq.)

Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	(67.6)		(59.6)	(59.3)	(60.7)	(62.5)	(62.8)	(62.7)	(63.2)
Organic Soils[a]	29.9		30.3	30.3	30.3	30.3	30.3	30.3	30.3
Liming of Soils[b]	4.7		4.7	4.5	4.3	4.4	5.0	3.7	4.0
Total Net Flux	(33.0)		(24.6)	(24.6)	(26.1)	(27.8)	(27.5)	(28.7)	(28.9)

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.
[a] Also includes emissions due to drainage of organic soils on Land Converted to Cropland
[b] Also includes emissions from liming on Land Converted to Cropland, Grassland Remaining Grassland, and Land Converted to Grassland.

Table 7-12: Net Soil C Stock Changes and Liming Emissions in Cropland Remaining Cropland (Tg C)

Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	(18.4)		(16.3)	(16.2)	(16.6)	(17.0)	(17.1)	(17.1)	(17.2)
Organic Soils[a]	8.1		8.3	8.3	8.3	8.3	8.3	8.3	8.3
Liming of Soils[b]	1.3		1.3	1.2	1.2	1.2	1.4	1.0	1.1
Total Net Flux	(9.0)		(6.7)	(6.7)	(7.1)	(7.6)	(7.5)	(7.8)	(7.9)

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.
[a] Also includes emissions due to drainage of organic soils on Land Converted to Cropland
[b] Also includes emissions from liming in Land Converted to Cropland, Grassland Remaining Grassland, and Land Converted to Grassland.

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

Figure 7-4

Net C Stock Change for Mineral Soils in Cropland Remaining Cropland, 1990-1992
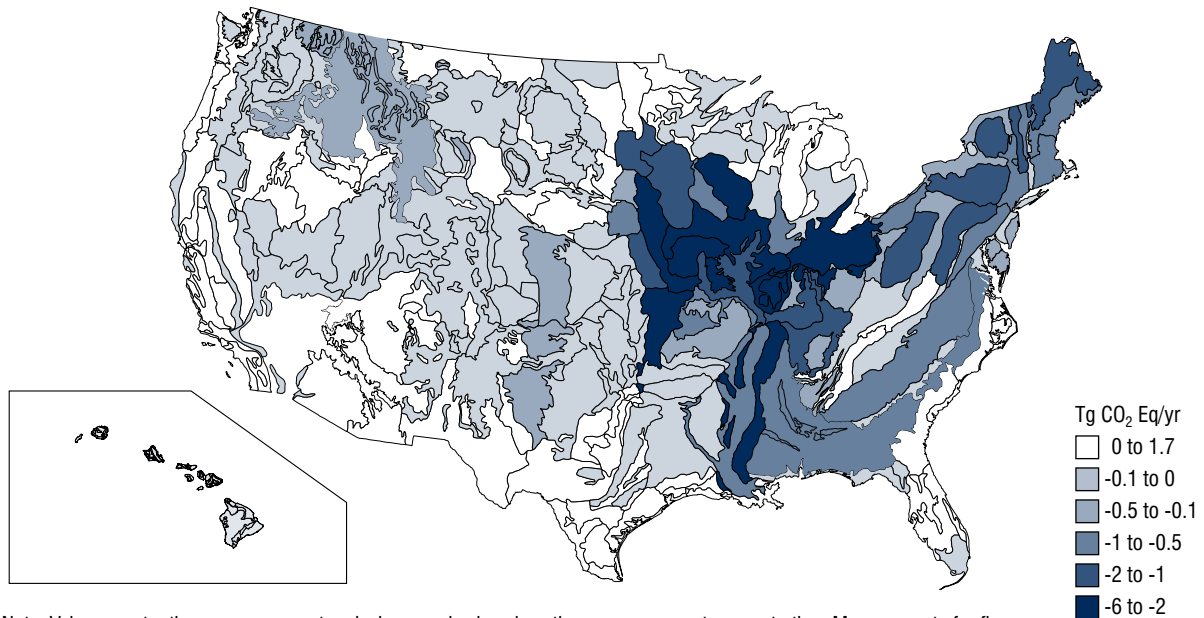
Tg CO$_2$ Eq/yr

- 0 to 1.7
- -0.1 to 0
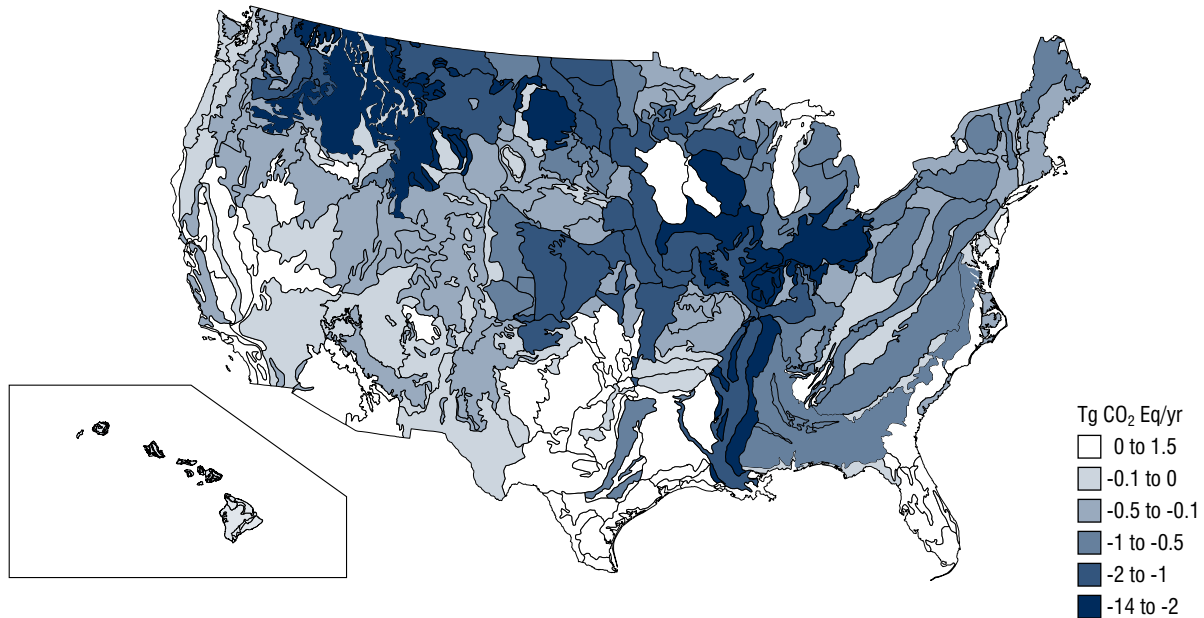- -0.5 to -0.1
- -1 to -0.5
- -2 to -1
- -6 to -2

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, but not the Tier 1 estimates. See Methodology for additional details.

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1990 through 1992. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.

Figure 7-5

Net C Stock Change for Mineral Soils in Cropland Remaining Cropland, 1993-2004

Tg CO$_2$ Eq/yr

- 0 to 1.5
- -0.1 to 0
- -0.5 to -0.1
- -1 to -0.5
- -2 to -1
- -14 to -2

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, but not the Tier 1 estimates. See Methodology for additional details.

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1993 through 2004. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.
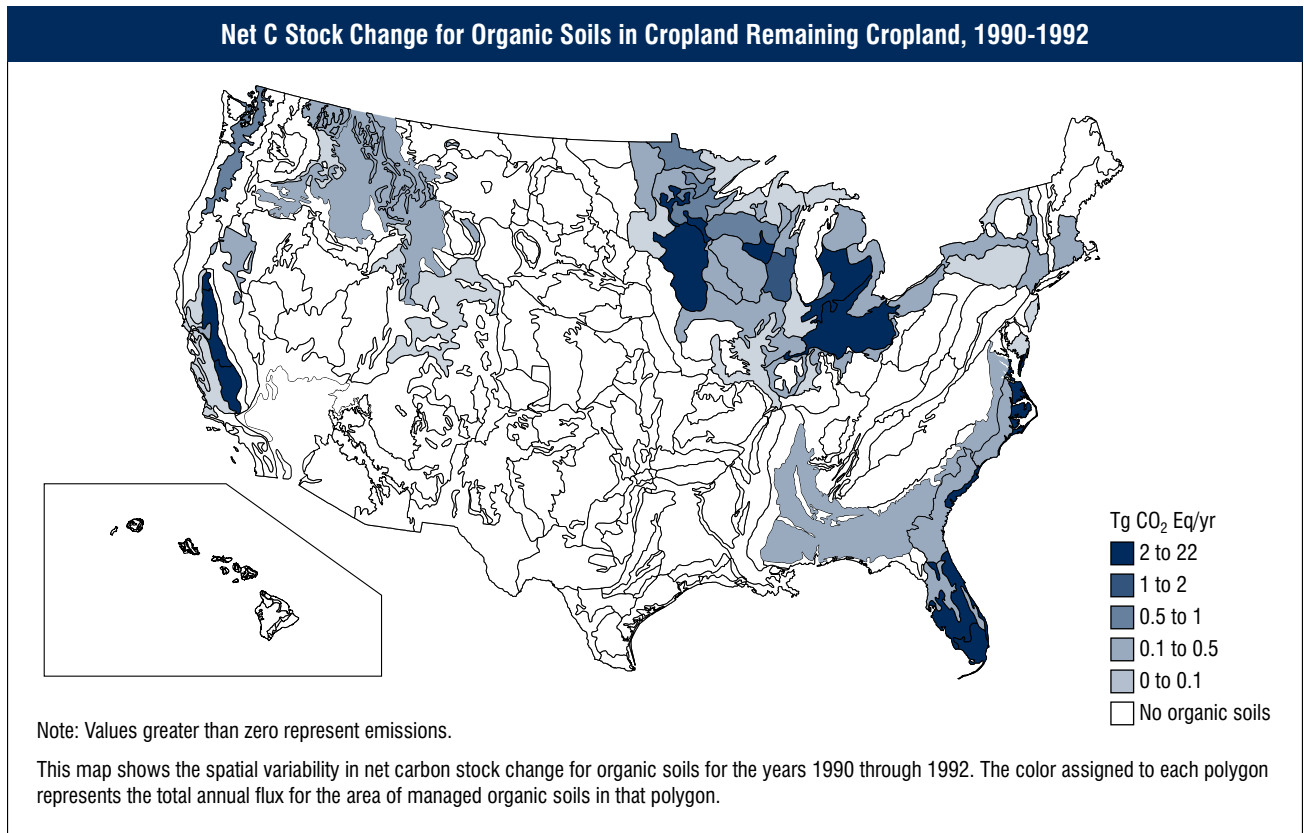
Figure 7-6

Net C Stock Change for Organic Soils in Cropland Remaining Cropland, 1990-1992

Tg CO$_2$ Eq/yr
- 2 to 22
- 1 to 2
- 0.5 to 1
- 0.1 to 0.5
- 0 to 0.1
- No organic soils

Note: Values greater than zero represent emissions.

This map shows the spatial variability in net carbon stock change for organic soils for the years 1990 through 1992. The color assigned to each polygon represents the total annual flux for the area of managed organic soils in that polygon.

Figure 7-7

Net C Stock Change for Organic Soils in Cropland Remaining Cropland, 1993-2004

Tg CO$_2$ Eq/yr
- 2 to 22
- 1 to 2
- 0.5 to 1
- 0.1 to 0.5
- 0 to 0.1
- No organic soils

Note: Values greater than zero represent emissions.

This map shows the spatial variability in net carbon stock change for organic soils for the years 1993 through 2004. The color assigned to each polygon represents the total annual flux for the area of managed organic soils in that polygon.
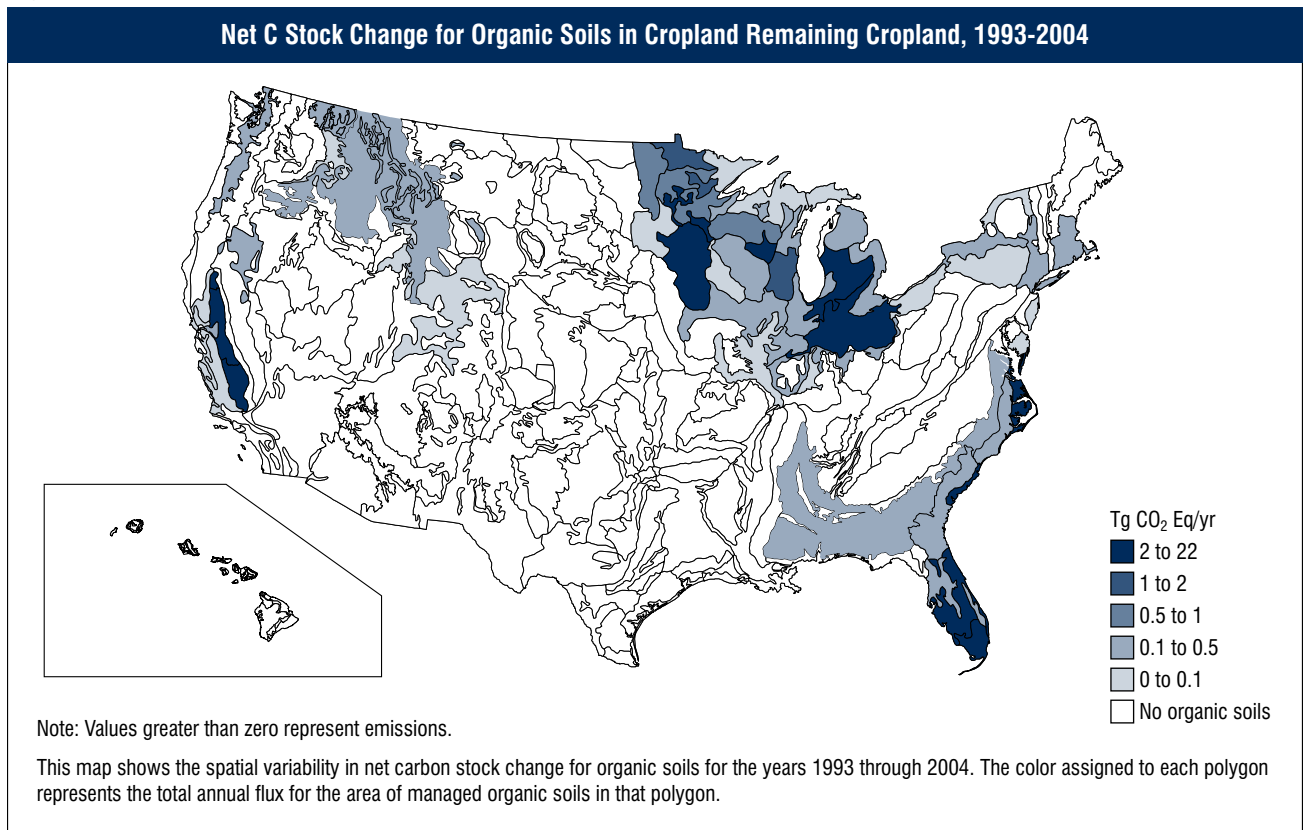
rates from drained organic soils were highest along the southeastern coastal region, in the northeast central United States surrounding the Great Lakes, and along the central and northern portions of the west coast.

The estimates presented here are restricted to C stock changes associated with land use and management of 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 methane (CH_4) from flooded rice cultivation. These emissions are accounted for under the Agriculture sector, 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 carbon stocks due to: (1) agricultural land-use and management activities on mineral soils; (2) agricultural land-use and management activities on organic soils; and (3) CO_2 emissions that result from liming of soils with dolomite and limestone for Cropland Remaining Cropland.

Mineral and Organic Soil Carbon Stock Changes

Soil C stock changes were estimated for agricultural land (i.e., Cropland Remaining Cropland, 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.[6] 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. Currently, the NRI is being revised to collect data

annually from a subset of points. However, at present, no additional national-level data are available after 1997.

NRI points were classified as Cropland Remaining Cropland if the land use had been cropland since the first year of the NRI in 1982. 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).

A new Tier 3 model-based approach was developed to estimate C stock changes for soils used to produce a majority of annual crops in the United States (i.e., all crops except vegetables, tobacco, perennial/horticultural crops, and rice). The Century biogeochemical model (Parton et al. 1987, 1988, 1994; Metherell et al. 1993) was used to simulate the changes in C stocks for this Tier 3 approach. The model simulates carbon (C) dynamics 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, temperature and water dynamics; in addition to turnover, stabilization, and mineralization of soil organic matter carbon and nutrient (N, K, S) elements.

An IPCC Tier 2 method was used to estimate C stock changes for cropland on mineral soils that were not addressed with the Tier 3 method, in addition to emissions from drained organic soils (Ogle et al. 2003). Emissions for liming were computed using a Tier 2 methodology that relies on national aggregate statistics of lime application and newly published research on emissions from liming of agricultural soils (West and McBride 2005).

Two additional stock change calculations were made for mineral soils using Tier 1 (IPCC default) emission factors. These calculations accounted for activities that were not addressed by the Tier 3 or Tier 2 methods, including the amount of area receiving manure amendments relative to 1997,[7] and enrollment patterns in the Conservation Reserve Program after 1997.

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

[7] The Tier 2 and 3 portions of the inventory use manure amendments based on 1997 values because application rates and the amount of land amended with manure have only been estimated for 1997 (Edmonds et al. 2003). However, manure N production and thus rates of application do vary from year to year. The effect of this variation on soil C stocks is discussed further in Annex 3.13.

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

Mineral Soils

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated for the majority of crops (i.e., all crops except vegetable crops, tobacco, perennial/horticultural crops, and rice) using the Century biogeochemical model. National estimates were obtained by using the model to simulate historical land-use and management patterns as recorded in the USDA National Resources Inventory (NRI) survey. For these simulations of soil organic C dynamics, land-use, and management activities were grouped into inventory time periods (i.e., time "blocks") for 1980-84, 1985-89, 1990-94 and 1995-2000, using NRI data from 1982, 1987, 1992, and 1997, respectively.

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 the inventory period were estimated from data compiled by the USDA Natural Resources Conservation Service for 1997 (Edmonds et al. 2003).

Monthly weather data, aggregated to county-scale from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) database (Daly et al. 1994), were used to drive the model simulations. Soil attributes were obtained from an NRI database, which 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 having 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. Carbon stock estimates from Century were adjusted using a structural uncertainty estimator accounting for uncertainty in model algorithms and parameter values. 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 2004 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

Mineral SOC stocks were estimated using a Tier 2 method for vegetable crops, tobacco, perennial/horticultural crops and rice in 1982, 1992, and 1997. In addition, the Tier 2 method was used to estimate C stock changes for crops that were rotated with vegetables, tobacco, perennial/horticultural crops and rice. The Century model has not been fully tested to address its adequacy for estimating C stock changes associated with these crops and rotations. Data on climate, soil types, land-use, and land management activity were used to classify land area to apply appropriate stock change factors. Major Land Resource Areas (MLRA) formed the base spatial unit for mapping climate regions in the United States; each Major Land Resource Area represents a geographic unit with relatively similar soils, climate, water resources, and land uses (NRCS 1981).[8] Major Land Resource Areas were classified into climate regions according to the IPCC categories using the PRISM climate-mapping program 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 the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003). Changing the reference condition was necessary because soil measurements under agricultural management are much more common and easily identified in the National Soil

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[8] The polygons displayed in Figure 7-4 through Figure 7-7 are the Major Land Resource Areas.

Survey Characterization Database (NRCS 1997) than those which 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. 2006b).[9] U.S. factors associated with organic matter amendments were not estimated because of an insufficient number of studies to analyze those impacts. Instead, factors from IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (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 Inventory, 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 2000) as described above. Euliss and Gleason (2002) provided activity data on wetland restoration of Conservation Reserve Program Land. Manure N amendments over the inventory time period were based on application rates and areas amended with manure N from Edmonds et al. (2003).

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 annual change in stocks between 1982 and 1992; annual C flux for 1993 through 2004 was determined by calculating the annual change in stocks between 1992 and 1997.

Additional Mineral C Stock Change Calculations

Annual C flux estimates for mineral soils between 1990 and 2004 were adjusted to account for additional C stock changes associated with variation in manure N production and thus areas amended with manure relative to 1997, as well as gains or losses in C sequestration after 1997 due to changes in Conservation Reserve Program enrollment.

Manure N application rates and cropland areas receiving manure amendments were based on 1997 estimates from Edmonds et al. (2003) for the Tier 3 Century simulations and the Tier 2 IPCC methods (described above). However, manure N production[10] varies from year to year (see Annex 3.13, Table A-204), and thus the amendment rates also vary through time. Consequently, manure N production data were used to approximate the relative amount of manure available for application based on the difference between manure N production in 1997 and other years in the reporting period. Higher manure N production relative to 1997 was assumed to increase the amount of area amended with manure, and thus lead to more soil C storage, while less manure N production relative to 1997 was assumed to reduce the amount of C added to soils from this activity. The rate of increase or decrease in soil C stocks was estimated at 0.22 metric tons C per hectare per year for the net increase or decrease in amended land area, which depended on the available manure N for application relative to 1997. The stock change rate is based on country-specific factors using the IPCC method (see Annex 3.13 for further discussion).

To estimate the impact of enrollment in the Conservation Reserve Program after 1997, the change in enrollment acreage relative to 1997 was derived based on Barbarika (2004) for 1998 through 2004, and the differences in mineral soil areas were multiplied by 0.5 metric tons C per hectare per year. Similar to manure amendments, the stock change rate is based on country-specific factors using the IPCC method (see Annex 3.13 for further discussion).

Organic Soils

Annual C emissions from drained organic soils in cropland were estimated using methods provided in the

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[9] 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.

[10] Manure N production does not include the Pasture/Range/Paddock manure for this analysis. Also, the poultry manure production values have been reduced by 4.8 percent that is used for feed.

Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/UNEP/OECD/IEA 1997) and the IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003), except that U.S.-specific C loss rates were used in the calculations rather than default IPCC rates (Ogle et al. 2003). Similar to 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 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 2004.

CO_2 Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to agricultural soils were estimated using a Tier 2 methodology. The annual amounts of limestone and dolomite applied (see Table 7-13) 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, 2003a, 2004, 2005; USGS 2005). To develop these data, 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 2004 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 2004 data, the previous year's fractions were applied to a 2004 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2005* (USGS 2005).

The primary source for limestone and dolomite activity data is the *Minerals Yearbook*, published by the Bureau of Mines through 1994 and by the U.S. Geological Survey 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.

Table 7-13: Applied Minerals (Million Metric Tons)

Mineral	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Limestone	19.01	20.31	17.98	15.61	16.69	17.30	17.48	16.54	14.88	16.89	15.86	16.10	20.45	14.73	15.71
D Dolomite	2.36	2.62	2.23	1.74	2.26	2.77	2.50	2.99	6.39	3.42	3.81	3.95	2.35	2.25	2.40

Note: These numbers represent amounts applied to all agricultural land, not just Cropland Remaining Cropland.

Uncertainty

Uncertainty associated with the Cropland Remaining Cropland category includes the uncertainty associated with changes in agricultural soil carbon stocks (including both mineral and organic soils) and soil liming emissions.

Mineral and Organic Soil Carbon Stock Changes

Uncertainties in Mineral Soil C Stock Changes

Tier 3 Approach

The uncertainty analysis for the Tier 3 Century inventory had three components: (1) Monte-Carlo approach to address uncertainties in model inputs, (2) an empirically-based approach for quantifying uncertainty inherent in the structure of the Century model, and (3) scaling uncertainty associated with the NRI survey (i.e., scaling from the individual NRI points to the entire U.S. agricultural land base using the expansion factors).

For the model input uncertainty, probability distribution functions (PDFs) were developed for fertilizer rates, manure application, and tillage practices. PDFs for fertilizer were based on survey data for major U.S. crops, both irrigated and rainfed (ERS 1997; NASS 2004, 1999, 1992; Grant and Krenz 1985). State-level PDFs were developed for each crop if a minimum of 15 data points existed for each of the two categories (irrigated and rainfed). Where data were insufficient at the state-level, PDFs were developed for multi-state Farm Production Regions. Uncertainty in manure applications for specific crops was incorporated in the analysis based on total manure available for use in each county, a weighted average application rate, and the crop-specific land area amended with manure (compiled from USDA data on animal numbers, manure production, storage practices, application rates and associated land areas receiving manure amendments – see Edmonds et al. 2003). Together with the total area for each crop within a county,

this yielded a probability that a given crop at a specific NRI point would either receive manure or not in the Monte Carlo analysis. If soils were amended with manure, a reduction factor was applied to the N fertilization rate accounting for the interaction between fertilization and manure N amendments (i.e., producers often reduce mineral fertilization rates if applying manure). Reduction factors were randomly selected from probability distribution factors based on relationships between manure N application and fertilizer rates (ERS 1997). For tillage uncertainty, transition matrices were constructed from CTIC data to represent tillage changes for two time periods, combining the first two and the second two management blocks (i.e., 1980-1989, 1990-2000). A Monte Carlo analysis was conducted with 100 iterations in which inputs values were randomly drawn from the PDFs to simulate the soil C stocks for each NRI cluster of points (i.e., inventory points in the same county were grouped into clusters if they had the same land-use/management history and soil type) using the Century model.

An empirically-based uncertainty estimator was developed to assess uncertainty in model structure associated with the algorithms and parameterization. The estimator was based on a linear mixed effect modeling analysis comparing modeled soil C stocks with field measurements from 45 long-term agricultural experiments with over 800 treatments, representing a variety of tillage, cropping, and fertilizer management practices (Ogle et al. 2006a). The final model included variables for organic matter amendments, N fertilizer rates, inclusion of hay/pasture in cropping rotations, use of no-till, setting-aside cropland from production, and inclusion of bare fallow in the rotation. Each of these variables met an alpha level of 0.05, and accounted for significant biases in the modeled estimates from Century. For example, Century tended to under-estimate the influence of organic amendments on soil C storage, so a variable was added to adjust the estimate from Century. Random

Table 7-14: Tier 2 Quantitative Uncertainty Estimates for C Stock Changes in Mineral Soils occurring within Cropland Remaining Cropland that were Estimated Using the Tier 3 Approach (Tg CO$_2$ Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Stock Change Estimate[a]			
		(Tg CO$_2$ Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Cropland Remaining Cropland	(62.5)	(60.9)	(64.2)	-3%	+3%

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

effects captured the dependence in time series and data collected from the same long-term experimental site, which were needed to estimate appropriate standard deviations for parameter coefficients. For each carbon stock estimate from the Monte Carlo analysis, the structural uncertainty estimator was applied to adjust the value accounting for bias and prediction error in the modeled values.

Finally, uncertainty in the land-use and management statistics from the NRI were incorporated into the analysis based on the sampling variance for the clusters of NRI points. The emission estimate for 2004 and associated 95 percent confidence interval are provided in Table 7-14. The uncertainty in the inventory estimate of 62.5 Tg CO_2Eq. was ±3 percent for Cropland Remaining Cropland that were estimated using the Tier 3 model-based inventory approach.

Tier 2 Approach

For the Tier 2 IPCC method, a Monte Carlo approach was used to simulate a range of values with 50,000 iterations by randomly selecting values from probability distribution functions (Ogle et al. 2003). PDFs for stock change factors were derived from a synthesis of 91 published studies, which addressed the impact of management on SOC storage. Uncertainties in land-use and management activity data were also derived from a statistical analysis. The NRI has a two-stage sampling design that allowed PDFs to be constructed assuming a multivariate normal distribution accounting for dependencies in activity data. PDFs for the tillage activity data, as provided by the CTIC, were constructed on a bivariate normal distribution with a log-ratio scale, accounting for the negative dependence among the proportions of land under conventional and conservation tillage practices. PDFs for the agricultural areas receiving manure were derived assuming a normal distribution from county-scale area amendment estimates derived from the USDA Census of Agriculture (Edmonds et al. 2003). Lastly,

enrollment in wetland restoration programs was estimated from contract agreements, but due to a lack of information, PDFs were constructed assuming a nominal ±50 percent uncertainty range.

The results of the uncertainty analysis for the Tier 2 portion of the analysis are summarized in Table 7-15. Mineral soils in Cropland Remaining Cropland, which were estimated using the Tier 2 approach, had a stock change between a gain of 4.03 to a loss of 6.6 Tg CO_2 Eq., at a 95 percent confidence level. This indicates a range of 430 percent below to 441 percent above the 2004 stock change estimate of 1.22 Tg CO_2 Eq.

Additional Mineral C Stock Change Calculations

A ±50 percent uncertainty was assumed for additional adjustments to the mineral soil C stocks between 1990 and 2004, accounting for additional C stock changes associated with variation in manure N production and thus areas amended with manure relative to 1997, as well as gains or losses in C sequestration after 1997 due to changes in Conservation Reserve Program enrollment. The estimated adjustment for 2004 and associated 95 percent confidence interval are provided in Table 7-16.

Uncertainties in Organic Soil C Stock Changes

Uncertainty in carbon emissions from organic soils were estimated in the same manner described for mineral soil using the Tier 2 method and Monte Carlo Analysis. PDFs 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 (above) for additional discussion. Organic soils in cropland were estimated to emit between 20.2 and 43.3 Tg CO_2 Eq. at a 95 percent confidence level (Table 7-17). This indicates a range of 33 percent below to 43 percent above the 2004 stock change estimate of 30.3 Tg CO_2 Eq.

Table 7-15: Tier 2 Quantitative Uncertainty Estimates for C Stock Changes in Mineral Soils Occurring within Cropland Remaining Cropland that were Estimated Using the Tier 2 Approach (Tg CO_2 Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate[a]			
		(Tg CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Cropland Remaining Cropland	1.2	(4.0)	6.6	-430%	+441%

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

Table 7-16: Uncertainty Estimates for C Stock Changes in Mineral Soils Occurring within Cropland Remaining Cropland that were Estimated Using the Tier 1 Approach (Tg CO$_2$ Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Stock Change Estimate			
		(Tg CO$_2$ Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Cropland Remaining Cropland (Variation in Manure Amendments Relative to 1997)	(0.4)	(0.6)	(0.2)	-50%	+50%
Mineral Soil C Stocks: Cropland Remaining Cropland (Change in CRP enrollment relative to 1997)	(1.5)	(2.3)	(0.8)	-50%	+50%

Table 7-17: Tier 2 Quantitative Uncertainty Estimates for CO2 Emissions from Organic Soils Occurring Within Cropland Remaining Cropland (Tg CO2 Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Stock Change Estimate[a]			
		(Tg CO$_2$ Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Organic Soil C Stocks: Cropland Remaining Cropland[b]	30.3	20.2	43.3	-33%	+43%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
[b] Cropland Remaining Cropland and Land Converted to Cropland are both reported in this section because cropland on organic soils has not been subdivided into land use/land use-change categories.

Additional Uncertainties in Mineral and Organic Soil C Stock Changes

The time-series calculations were consistent for each reporting year of the inventory in terms of methodology, with the only difference in reported values stemming from the changes in land-use and management activities across U.S. agricultural land. For the Tier 2 method, the same stock change and organic soil emission factors (i.e., emission factors) were used each year in order to calculate the impact of land use and management on SOC stocks. Moreover, parameterization of the Tier 3 model was not adjusted from year to year. There is no evidence that changing management practices has a quantitatively different impact on SOC stocks over the inventory period as represented in each of these models, and it was assumed the Tier 2 stock change/emission factors and Tier 3 parameters were robust for addressing land-use and management impacts over the time series.

The agricultural soil C inventory has undergone several improvements during the past few years, such as the development of the Tier 3 inventory method to estimate mineral soil C stock changes for the majority of U.S. cropland. However, some limitations remain in the analysis. First, the current agricultural soil C inventory includes some points designated as non-agricultural land-uses in the NRI if the points were categorized as agricultural land use in either 1992 or 1997, but were urban, water, or miscellaneous non-cropland (e.g., roads and barren areas) in the other year. The impact on SOC storage that results from converting cropland to non-agricultural uses is not well-understood, and therefore, those points were not included in the calculations for mineral soils (emissions from organic soils, however, were computed for those points in the years that they were designated as an agricultural use). Similarly, the effect of aquaculture (e.g., rice cultivation followed by crayfish production in flooded fields) on soil C stocks has not been estimated due to a lack of knowledge. Second, the current estimates may underestimate losses of C from organic soils because the *1997 National Resources Inventory* was not designed as a soil survey and organic soils frequently occur as relatively small inclusions within major soil types. Lastly, this methodology does not take into account changes in SOC stocks due to pre-1982 land use and land-use change.

Table 7-18: Tier 2 Quantitative Uncertainty Estimates for CO$_2$ Emissions from Liming of Agricultural Soils (Tg CO$_2$ Eq. and Percent)

Source	Gas	2004 Emissions (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Flux Estimate[a] (Tg CO$_2$ Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Liming of Agricultural Soils[b]	CO$_2$	4.0	0.3	7.8	-94%	+96%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
[b] Also includes emissions from liming in Land Converted to Cropland, Grassland Remaining Grassland, and Land Converted to Grassland.

Uncertainties in CO$_2$ Emissions from Liming

Uncertainties in the estimates of emissions from liming result from both the emission factors and the activity data. The emission factors used for limestone and dolomite take into account the fate of carbon following application to soils, including: dissolution of liming constituents; leaching of bicarbonates into the soil and transport to the ocean; and emissions to the atmosphere (West and McBride 2005). The carbon accounting behind these emission factors entails assumptions about several uncertain factors. First, it is uncertain what fraction of agricultural lime is dissolved by nitric acid (HNO$_3$)—a process that releases CO$_2$—and what portion reacts with carbonic acid (H$_2$CO$_3$), resulting in the uptake of CO$_2$. The fractions can vary depending on soil pH and nitrogen fertilizer use. The second major source of uncertainty is the fraction of bicarbonate (HCO$_3^-$) that leaches through the soil profile and is transported into groundwater, which can eventually be transferred into rivers and into the ocean. This fraction can vary depending on the soil pH and whether calcium (Ca^{2+}) and magnesium (Mg^{2+}) liming constituents that might otherwise accompany HCO$_3^-$, are taken up by crops, remain in the upper soil profile, or are transported through or out of the soil profile. Finally, the emission factors do not account for the time that is needed for leaching and transport processes to occur.

There are several sources of uncertainty in the limestone and dolomite activity data. When reporting data to the USGS (or U.S. Bureau of Mines), some producers do not distinguish between limestone and dolomite. In these cases, data are reported as limestone, so this reporting could lead to an overestimation of limestone and an underestimation of dolomite. In addition, the total quantity of crushed stone listed each year in the *Minerals Yearbook* excludes American Samoa, Guam, Puerto Rico, and the U.S. Virgin Islands.

Uncertainty regarding limestone and dolomite activity data inputs were estimated at plus or minus 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 factors: 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.

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 7-18. Carbon dioxide emissions from Liming of Agricultural Soils in 2004 were estimated to be between 0.3 and 7.8 Tg CO$_2$ Eq. at the 95 percent confidence level. This indicates a range of 94 percent below to 96 percent above the 2004 emission estimate of 4.0 Tg CO$_2$ Eq.

QA/QC and Verification

With the development of a Tier 3 inventory, there was considerable effort required to review inventory procedures and results. Quality control measures included checking input data, model execution scripts, and results to ensure data were properly handled through the inventory process. Errors were found in these steps and corrective actions were taken. Results were compared against field measurements and a statistical relationship was developed to assess uncertainties in the model's predictive capability (discussed under the

Uncertainty section). The comparisons included over 40 long-term experiments, representing about 800 combinations of management treatments across all of the sites. Inventory reporting forms and text were reviewed and revised as needed to correct transcription errors.

Recalculations Discussion

The key difference in the current inventory compared to previous years is in the implementation of the Tier 3 model-based approach for mineral soils, which was used to estimate soil C stock changes in Agricultural Land (i.e., Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, and Land Converted to Grassland). This entails several fundamental differences compared with the IPCC Tier 2 method, which is 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 6 climate regions and 7 soil types and 11 management systems occur in U.S. agricultural land. 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 2 approach. The spatial resolution of the analysis is also finer in the Tier 3 method compared to the Tier 2 inventory (3037 counties vs. 181 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. Carbon 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 2 approach 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. By addressing these additional management influences on soil C stocks, the Tier 3 approach produced C stock change estimates that were 27-50 percent greater than the Tier 2 inventory approach used to report agricultural soil C in the previous year As noted above, these estimates include the C stock changes for Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, and Land Converted to Grassland.

A small adjustment was also made in the estimation of organic soils. There are some areas included in the land base that were converted during the 1990s between agricultural land and forest, miscellaneous non-agricultural, and urban land. In past inventories, emissions from drained organic soils were reported in this inventory even during the years that the land parcels were under a non-agricultural land use. These areas were removed in this year's inventory, and a re-calculation was done to obtain a more accurate CO_2 emissions estimate from drained organic soils under agricultural management. Estimated values were reduced by about 0.6 Tg CO_2 Eq. in each reporting year.

The quantity of applied minerals reported in the previous inventory for 2003 has been revised. Consequently, the reported emissions resulting from liming in 2003 have also changed. In the previous inventory, to estimate 2003 data, the previous year's fractions were applied to a 2003 estimate of total crushed stone presented in the USGS *Mineral Industry Surveys: Crushed Stone and Sand and Gravel in the First Quarter of 2004* (USGS 2004). 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 2003. These values have replaced those used in the previous inventory to calculate the quantity of minerals applied to soil and the emissions from liming.

The emission factors used in the calculation of emissions due to liming have changed since the previous inventory. Previously, the default emission factor values from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003) formed the basis for these calculations using the IPCC Tier 1 method. A study published in 2005 provides new emission factors based on a more detailed accounting of the fate of carbon following application to soils (West and McBride 2005). The IPCC Tier 1 approach assumes that all inorganic C in the applied minerals evolves to CO_2. It is more likely, though, that some of the carbon may leach through the soil and travel by rivers to the ocean, where it precipitates as $CaCO_3$. Use of these new emission factors represents a Tier 2 approach as described in IPCC (2003), which should result in a more accurate accounting of emissions due to liming.

Overall, these changes resulted in an average annual decrease of 35.7 Tg CO_2 Eq. (224 percent) in agricultural soil carbon stocks for the period 1990 through 2003.

Planned Improvements

Four major improvements are planned for the next year. 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. This will greatly improve the accuracy of land-use and management influences on soil C in the latter part of the time series.

The second planned improvement will be to achieve consistency in N fertilization rates and organic amendments between the soil C and soil N_2O inventories. Currently, each inventory is using a combination of shared and different sources to model these activities. The goal will be to ensure that each is using the most accurate information in a consistent manner.

The third improvement is to develop a consistent representation of the U.S. managed land base. More details on this planned improvement are provided previously in the chapter under Forest Land Remaining Forest Land. In addition, agricultural areas on organic soils and the mineral soils, which are estimated with the Tier 2 approach, will be further subdivided into land use and land-use change subcategories in order to achieve consistency with reporting requirements.

The last improvement will be to further develop the uncertainty analysis to address the uncertainty inherent in the Century model results for agricultural land (i.e., Grassland Remaining Grassland, Land Converted to Grassland, and Land Converted to Cropland) in the Tier 3 method. 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 in the upcoming year is to revise the inventory to address uncertainties in management activity prior to 1979.

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

Background on agricultural carbon stock changes is provided in the Cropland Remaining Cropland (Section 1.3.1) and will only be summarized here. 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 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils; (2) agricultural land-use and management activities on organic soils, and (3) CO_2 emissions that result from liming of soils with dolomite and limestone. Mineral soil C stock changes are reported here for Land Converted to Cropland, but stock changes associated with management of

organic soils and liming are reported in Cropland Remaining Cropland because it was not possible to subdivide those estimates by land use and land-use change categories (see Methodology section below for additional discussion).

Land-use and management of mineral soils in Land Converted to Cropland led to small losses of soil C during the early 1990s but this trend was reversed over the decade, so that these soils were gaining small amounts of C through the latter part of the time series (Table 7-19 and Table 7-20). The rate of change in soil C stocks was 2.8 Tg CO_2 Eq. (0.8 Tg C) in 2004.

The spatial variability in annual CO_2 flux associated with C stock changes in mineral soils for Land Converted to Cropland is displayed in Figure 7-8 and Figure 7-9. 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 the cropland were irrigated or receiving higher fertilizer inputs relative to the previous land use.

The estimates presented here are restricted to C stock changes associated with land use and management of 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 methane (CH_4) from flooded rice cultivation. These emissions are accounted for under the Agriculture sector, 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 carbon stocks due to agricultural land-use and management activities on mineral soils for Land Converted to Cropland.

Mineral and Organic Soil Carbon Stock Changes

Soil C stock changes were estimated for Land Converted to Cropland according to land-use histories recorded in the USDA National Resources Inventory (NRI) survey (USDA-NRCS 2000).[11] 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. NRI points were classified as Land Converted to Cropland if the land use was currently cropland but had been converted from

Table 7-19: Net Soil C Stock Changes in Land Converted to Cropland (Tg CO₂ Eq.)

Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	1.5		(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)	(2.8)
Organic Soils[a]	-		-	-	-	-	-	-	-
Liming of Soils[a]	-		-	-	-	-	-	-	-
Total Net Flux	**1.5**		**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**	**(2.8)**

[a] Emissions from liming and organic soils from Land Converted to Cropland are reported in Cropland Remaining Cropland
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.

Table 7-20: Net Soil C Stock Changes in Land Converted to Cropland (Tg C)

Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	0.4		(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Organic Soils[a]	-		-	-	-	-	-	-	-
Liming of Soils[a]	-		-	-	-	-	-	-	-
Total Net Flux	**0.4**		**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**	**(0.8)**

[a] Emissions from liming and organic soils from Land Converted to Cropland are reported in Cropland Remaining Cropland
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.

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

Figure 7-8

Net C Stock Change for Mineral Soils in Land Converted to Cropland, 1990-1992

Tg CO$_2$ Eq/yr
- 0 to 2
- -0.1 to 0
- -0.5 to -0.1
- -1 to -0.5
- -1.1 to -1

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

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1990 through 1992. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.

Figure 7-9

Net C Stock Change for Mineral Soils in Land Converted to Cropland, 1993-2004

Tg CO$_2$ Eq/yr
- 0 to 0.5
- -0.1 to 0
- -0.5 to -0.1
- -0.8 to -0.5

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

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1993 through 2004. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.
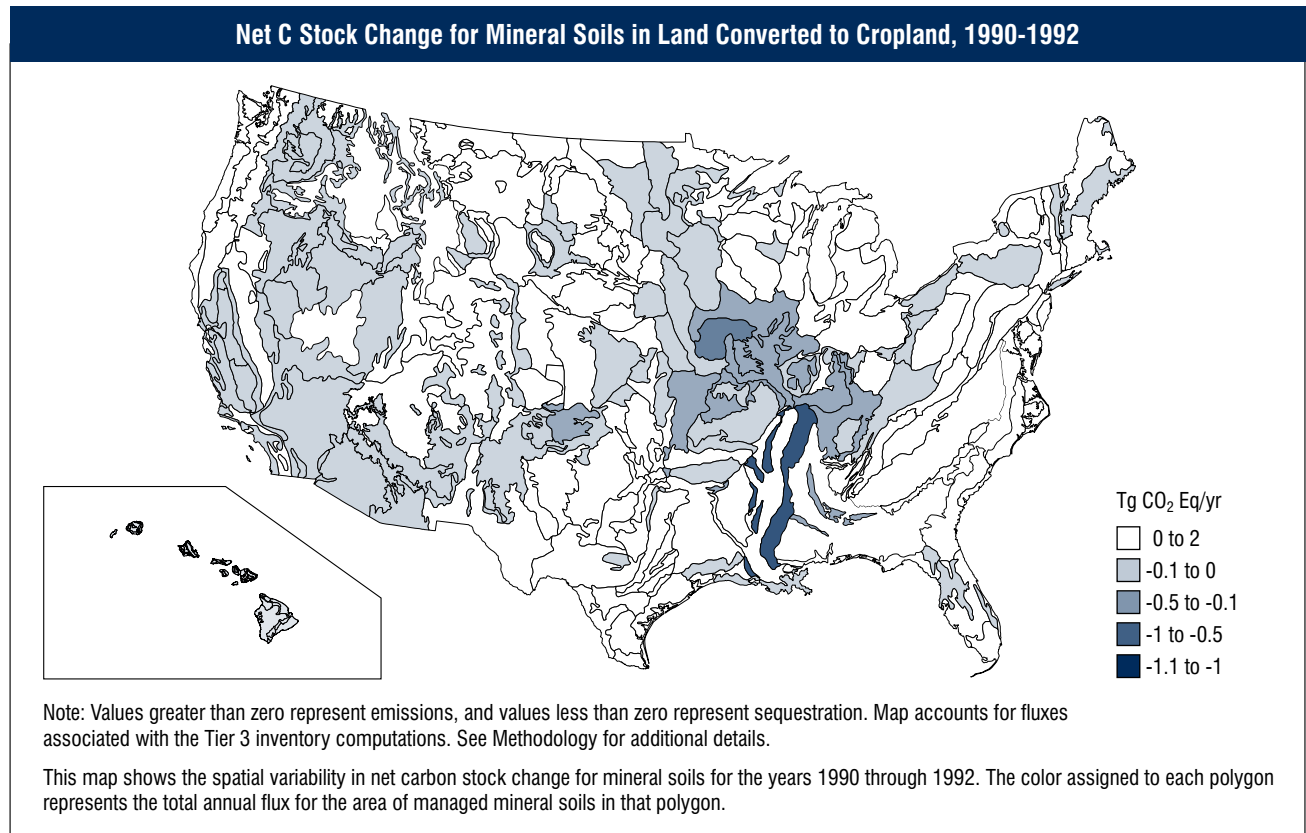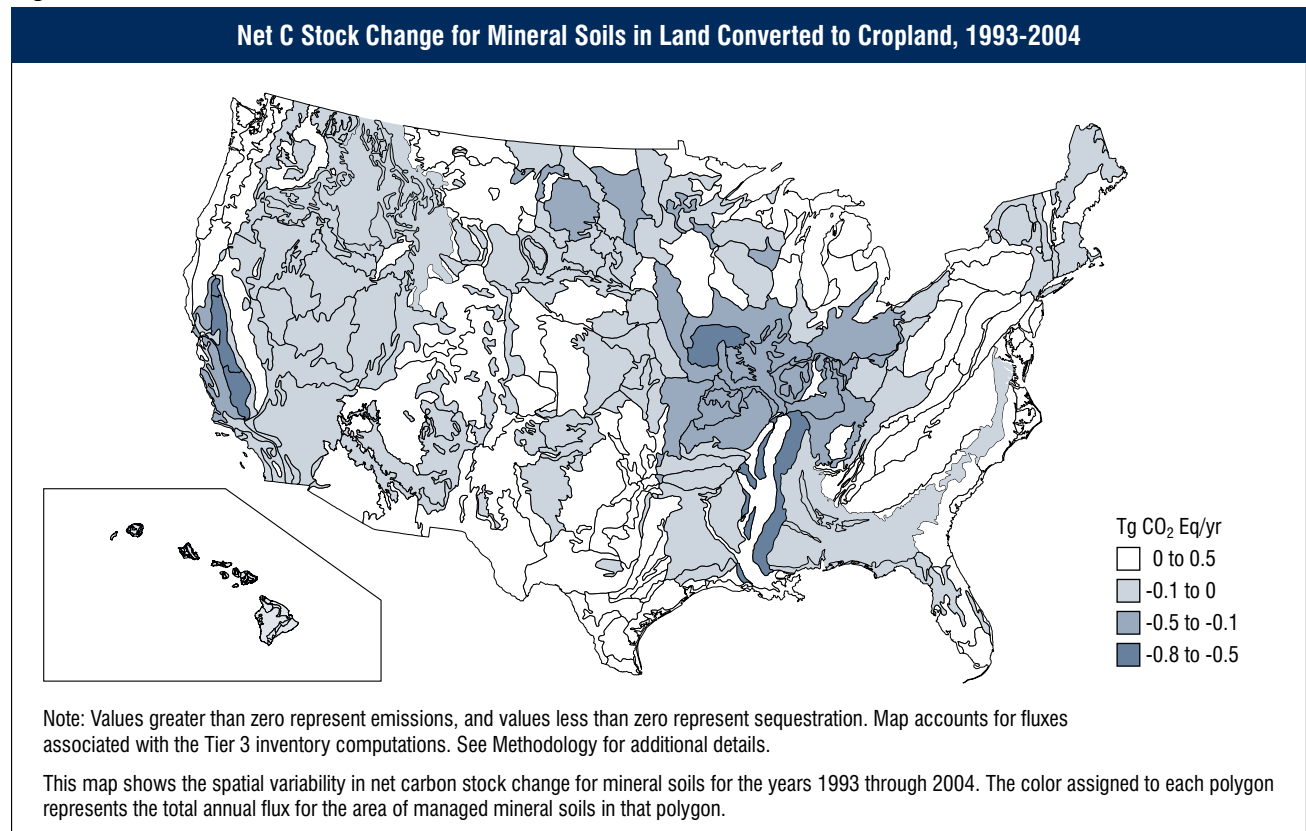
another use since 1982. Cropland includes all land used to produce food or fiber, as well as forage that is harvested and used as feed (e.g., hay and silage).

A new Tier 3 model-based approach was developed to estimate C stock changes for soils on Land Converted to Cropland used to produce a majority of annual crops in the United States (i.e., all crops except vegetables, tobacco, perennial/horticultural crops, and rice), in addition to C stock changes for grassland soils. An IPCC Tier 2 method was used to estimate C stock changes on the remaining land base for Land Converted to Cropland on mineral soils that were not addressed with the Tier 3 method, in addition to emission estimates for organic soils (Ogle et al. 2003). Tier 1 methods were used to estimate additional changes in mineral soil C stocks due to manure amendments that were not included in the Tier 2 and 3 analyses.

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 Soils

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model for grassland converted to cropland, with the exception of vegetable crops, tobacco, perennial/horticultural crops, and rice. National estimates were obtained by using the model to simulate historical land-use change patterns as recorded in the USDA National Resources Inventory.

Tier 2 Approach

Mineral SOC stock changes were estimated using a Tier 2 Approach for land converted from forest or federal land to cropland, in addition to grassland converted to perennial, horticultural, tobacco and rice cropland. These cropland areas have not been subdivided into land use/land-use change categories, which is a planned improvement for the soil C inventory. Consequently the stock changes are reported in Cropland Remaining Cropland.

Additional Mineral C Stock Change Calculations

Annual C stock changes for Land Converted to Cropland on mineral soils between 1990 and 2004 were adjusted to account for additional C stock changes associated with variation in manure N production (see Annex 3.13, Table A-

195) and thus areas amended with manure relative to 1997. Additional changes are reported in the Cropland Remaining Cropland section because it is not possible to subdivide these changes into the individual land use/land-use change categories.

Organic Soils

Annual C emission estimates from drained organic soils in Land Converted to Cropland were estimated using the Tier 2 Approach, and reported in Cropland Remaining Cropland because organic soil areas have not subdivided into land use/land-use change categories. Differentiating organic soils between Land Converted to Cropland and Cropland Remaining Cropland is a planned future improvement for the soil C inventory.

CO_2 Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to Land Converted to Cropland are reported in the Cropland Remaining Cropland, because it was not possible to disaggregate liming application among land use and land-use change categories.

Uncertainty

Uncertainty associated with the Land Converted to Cropland category includes the uncertainty associated with changes in mineral soil carbon stocks.

Mineral and Organic Soil Carbon Stock Changes

Uncertainties in Mineral Soil C Stock Changes

Tier 3 Approach

The uncertainty analysis for Land Converted to Cropland using the Tier 3 approach was 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 empirically-based uncertainty estimator described in the Cropland Remaining Cropland section has not been developed to estimate uncertainties in Century model results for Land Converted to Cropland but this is a planned improvement for the inventory. See the Tier 3 approach for mineral soils under Cropland Remaining Cropland for additional discussion. The inventory estimate for 2004 and associated 95 percent confidence interval are provided in Table 7-21. The uncertainty in the inventory

Table 7-21: Quantitative Uncertainty Estimates for C stock changes in mineral soils occurring within Land Converted to Cropland, which were estimated using the Tier 3 Approach (Tg CO$_2$ Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Stock Change Estimate			
		(Tg CO$_2$ Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Land Converted to Cropland	(2.8)	(2.2)	(3.3)	-22%	+17%

estimate of 2.8 Tg CO$_2$ Eq. was 22 percent below the mean and 17 percent above the mean.

Uncertainties in Organic Soil C Stock Changes

Annual C emission estimates from drained organic soils in Land Converted to Cropland were estimated using the Tier 2 Approach, and reported in the Cropland Remaining Cropland Section because organic soil areas have not subdivided into land use/land-use change categories. Differentiating organic soils between Land Converted to Cropland and Cropland Remaining Cropland is a planned future improvement for the soil C inventory. See Cropland Remaining Cropland for discussion on the uncertainty estimation for drained organic soils in grasslands.

Additional Uncertainties in Mineral and Organic Soil C Stock Changes

Additional uncertainties are discussed in Cropland Remaining Cropland.

QA/QC and Verification

See Cropland Remaining Cropland.

Recalculations Discussion

See Cropland Remaining Cropland.

Planned Improvements

See Cropland Remaining Cropland.

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

Background on agricultural carbon stock changes is provided in the Cropland Remaining Cropland section and will only be summarized here. 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 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils; (2) agricultural land-use and management activities on organic soils, and (3) CO$_2$ emissions that result from liming of soils with dolomite and limestone. Mineral and organic soil C stock changes are reported here for Grassland Remaining Grassland, but stock changes associated with liming are reported in Cropland Remaining Cropland because it was not possible to subdivide those estimates by land use/land-use change categories (see Methodology section below for additional discussion).

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 (see Table 7-22 and Table 7-23). Organic soils lost about the same amount of C in each year of the inventory. The overall trend shifted from small increases in soil C during 1990 to decreases during the latter years, estimated at 7.3 Tg CO$_2$ Eq. (2.0 Tg C) in 2004.

The spatial variability in annual CO$_2$ flux associated with C stock changes in mineral and organic soils is displayed in Figure 7-10 through Figure 7-13. The highest rates of sequestration occurred in Major Land Resource Areas found in the southern portion of the United States, although these rates declined over the 1990s. Sequestration was driven by irrigation and seeding legumes. Similar to Cropland Remaining Cropland, emission rates from drained organic

Table 7-22: Net Soil C Stock Changes in Grassland Remaining Grassland (Tg CO$_2$ Eq.)

Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	(8.8)		2.9	2.9	2.9	2.8	2.8	2.7	2.7
Organic Soils[a]	4.3		4.6	4.6	4.6	4.6	4.6	4.6	4.6
Liming of Soils[b]	-		-	-	-	-	-	-	-
Total Net Flux	(4.5)		7.5	7.5	7.4	7.4	7.4	7.3	7.3

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.
[a] Also includes emissions due to drainage of organic soils in Land Converted to Grassland.
[b] Emissions from liming in Grassland Remaining Grassland are reported in Cropland Remaining Cropland.

Table 7-23: Net Soil C Stock Changes in Grassland Remaining Grassland (Tg C)

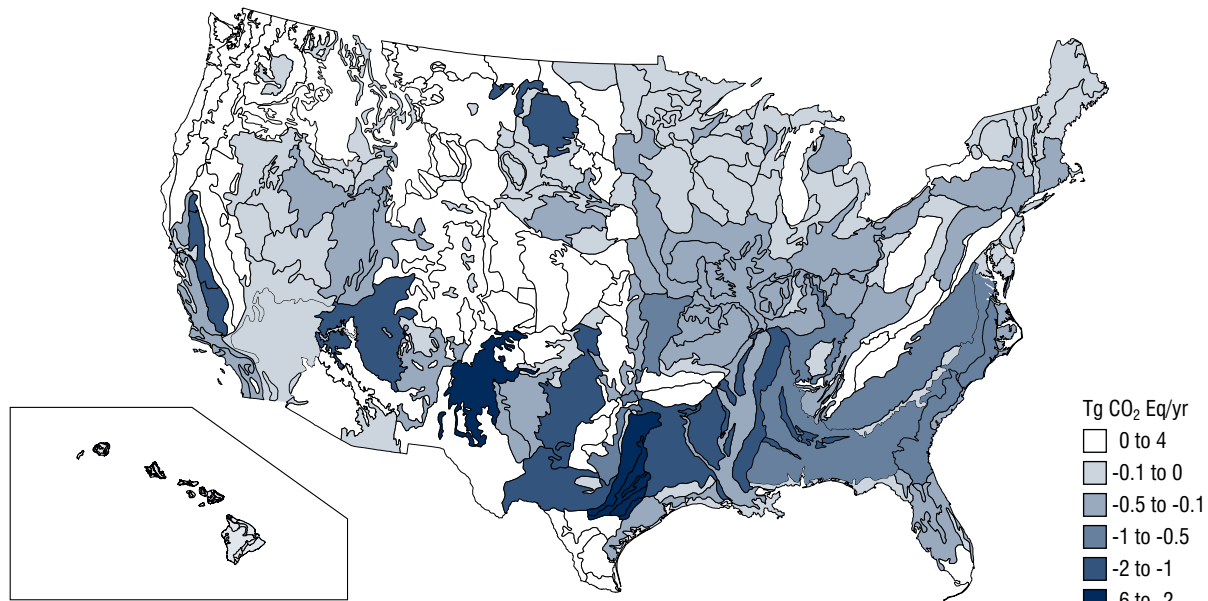| Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	(2.4)		0.8	0.8	0.8	0.8	0.8	0.7	0.7
Organic Soils[a]	1.2		1.3	1.3	1.3	1.3	1.3	1.3	1.3
Liming of Soils[b]	-		-	-	-	-	-	-	-
Total Net Flux	(1.2)		2.1	2.0	2.0	2.0	2.0	2.0	2.0

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.
[a] Also includes emissions due to drainage of organic soils in Land Converted to Grassland.
[b] Emissions from liming in Grassland Remaining Grassland are reported in Cropland Remaining Cropland.

Figure 7-10

Net Soil C Stock Change for Mineral Soils in Grassland Remaining Grassland, 1990-1992

Tg CO$_2$ Eq/yr
- 0 to 4
- -0.1 to 0
- -0.5 to -0.1
- -1 to -0.5
- -2 to -1
- -6 to -2

Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 3 inventory computations, but not the Tier 1 estimates for sewage sludge additions. See Methodology for additional details.

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1990 through 1992. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.

Figure 7-11

Net Soil C Stock Change for Mineral Soils in Grassland Remaining Grassland, 1993-2004

Tg CO$_2$ Eq/yr
- 0 to 8
- -0.1 to 0
- -0.5 to -0.1
- -1 to -0.5
- -2 to -1
- -3 to -2

Note: Values greater than zero represent emissions, and values less than zero represent sequestration. Map accounts for fluxes associated with the Tier 3 inventory computations, but not the Tier 1 estimates for sewage sludge additions. See Methodology for additional details.

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1993 through 2004. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.
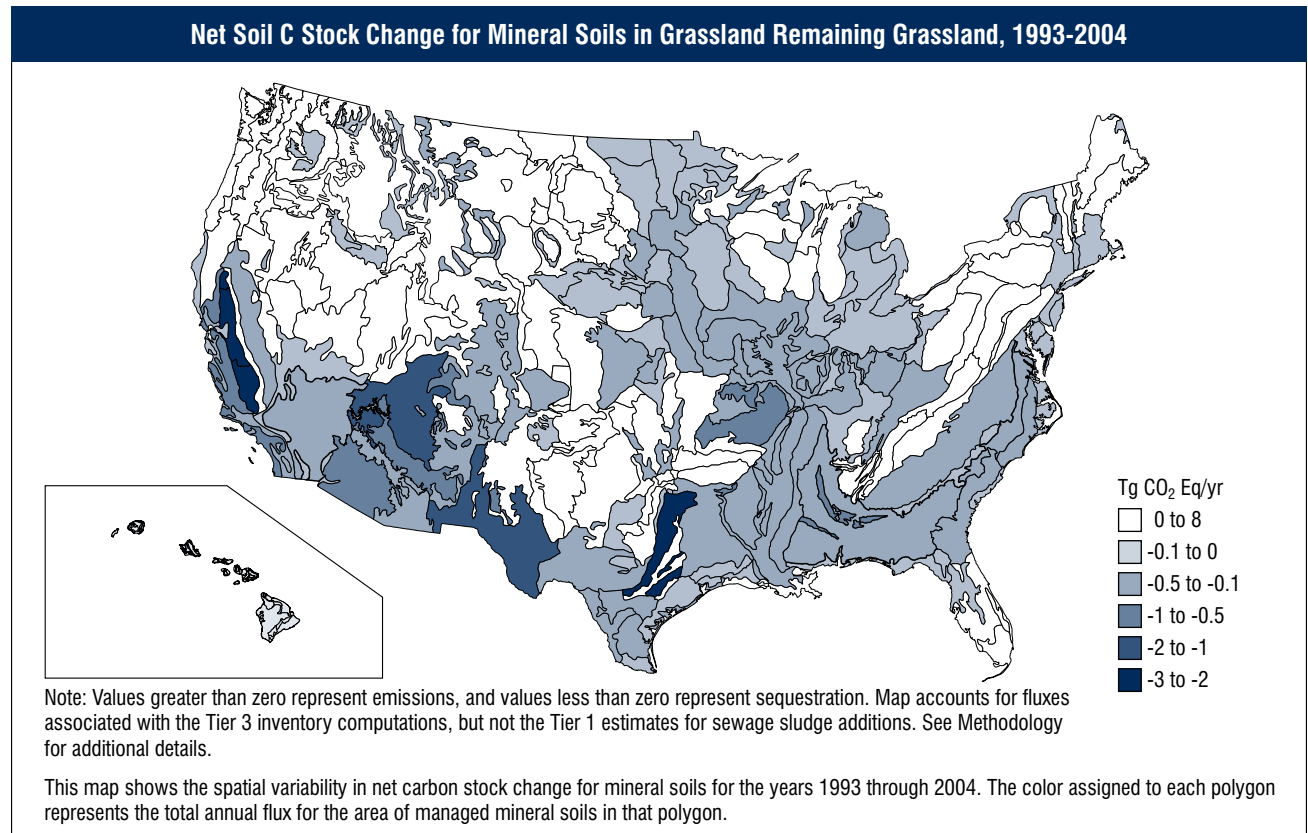
Figure 7-12

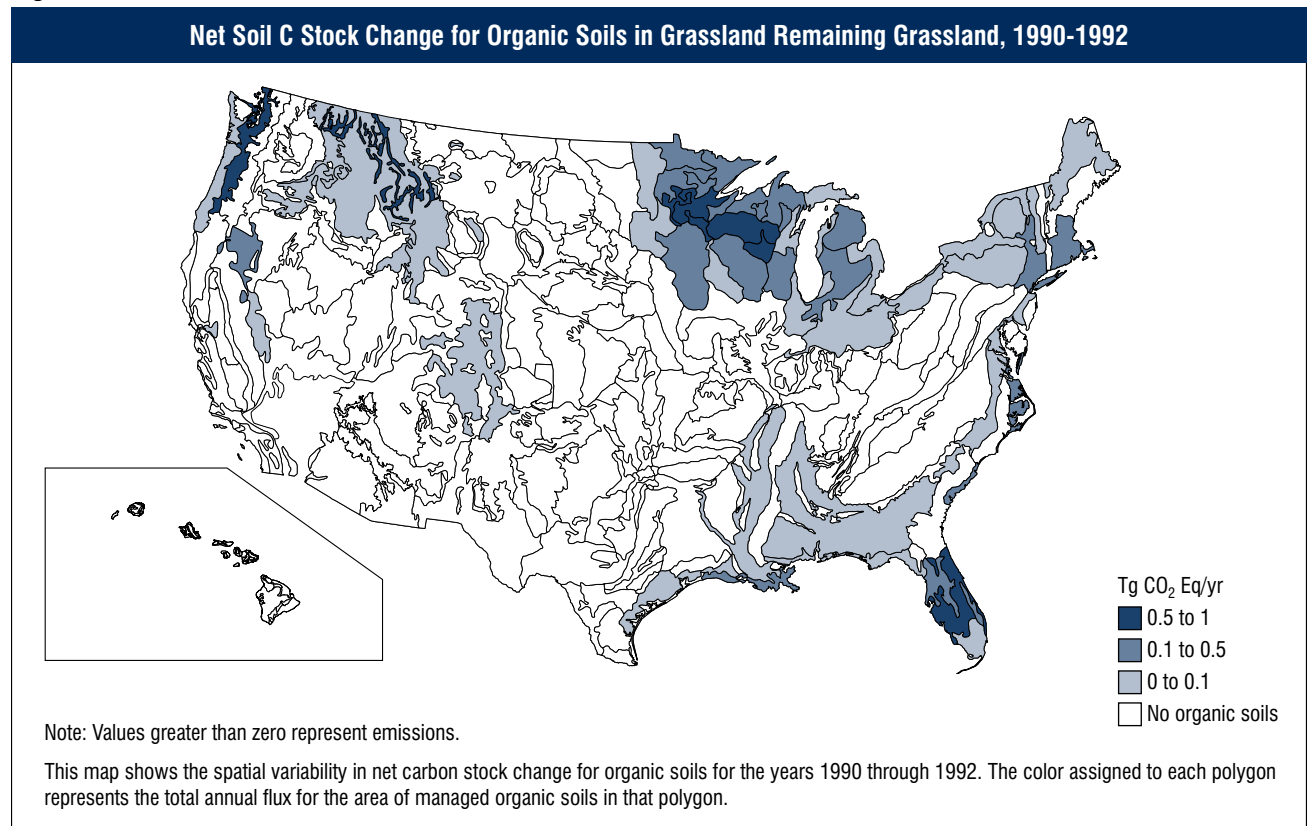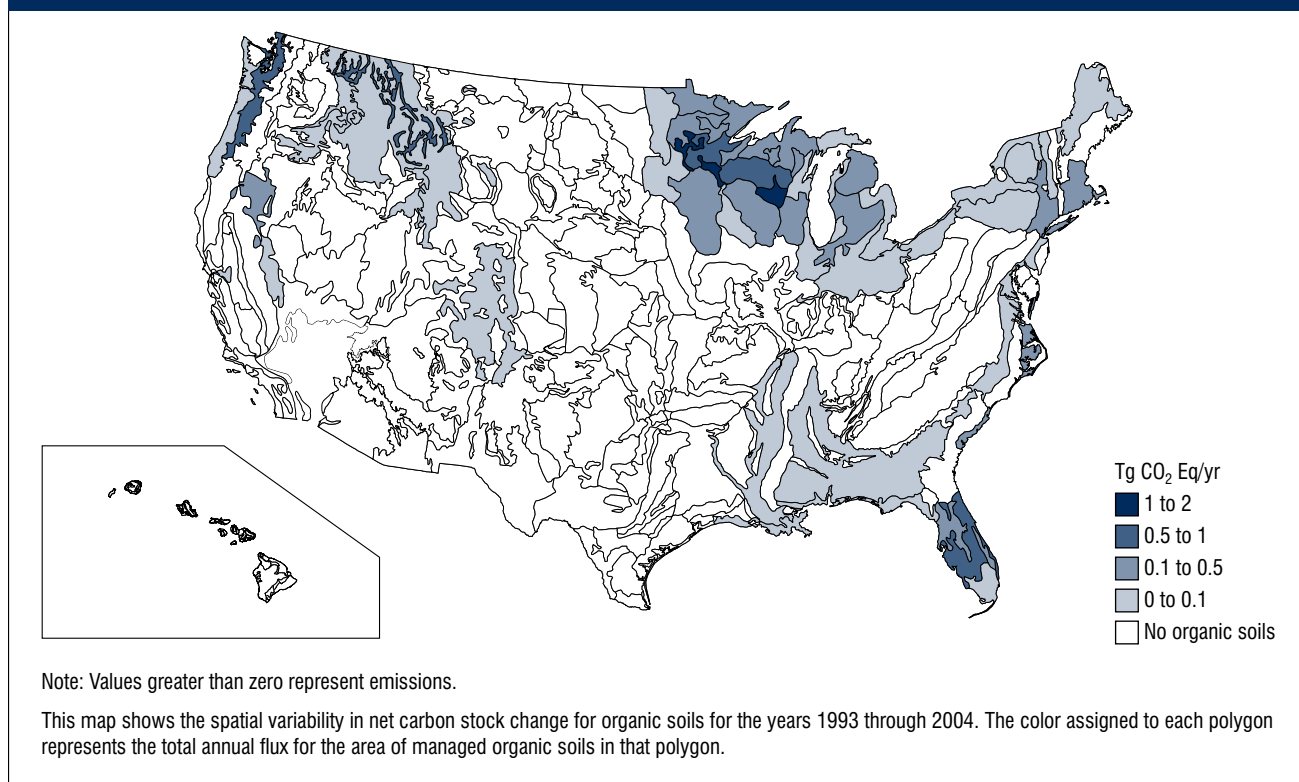**Net Soil C Stock Change for Organic Soils in Grassland Remaining Grassland, 1990-1992**

Tg CO$_2$ Eq/yr
- 0.5 to 1
- 0.1 to 0.5
- 0 to 0.1
- No organic soils

Note: Values greater than zero represent emissions.

This map shows the spatial variability in net carbon stock change for organic soils for the years 1990 through 1992. The color assigned to each polygon represents the total annual flux for the area of managed organic soils in that polygon.

Figure 7-13

Net Soil C Stock Change for Organic Soils in Grassland Remaining Grassland, 1993-2004

Tg CO₂ Eq/yr

- 1 to 2
- 0.5 to 1
- 0.1 to 0.5
- 0 to 0.1
- No organic soils

Note: Values greater than zero represent emissions.

This map shows the spatial variability in net carbon stock change for organic soils for the years 1993 through 2004. The color assigned to each polygon represents the total annual flux for the area of managed organic soils in that polygon.

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.

The estimates presented here are restricted to C stock changes associated with land use and management of 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 methane (CH_4) from flooded rice cultivation. These emissions are accounted for under the Agriculture sector, 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 carbon stocks due to agricultural land-use and management activities

on mineral and organic soils for Grassland Remaining Grassland.

Mineral and Organic Soil Carbon Stock Changes

Soil C stock changes were estimated for Grassland Remaining Grassland according to land-use histories recorded in the USDA National Resources Inventory (NRI) survey (USDA-NRCS 2000).[12] 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. NRI points were classified as Grassland Remaining Grassland if the land use was grassland since 1982. Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangeland 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.

A new Tier 3 model-based approach was developed to estimate C stock changes for mineral soils in Grassland

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

Remaining Grassland. An IPCC Tier 2 method was used to estimate emissions from organic soils (Ogle et al. 2003). Tier 1 methods were used to estimate additional changes in C stocks in mineral soils due to manure amendments and sewage sludge additions to soils. 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 Soils

Tier 3 Approach

Mineral SOC 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 for grassland in different regions of the United States from the USDA Economic Research Service Cropping Practices Survey (ERS 1997) and National Agricultural Statistics Service (NASS 1992, 1999, 2004). Manure application frequency to grassland and rates were estimated from data compiled by the USDA Natural Resources Conservation Service for 1997 (Edmonds et al. 2003). Pasture/Range/Paddock (PRP) manure N additions were estimated internally in the Century model, as part of the grassland system simulations (i.e., PRP manure production was not an external input into the model). See the Cropland Remaining Cropland section for additional discussion on the Tier 3 methodology for mineral soils.

Tier 2 Approach

No Tier 2 method was used to estimate mineral soil C stock changes for Grassland Remaining Grassland because the Tier 3 Century-based method was used to estimate stock changes for the entire land base classified in this land use category.

Additional Mineral C Stock Change Calculations

Annual C flux estimates for mineral soils between 1990 and 2004 were adjusted to account for additional C stock changes associated with sewage sludge amendments.

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, and a projection for 2000, in dry mass units, were obtained from EPA reports (EPA 1993, 1999), and 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 be rarely if ever amended with sewage sludge due to the high metal content and other pollutants in human waste. The soil C storage rate was estimated at 0.33 metric tons C per hectare per year for sewage sludge amendments to grassland. The stock change rate is based on country-specific factors using the IPCC method (see Annex 3.13 for further discussion).

The influence of variation in application of manure to grassland soils may also affect C stock changes in Grassland Remaining Grassland. However, the net impact is reported in Cropland Remaining Cropland because it was not possible to differentiate between manure amendments on cropland and grassland in reporting years other than 1997 but the manure is differentiated in the Agricultural Soil Management section (i.e., Edmonds et al. 2003 only provides information on amendments for the 1997 reporting year). Note that variation in manure deposited directly onto PRP was assumed to not increase soil C stocks. Much of the carbon in biomass is returned to soils in grassland systems, either through grazers as manure or directly in litter fall, and variation in the manure production is assumed to have a minimal impact on soil C stocks.

Organic Soils

Annual C emissions from grassland (Grassland Remaining Grassland and Land Converted to Grassland) on drained organic soils were estimated using methods provided in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and IPCC *Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003), except that U.S.-specific C loss rates were used in the calculations rather than default IPCC rates (Ogle et al. 2003). See the Cropland Remaining Cropland section for additional discussion on the estimation of C emissions from drained organic soils.

CO₂ Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to Grassland Remaining Grassland are reported in the Cropland Remaining Cropland, because it was not possible to disaggregate liming application among land use/land-use change categories.

Uncertainty

Uncertainty associated with the Grassland Remaining Grassland category includes the uncertainty associated with changes in mineral and organic soil carbon stocks.

Mineral and Organic Carbon Stock Changes

Uncertainties in Mineral Soil C Stock Changes

Tier 3 Approach

The uncertainty analysis for Grassland Remaining Grassland using the Tier 3 approach was 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 empirically-based uncertainty estimator described in the Cropland Remaining Cropland section has not been developed to estimate uncertainties in Century model results for Grassland Remaining Grassland, but this is a planned improvement for the inventory. See the Tier 3 approach for mineral soils under the Cropland

Remaining Cropland section for additional discussion. The inventory estimate for 2004 and associated 95 percent confidence interval are provided in Table 7-24. The uncertainty in the inventory estimate of 3.96 Tg CO_2 Eq. was -44 percent and +39 percent.

Additional Mineral C Stock Change Calculations

A ±50 percent uncertainty was assumed for additional adjustments to the soil C stocks between 1990 and 2004 to account for additional C stock changes associated with amending grassland soils with sewage sludge. The estimated adjustment for 2004 and associated 95 percent confidence interval are provided in Table 7-25.

Uncertainties in Organic Soil C Stock Changes

Uncertainty in carbon emissions from organic soils were estimated using country specific factors and a Monte Carlo Analysis. PDFs 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. Organic soils in Grassland Remaining Grassland were estimated to emit between 2.2 and 7.7 Tg CO_2 Eq. at a 95 percent confidence level (Table 7-26). This indicates a range of 52 percent below to 68 percent above the 2004 flux estimate of 4.58 Tg CO_2 Eq.

Table 7-24: Quantitative Uncertainty Estimates for C Stock Changes in Mineral Soils Occurring within Grassland Remaining Grassland, which were Estimated Using the Tier 3 Approach (Tg CO₂ Eq. and Percent)

| Source | 2004 Stock Change Estimate (Tg CO₂ Eq.) | Uncertainty Range Relative to Stock Change Estimate | | | |
| | | (Tg CO₂ Eq.) | | (%) | |
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Grassland Remaining Grassland	4.0	2.2	5.5	-44%	+39%

Table 7-25: Uncertainty Estimates for C Stock Changes in Mineral Soils Occurring within Grassland Remaining Grassland, which were Estimated Using the Tier 2 Approach (Tg CO₂ Eq. and Percent).

| Source | 2004 Stock Change Estimate (Tg CO₂ Eq.) | Uncertainty Range Relative to Stock Change Estimate | | | |
| | | (Tg CO₂ Eq.) | | (%) | |
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Grassland Remaining Grassland (Change in Soil C due to Sewage Sludge Amendments)	(1.3)	(1.9)	(0.6)	-50%	+50%

Table 7-26: Tier 2 Quantitative Uncertainty Estimates for CO$_2$ Emissions from Organic Soils Occurring within Grassland Remaining Grassland (Tg CO$_2$ Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Stock Change Estimate[a]			
		(Tg CO$_2$ Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Organic Soil C Stocks: Grassland Remaining Grassland[b]	4.6	2.2	7.7	-52%	+68%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
[b] Grassland Remaining Grassland and Land Converted to Grassland are both reported in this section because grassland on organic soils has not been subdivided into land use/land-use change categories.

Additional Uncertainties in Mineral and Organic Soil C Stock Changes

Minimal data exist on where and how much sewage sludge has been applied to U.S. agricultural land and the accounting of this activity appears to be much more difficult than the related-activity of using manure to amend agricultural soils. Consequently, there is considerable uncertainty in the application of sewage sludge, which is assumed to be applied to Grassland Remaining Grassland. However, some sludge may be applied to other agricultural land, but there is not sufficient information to further subdivide application among the agricultural land use/ land-use change categories. See section on "Additional Uncertainties in Soil C Stock Changes" in Cropland Remaining Cropland (Section 1.3.1) for discussion of other uncertainties.

QA/QC and Verification

See Cropland Remaining Cropland.

Recalculations Discussion

See Cropland Remaining Cropland.

Planned Improvements

See Cropland Remaining Cropland.

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

Background on agricultural carbon stock changes is provided in the Cropland Remaining Cropland and will only be summarized here. 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 *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) recommend reporting changes in soil organic C stocks due to: (1) agricultural land-use and management activities on mineral soils; (2) agricultural land-use and management activities on organic soils, and (3) CO$_2$ emissions that result from liming of soils with dolomite and limestone. Mineral soil C stock changes are reported here for Land Converted to Grassland, but stock changes associated with management of organic soils and liming are reported in Cropland Remaining Cropland because it was not possible to subdivide those estimates by land use and land-use change categories (see Methodology section below for additional discussion).

Land-use and management of mineral soils in Land Converted to Grassland led to an increase in soil C stocks over the entire time series, which was largely caused by annual cropland converted into pasture (see Table 7-26 and Table 7-28). Stock change rates varied from 17.6 to 21.1 Tg CO$_2$ Eq. (4.8 to 5.8 Tg C).

The spatial variability in annual CO$_2$ flux associated with C stock changes in mineral soils is displayed in Figure 7-14 and Figure 7-15. Soil C stock increased in most MLRAs 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.

The estimates presented here are restricted to C stock changes associated with the use and management of agricultural soils. Agricultural soils are also important sources of other greenhouse gases, particularly N$_2$O from application of fertilizers, manure, and crop residues and from cultivation of legumes, as well as methane (CH$_4$) from

Table 7-27: Net Soil C Stock Changes for Land Converted to Grassland (Tg CO$_2$ Eq.)

Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	(17.6)		(21.1)	(21.1)	(21.1)	(21.1)	(21.1)	(21.1)	(21.1)
Organic Soils[a]	-		-	-	-	-	-	-	-
Liming of Soils[b]	-		-	-	-	-	-	-	-
Total Net Flux	**(17.6)**		**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**	**(21.1)**

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.
[a] Emissions from organic soils in Land Converted to Grassland are reported in Grassland Remaining Grassland.
[b] Emissions from liming in Land Converted to Grassland are reported in Cropland Remaining Cropland.

Table 7-28: Net Soil C Stock Changes for Land Converted to Grassland (Tg C)

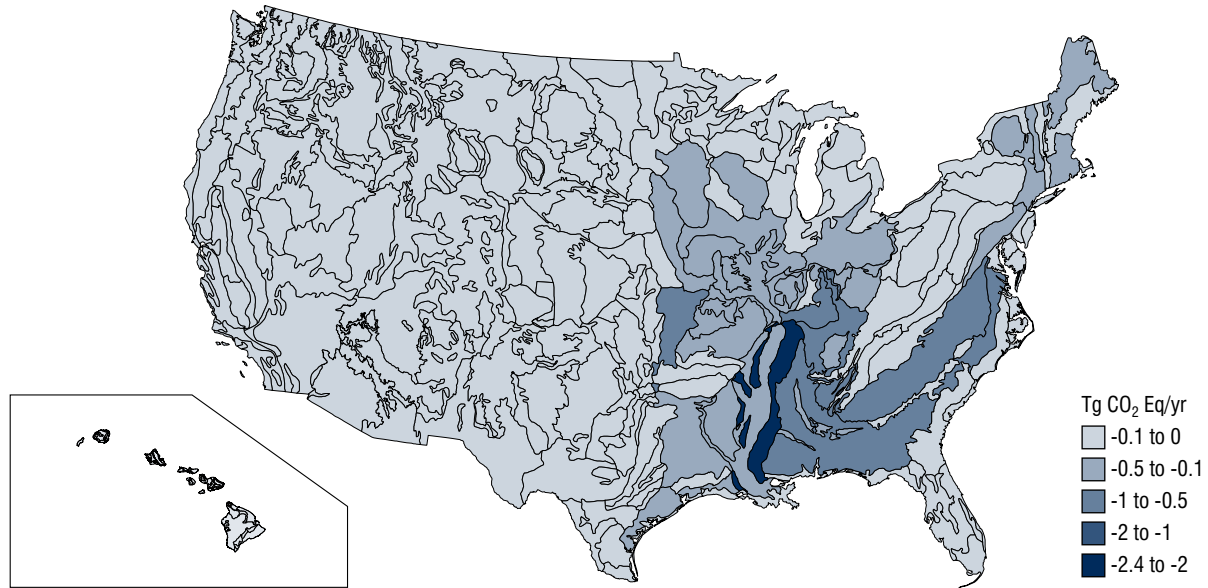| Soil Type	1990		1998	1999	2000	2001	2002	2003	2004
Mineral Soils	(4.8)		(5.8)	(5.8	(5.8)	(5.8)	(5.8)	(5.8)	(5.8)
Organic Soils[a]	-		-	-	-	-	-	-	-
Liming of Soils[b]	-		-	-	-	-	-	-	-
Total Net Flux	**(4.8)**		**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**	**(5.8)**

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.
[a] Emissions from organic soils in Land Converted to Grassland are reported in Grassland Remaining Grassland.
[b] Emissions from liming in Land Converted to Grassland are reported in Cropland Remaining Cropland.
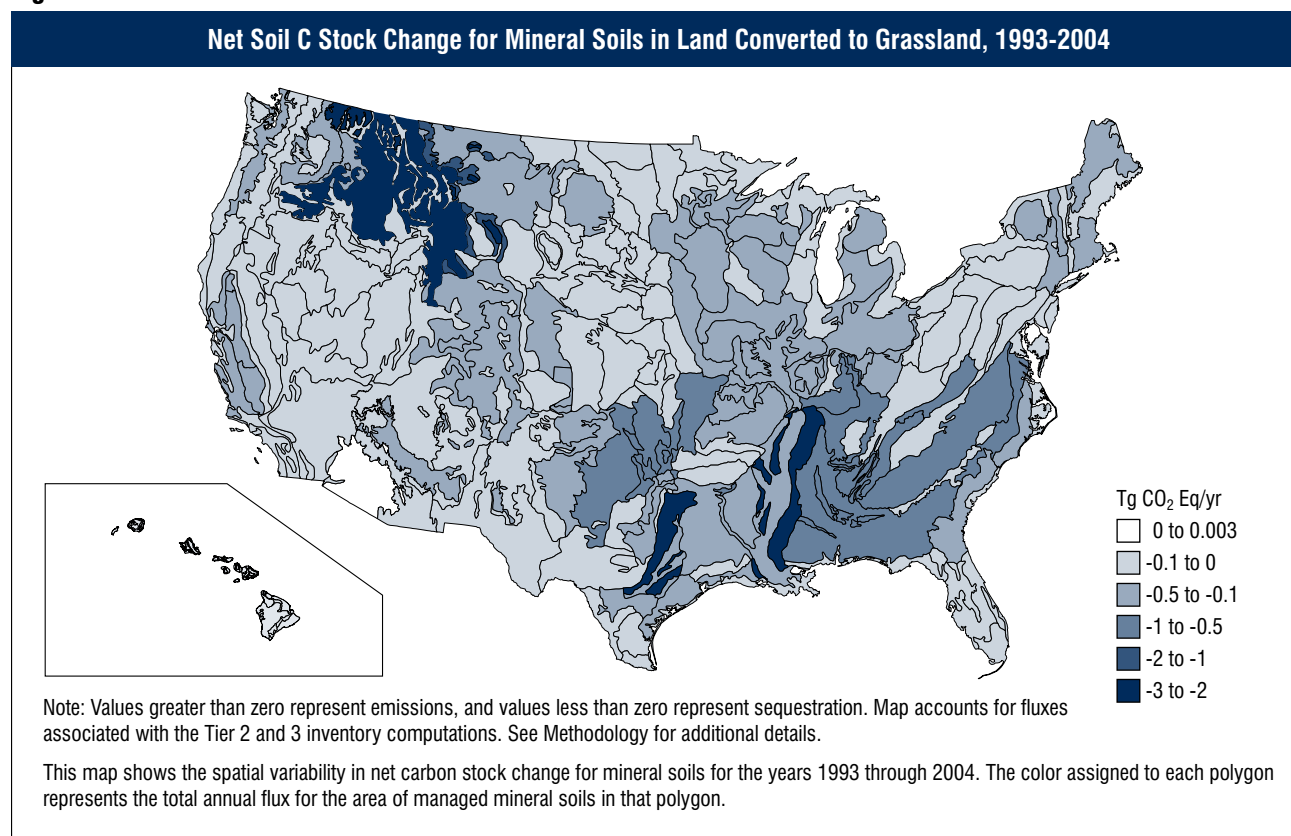
Figure 7-14

Net Soil C Stock Change for Mineral Soils in Land Converted to Grassland, 1990-1992

Tg CO$_2$ Eq/yr
- -0.1 to 0
- -0.5 to -0.1
- -1 to -0.5
- -2 to -1
- -2.4 to -2

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.

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1990 through 1992. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.

Figure 7-15

Net Soil C Stock Change for Mineral Soils in Land Converted to Grassland, 1993-2004

Tg CO_2 Eq/yr
- ☐ 0 to 0.003
- ☐ -0.1 to 0
- ☐ -0.5 to -0.1
- ☐ -1 to -0.5
- ☐ -2 to -1
- ■ -3 to -2

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.

This map shows the spatial variability in net carbon stock change for mineral soils for the years 1993 through 2004. The color assigned to each polygon represents the total annual flux for the area of managed mineral soils in that polygon.

flooded rice cultivation. These emissions are accounted for under the Agriculture sector, 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 carbon stocks due to agricultural land-use and management activities on mineral soils for Land Converted to Grassland.

Mineral and Organic Soil Carbon Stock Changes

Soil C stock changes were estimated for Land Converted to Grassland, according to land-use histories recorded in the USDA National Resources Inventory (NRI) survey (USDA-NRCS 2000).[13] Land use and some management information (e.g., legume pastures, crop type, soil attributes, and irrigation) were collected for each NRI point on a 5-year cycle beginning in 1982. NRI points were classified as

Land Converted to Grassland if the land use was currently grassland but had been converted from another use since 1982. Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangeland 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.

A new Tier 3 model-based approach was developed to estimate C stock changes for Land Converted to Grassland on mineral soils. An IPCC Tier 2 method was used to estimate C stock changes for portions of the land base for Land Converted to Grassland on mineral soils that were not addressed with the Tier 3 method, in addition to emission estimates for organic soils (Ogle et al. 2003). An IPCC Tier 2 method was used to estimate emissions from organic soils (Ogle et al. 2003). Tier 1 methods were used to estimate additional changes in mineral soil C stocks due to manure amendments that were not included in the Tier

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

2 and 3 analyses, and also for sewage sludge amendments. 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 Soils

Tier 3 Approach

Mineral SOC stocks and stock changes were estimated using the Century biogeochemical model for cropland converted into grassland, with the exception of prior cropland used to produce vegetables, tobacco, perennial/horticultural crops, and rice. Similar to 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 USDA Economic Research Service Cropping Practices Survey (ERS 1997) and National Agricultural Statistics Service (NASS 1992, 1999, 2004). Manure application frequency and rates were simulated based on data compiled by the USDA Natural Resources Conservation Service for 1997 (Edmonds et al. 2003). PRP manure N additions were estimated internally in the Century model, as part of the grassland system simulations (i.e., PRP manure was not an input into the model). See Cropland Remaining Cropland for additional discussion on the Tier 3 methodology for mineral soils.

Tier 2 Approach

Mineral SOC stock changes were estimated using a Tier 2 Approach for land converted to grassland from perennial, horticultural, tobacco and rice cropland. See Cropland Remaining Cropland for additional discussion on the Tier 2 methodology for mineral soils.

Additional Mineral C Stock Change Calculations

Annual C stock changes for Land Converted to Grassland on mineral soils between 1990 and 2004 were adjusted to account for additional C stock changes associated with sewage sludge amendments to soils, variation in manure N production (see Annex 3.13, Table A-204) and thus areas amended with manure relative to 1997. Additional changes due to sewage sludge amendments are reported in Grassland Remaining Grassland because it is not possible to subdivide these changes into the individual land use/land-use change categories. Similarly, additional changes due to

manure amendments were reported in Cropland Remaining Cropland. See Grassland Remaining Grassland and Cropland Remaining Cropland for further elaboration on the methods used to estimate these additional changes in mineral soil C stocks.

Organic Soils

Annual C emission estimates from drained organic soils in Land Converted to Grassland were estimated using the Tier 2 Approach, and reported in the Grassland Remaining Grassland section because organic soil areas have not been subdivided into land use/land-use change categories. Differentiating organic soils between Land Converted to Grassland and Grassland Remaining Grassland is a planned future improvement for the soil C inventory. See Grassland Remaining Grassland for discussion on the estimation of C emissions from drained organic soils.

CO$_2$ Emissions from Agricultural Liming

Carbon dioxide emissions from degradation of limestone and dolomite applied to Land Converted to Grassland are reported in the Cropland Remaining Cropland, because it was not possible to disaggregate liming application among land use and land-use change categories.

Uncertainty

Uncertainty associated with the Land Converted to Grassland category includes the uncertainty associated with changes in mineral soil carbon stocks.

Mineral and Organic Soil Carbon Stock Changes

Uncertainties in Mineral Soil C Stock Changes

Tier 3 Approach

The uncertainty analysis for Land Converted to Grassland using the Tier 3 approach was based on the same method described Cropland Remaining Cropland, except that the uncertainty inherent in the structure of the Century model was not addressed. The empirically-based uncertainty estimator described in the Cropland Remaining Cropland section 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. See the Tier 3 approach for mineral soils under Cropland Remaining Cropland for additional discussion. The inventory estimate for 2004 and associated 95 percent confidence interval are

Table 7-29: Quantitative Uncertainty Estimates for C Stock Changes in Mineral Soils Occurring within Land Converted to Grassland, which were Estimated Using the Tier 3 Approach (Tg CO_2 Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate			
		(Tg CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Land Converted to Grassland	(16.0)	(15.8)	(16.1)	-1%	+1%

provided in Table 7-29. The uncertainty in the inventory estimate of -16.0 Tg CO_2 Eq. was ±1 percent.

Tier 2 Approach

The uncertainty analysis for Land Converted to Grassland using the Tier 2 approach was based on the same method described for Cropland Remaining Cropland. See the Tier 2 section under minerals soils in Cropland Remaining Cropland section for additional discussion. Mineral soils on Land Converted to Grassland, which were estimated using the Tier 2 approach, had a carbon stock change between -2.9 and -7.3 Tg CO_2 Eq. at a 95 percent confidence level (Table 7-30). This indicates a range of 43 percent below to 43 percent above the 2004 stock change estimate of -5.1 Tg CO_2 Eq.

Uncertainties in Organic Soil C Stock Changes

Annual C emission estimates from drained organic soils in Land Converted to Grassland were estimated using the Tier 2 Approach, and reported in the Grassland Remaining Grassland Section because organic soil areas have not subdivided into land use/land-use change categories. Differentiating organic soils between Land Converted to Grassland and Grassland Remaining Grassland is a planned future improvement for the soil C inventory. See Grassland Remaining Grassland for discussion on the uncertainty estimation for drained organic soils in grassland.

Additional Uncertainties in Mineral and Organic Soil C Stock Changes

Additional uncertainties are discussed in Cropland Remaining Cropland.

QA/QC and Verification

See Cropland Remaining Cropland.

Recalculations Discussion

See Cropland Remaining Cropland.

Planned Improvements

See Cropland Remaining Cropland.

7.7. Settlements Remaining Settlements

Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills (IPCC Source Category 5E1)

As is the case with carbon in landfilled forest products, carbon contained in landfilled yard trimmings and food scraps can be stored for very long periods. In the United States, yard trimmings (i.e., grass clippings, leaves, and

Table 7-30: Tier 2 Quantitative Uncertainty Estimates for C Stock Changes in Mineral Soils Occurring within Land Converted to Grassland that were Estimated Using the Tier 2 Approach (Tg CO_2 Eq. and Percent)

Source	2004 Stock Change Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Stock Change Estimate[a]			
		(Tg CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mineral Soil C Stocks: Land Converted to Grassland	(5.1)	(7.3)	(2.9)	-43%	+43%

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

branches) and food scraps comprise a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are discarded in landfills. However, 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, nearly 51 million metric tons (wet weight) of yard trimmings and food scraps were generated (i.e., put at the curb for collection or taken to disposal or composting facilities) (EPA 2005). Since then, programs banning or discouraging disposal have led to an increase in backyard composting and the use of mulching mowers, and a consequent 18 percent decrease in the amount of yard trimmings collected. 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 35 percent in 2003 (the most recent year for which data are available; 2004 values are assumed equal to 2003). There is considerably less centralized composting of food scraps; generation has grown by 32 percent since 1990, though the proportion of food scraps discarded in landfills has decreased slightly from 81 percent in 1990 to 78 percent in 2003. Overall, there has been a decrease in the yard trimmings and food scrap landfill disposal rate, which has resulted in a decrease in the rate of landfill carbon storage

to 9.3 Tg CO_2 Eq. in 2004 from 24.5 Tg CO_2 Eq. in 1990 (Table 7-31 and Table 7-32).

Methodology

Estimates of net carbon flux resulting from landfilled yard trimmings and food scraps were developed by estimating the change in landfilled carbon stocks between inventory years. Carbon stock estimates were calculated by determining the mass of landfilled carbon resulting from yard trimmings or food scraps discarded in a given year; adding the accumulated landfilled carbon from previous years; and subtracting the portion of carbon landfilled in previous years that decomposed.

To determine the total landfilled carbon 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 carbon storage factor of the landfilled yard trimmings and food scraps adjusted by mass balance; and (4) the rate of decomposition of the degradable carbon. 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 carbon storage factor and rate

Table 7-31: Net Changes in Yard Trimming and Food Scrap Stocks in Landfills (Tg CO_2 Eq.)

Carbon Pool	1990	1997	1998	1999	2000	2001	2002	2003	2004
Yard Trimmings	**(21.7)**	**(8.7)**	**(8.0)**	**(6.9)**	**(5.6)**	**(5.8)**	**(6.1)**	**(6.3)**	**(6.4)**
Grass	(2.4)	(0.8)	(0.8)	(0.6)	(0.5)	(0.6)	(0.6)	(0.7)	(0.7)
Leaves	(9.8)	(3.9)	(3.6)	(3.0)	(2.5)	(2.5)	(2.6)	(2.7)	(2.8)
Branches	(9.6)	(4.0)	(3.7)	(3.2)	(2.7)	(2.7)	(2.8)	(2.9)	(2.9)
Food Scraps	**(2.8)**	**(2.6)**	**(2.9)**	**(2.9)**	**(3.2)**	**(3.2)**	**(3.2)**	**(3.1)**	**(2.9)**
Total Net Flux	**(24.5)**	**(11.3)**	**(10.9)**	**(9.8)**	**(8.9)**	**(9.0)**	**(9.3)**	**(9.4)**	**(9.3)**

Note: Totals may not sum due to independent rounding.

Table 7-32: Net Changes in Yard Trimming and Food Scrap Stocks in Landfills (Tg C)

Carbon Pool	1990	1997	1998	1999	2000	2001	2002	2003	2004
Yard Trimmings	**(5.9)**	**(2.4)**	**(2.2)**	**(1.9)**	**(1.5)**	**(1.6)**	**(1.7)**	**(1.7)**	**(1.7)**
Grass	(0.6)	(0.2)	(0.2)	(0.2)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)
Leaves	(2.7)	(1.1)	(1.0)	(0.8)	(0.7)	(0.7)	(0.7)	(0.7)	(0.8)
Branches	(2.6)	(1.1)	(1.0)	(0.9)	(0.7)	(0.7)	(0.8)	(0.8)	(0.8)
Food Scraps	**(0.8)**	**(0.7)**	**(0.8)**	**(0.8)**	**(0.9)**	**(0.9)**	**(0.9)**	**(0.8)**	**(0.8)**
Total Net Flux	**(6.7)**	**(3.1)**	**(3.0)**	**(2.7)**	**(2.4)**	**(2.5)**	**(2.5)**	**(2.6)**	**(2.5)**

Note: Totals may not sum due to independent rounding.

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: 2003 Facts and Figures* (EPA 2005). That report provides data for 1960, 1970, 1980, 1990, 1995, and 2000 through 2003. To provide data for some of the missing years in the 1990 through 1999 period, two earlier reports were used (*Characterization of Municipal Solid Waste in the United States: 1998 Update* (EPA 1999), and *Municipal Solid Waste in the United States: 2001 Facts and Figures* (EPA 2003)). Remaining years in the time series for which data were not provided were estimated using linear interpolation. Values for 2004 are assumed to be equal to values for 2003. The reports do not subdivide discards of individual materials into volumes landfilled and combusted, although they provide an estimate of the proportion of overall wastestream discards managed in landfills and combustors (i.e., ranging from 81 percent and 19 percent respectively in 1990, to 80 percent and 20 percent in 2000).

The amount of carbon 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) carbon 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 carbon contents were determined by Barlaz (1998; 2005) (Table 7-33).

The amount of carbon remaining in the landfill for each subsequent year was tracked based on a simple model

of carbon fate. As demonstrated by Barlaz (1998; 2005), a portion of the initial carbon resists decomposition and is essentially persistent in the landfill environment; the modeling approach applied here builds on his findings. Barlaz (1998; 2005) 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 carbon 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 carbon content; the carbon remaining in the solid sample can be expressed as a proportion of initial carbon (shown in the row labeled "CS" in Table 7-33).

For purposes of simulating U.S. landfill carbon flows, the proportion of carbon stored is assumed to persist in landfills; the remaining portion is assumed to degrade (and results in emissions of CH_4 and CO_2; the methane emissions resulting from decomposition of yard trimmings and food scraps are counted in the Waste chapter). The degradable portion of the carbon is assumed to decay according to first order kinetics. Grass and food scraps are assumed to have a half-life of 5 years; leaves and branches are assumed to have a half-life of 20 years.

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

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

where,

t $\qquad$ = the year for which carbon stocks are being estimated,

Table 7-33: Moisture Content (%), Carbon Storage Factor, Initial Carbon Content (%), Proportion of Initial Carbon Sequestered (%), 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 carbon C stored	68%	72%	77%	16%
Initial Carbon Content (%)	45	42	49	51
Half-life (years)	5	20	20	5

$LFC_{i,t}$ = the stock of carbon in landfills in year t, for waste i (grass, leaves, branches, food scraps)

$W_{i,n}$ = the mass of waste i disposed in landfills in year n, in units of wet weight

n = the year in which the waste was disposed, where $1960 \leq n \leq t$

MC_i = moisture content of waste i,

CS_i = the proportion of initial carbon that is stored for waste i,

ICC_i = the initial carbon content of waste i,

e = the natural logarithm, and

k = the first order rate constant for waste i, and is equal to 0.693 divided by the half-life for decomposition.

For a given year t, the total stock of carbon in landfills ($TLFC_t$) is the sum of stocks across all four materials. The annual flux of carbon 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 carbon placed in a landfill in year n is tracked for each year t through the end of the inventory period (2004). For example, disposal of food scraps in 1960 resulted in depositing about 1,140,000 metric tons of carbon. Of this amount, 16 percent (180,000 metric tons) is persistent; the remaining 84 percent (960,000 metric tons) is degradable. By 1965, half of the degradable portion (480,000 metric tons) decomposes, leaving a total of 660,000 metric tons (the persistent portion, plus the remaining half of the degradable portion).

Continuing the example, by 2004, the total food scraps carbon originally disposed in 1960 had declined to 181,000 metric tons (i.e., virtually all of the degradable carbon

had decomposed). By summing the carbon remaining from 1960 with the carbon remaining from food scraps disposed in subsequent years (1961 through 2004), the total landfill carbon from food scraps in 2004 was 30.5 million metric tons. This value is then added to the carbon stock from grass, leaves, and branches to calculate the total landfill carbon stock in 2004, yielding a value of 232.6 million metric tons (as shown in Table 7-34). In exactly the same way total net flux is calculated for forest carbon and harvested wood products, the total net flux of landfill carbon for yard trimmings and food scraps for a given year (Table 7-32) is the difference in the landfill carbon stock for a given year and the stock in the preceding year. For example, the net change in 2004 shown in Table 7-32 (2.5 Tg C) is equal to the stock in 2004 (232.6 Tg C) minus the stock in 2003 (230.0 Tg C).

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

- Initial carbon content (ICC, measured),

- Carbon output as methane (CH_4-C, measured),

- Carbon output as carbon dioxide (CO_2-C, not measured), and

- Residual stored carbon (CS, measured).

In a simple system where the only carbon fates are CH_4, CO_2, and carbon 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, Eleazer et al. 1997) did not measure CO_2 outputs in experiments. However, if the only decomposition is

Table 7-34: Carbon Stocks in Yard Trimmings and Food Scraps in Landfills (Tg C)

Carbon Pool	1990	1997	1998	1999	2000	2001	2002	2003	2004
Yard Trimmings	**161.3**	**189.7**	**191.9**	**193.7**	**195.3**	**196.9**	**198.5**	**200.3**	**202.0**
Grass	18.2	21.1	21.4	21.5	21.7	21.8	22.0	22.2	22.4
Leaves	72.8	85.5	86.5	87.3	88.0	88.7	89.4	90.2	90.9
Branches	70.3	83.0	84.0	84.9	85.6	86.4	87.1	87.9	88.7
Food Scraps	**20.3**	**24.7**	**25.5**	**26.3**	**27.2**	**28.1**	**28.9**	**29.8**	**30.5**
Total Carbon Stocks	**181.6**	**214.4**	**217.4**	**220.1**	**222.5**	**224.9**	**227.5**	**230.0**	**232.6**

Note: Totals may not sum due to independent rounding.

anaerobic, then $CH_4\text{-}C = CO_2\text{-}C$.[14] Thus, the system should be defined by:

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

The carbon outputs ($= 2 \times CH_4\text{-}C + CS$) were less than 100 percent of the initial carbon mass for food scraps, leaves, and branches (75, 86, and 90 percent, respectively). For these materials, it was assumed that the unaccounted for carbon had exited the experiment as CH_4 and CO_2, and no adjustment was made to the measured value of CS.

In the case of grass, the outputs were slightly more (103 percent) than initial carbon mass. To resolve the mass balance discrepancy, it was assumed that the measurements of initial carbon content and methane mass were accurate. Thus, the value of CS was calculated as the residual of ICC (initial carbon content) minus ($2 \times CH_4\text{-}C$). This adjustment, reduced the carbon storage value from the 71 percent reported by Barlaz (1998) to 68 percent (as shown in Table 7-33).

Uncertainty

The estimation of carbon storage in landfills is directly related to the following yard trimming and food scrap data and factors: disposal in landfills per year (tons of carbon), initial carbon content, moisture content, decomposition rate (half-life), and proportion of carbon stored. The carbon 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 uncertainties associated with each of these factors.

The uncertainty ranges were assigned based on expert judgment and are assumed to be uniformly distributed around the inventory estimate (e.g., ±10 percent), except for the

values for decomposition rate, proportion of carbon stored, and moisture content for branches.

The uncertainty ranges associated with the input variables for the proportion of grass and leaves in yard trimmings, as well as the initial carbon content and moisture content for grass, leaves, and food scraps (all expressed as percentages in the calculations for the inventory) were plus or minus 10 percent. For the moisture content of branches (where the inventory estimate is 10 percent), the uncertainty range was assumed to be 5 to 30 percent.

The uncertainty ranges associated with the disposal of grass, leaves, branches, and food scraps were bound at 50 percent to 150 percent times the inventory estimates. The half-life of grass and food scraps were assumed to range from 1 to 20 years, and the half-lives of leaves and branches were assumed to range from 5 to 30 years. Finally, the proportion of carbon stored in grass, leaves, branches, and food scraps was assumed to vary plus or minus 20 percent from the best estimate, with an upper bound of 100 percent and a lower bound of 0 percent.

A Monte Carlo (Tier 2) uncertainty analysis was then applied to estimate the overall uncertainty of the sequestration estimate. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 7-35. Total yard trimmings and food scraps CO_2 flux in 2004 was estimated to be between -16.3 and -5.7 Tg CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo Stochastic Simulations). This indicates a range of 75 percent below to 39 percent above the 2004 flux estimate of -9.3 Tg CO_2 Eq.

The uncertainty of the landfilled carbon storage estimate arises from the disposal data and the factors applied to the following data.

Table 7-35: Tier 2 Quantitative Uncertainty Estimates for CO$_2$ Flux from Yard Trimmings and Food Scraps in Landfills (Tg CO$_2$ Eq. and Percent)

Source	Gas	2004 Emission Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Emission Estimate[a]			
			(Tg CO$_2$ Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Yard Trimmings and Food Scraps	CO$_2$	(9.3)	(16.3)	(5.7)	-75%	+39%

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

[14] 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.

Disposal per Year (tons of carbon)

A source of uncertainty affecting CO_2 sequestration is the estimate of the tonnage of yard trimmings and food scraps which are disposed of in landfills each year. Of all the individual inputs tested for sensitivity in the uncertainty analysis, net carbon storage in landfills is most sensitive to the estimate of the food scrap disposal rate. The estimates for yard trimming and food scrap disposal in landfills are determined using data from EPA (1999, 2002, 2003) estimates of materials generated, discarded, and combusted, which carry considerable uncertainty associated with the wastestream sampling methodology used to generate them.

Moisture Content and Initial Carbon Content

Moisture content, and to a lesser extent carbon content, vary widely. Moisture content for a given sample of waste can be affected by the precipitation conditions when the waste is placed at the curb for collection, as well as the status and condition of the landfill cover. Carbon content (on a dry weight basis) is a function of the specific waste constituents (e.g., oak leaves versus pine needles or banana peels versus bacon grease), which in turn vary temporally, geographically, and demographically (i.e., characteristics of households in the wasteshed).

Decomposition Rate

Although several investigators have made estimates of the decomposition rate of mixed solid waste in a landfill environment, there are no known studies of decomposition rates for individual materials in actual landfills, and thus the inventory estimate is based on assumed values. The uncertainty analysis indicates that the results are sensitive to decomposition rates, especially the food scraps half-life, and thus the decomposition rates introduce considerable uncertainty into the analysis.

Proportion of Carbon Stored

The estimate of the proportion of carbon stored is based on a set of experiments measuring the amount of carbon persisting in conditions promoting decomposition. Because these experiments have only used conditions conducive to decomposition, they are more likely to underestimate than to overestimate carbon storage. Nonetheless, measurement error may be the dominant source of uncertainty, and so the uncertainty analysis used symmetrical values (plus or minus 20 percent) as inputs.

Recalculations Discussion

The principal change this year is the addition of newly generated experimental results for leaves, provide by Barlaz (2005). This has the effect of reducing the overall estimate of landfill carbon storage, as the new results for leaves indicate more decomposition than the earlier values.

This year's inventory also reflects changes in the estimate for carbon storage from grass, reflecting the mass balance constraint described above in the methodology section. This mass balance constraint had not been applied in previous years.

Overall, the recalculations have the effect of reducing carbon stocks by about 4 percent in this year's inventory compared to those reported last year.

Planned Improvements

Future work may evaluate the potential contribution of inorganic carbon to landfill sequestration and to assure consistency between the estimates of carbon storage described in this chapter and the estimates of landfill CH_4 emissions described in the Waste chapter.

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. (in review)). With an average tree canopy cover of 27.1 percent, urban areas account for approximately 3 percent of total tree cover in the

Table 7-36: Net C Flux from Urban Trees (Tg CO$_2$ Eq. and Tg C)

Year	Tg CO$_2$ Eq.	Tg C
1990	(58.7)	(16.0)
1998	(73.3)	(20.0)
1999	(77.0)	(21.0)
2000	(77.0)	(21.0)
2001	(80.7)	(22.0)
2002	(80.7)	(22.0)
2003	(84.3)	(23.0)
2004	(88.0)	(24.0)

Note: Parentheses indicate net sequestration.

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 72.1 Tg CO_2 Eq. (19.7 Tg C) over the period from 1990-2004. Total sequestration increased by 50 percent between 1990 and 2004 due to increases in urban land area. Data on carbon storage and urban tree coverage were collected throughout the 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 7-36).

Net carbon 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 carbon 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 carbon density than forested areas (Nowak and Crane 2002).

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 the IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), although sufficient data are not yet available to determine interannual changes in carbon 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.

Nowak and Crane (2002) developed estimates of annual gross carbon sequestration from tree growth and annual gross carbon emissions from decomposition for ten U.S. cities: Atlanta, GA; Baltimore, MD; Boston, MA; Chicago, IL; Jersey City, NJ; New York, NY; Oakland, CA; Philadelphia, PA; Sacramento, CA; and Syracuse, NY. The gross carbon sequestration estimates were derived from field

data that were collected in these ten cities during the period from 1989 through 1999, 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 carbon 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 carbon 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 carbon sequestration rates for each species (or genus), diameter class, and land-use condition were then scaled up to city estimates using tree population information. The field data from the 10 cities, some of which are unpublished, are described in Nowak and Crane (2002) 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). Adjustment factors to account for tree condition were based on percent crown dieback (Nowak and Crane 2002). Tree growth rates were also 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.

Annual gross carbon emission estimates were derived by applying estimates of annual mortality and condition, and assumptions about whether dead trees were removed from the site, to carbon 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 carbon 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 carbon sequestration by urban trees was estimated from estimates of gross and net sequestration from seven of the ten cities, and urban area and urban tree cover data for the United States. Annual net carbon sequestration estimates were derived for seven cities by subtracting the annual gross emission estimates from the annual gross sequestration estimates.[15] 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. (in review) 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). National urban tree cover area was estimated by Nowak et al. (2002) to be 27.1 percent of urban areas.

The gross and net carbon 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 (0.30 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 (0.70). The urban tree cover area estimates for each of the 10 cities and the United States were obtained from Dwyer et al. (2000) and Nowak et al. (in review).

Uncertainty

The only quantifiable uncertainty associated with changes in C stocks in urban trees was sampling, as reported by Nowak and Crane (2002). The average standard deviation for urban tree carbon storage was 27 percent of the mean carbon storage on an area basis. Additionally, a 5 percent uncertainty was associated with national urban tree covered area. These estimates are based on field data collected in ten U.S. cities, and uncertainty in these estimates increases as they are scaled up to the national level.

Table 7-37: Carbon Stocks (Metric Tons C), Annual Carbon Sequestration (Metric Tons C/yr), Tree Cover (Percent), and Annual Carbon Sequestration per Area of Tree Cover (kg C/m² cover-yr) for Ten U.S. Cities

City	Carbon Stocks	Gross Annual Sequestration	Net Annual Sequestration	Tree Cover	Gross Annual Sequestration per Area of Tree Cover	Net Annual Sequestration per Area of Tree Cover
New York, NY	1,225,200	38,400	20,800	20.9	0.23	0.12
Atlanta, GA	1,220,200	42,100	32,200	36.7	0.34	0.26
Sacramento, CA	1,107,300	20,200	NA	13.0	0.66	NA
Chicago, IL	854,800	40,100	NA	11.0	0.61	NA
Baltimore, MD	528,700	14,800	10,800	25.2	0.28	0.20
Philadelphia, PA	481,000	14,600	10,700	15.7	0.27	0.20
Boston, MA	289,800	9,500	6,900	22.3	0.30	0.22
Syracuse, NY	148,300	4,700	3,500	24.4	0.30	0.22
Oakland, CA	145,800	NA	NA	21.0	NA	NA
Jersey City, NJ	19,300	800	600	11.5	0.18	0.13

NA = not analyzed

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[15] Three cities did not have net estimates.

Table 7-38: Tier 1 Quantitative Uncertainty Estimates for Net C Flux from Changes in Carbon Stocks in Urban Trees (Tg CO$_2$ Eq. and Percent)

Source	Gas	2004 Flux Estimate (Tg CO$_2$ Eq.)	Uncertainty Range Relative to Emission Estimate			
			(Tg CO$_2$ Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Changes in C Stocks in Urban Trees	CO$_2$	(88.0)	(120.5)	(55.5)	-37%	+37%

Note: Parentheses indicate negative values or net sequestration.

There is additional uncertainty associated with the biomass equations, conversion factors, and decomposition assumptions used to calculate carbon sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil carbon stocks, and there may be some overlap between the urban tree carbon estimates and the forest tree carbon estimates. However, both the omission of urban soil carbon flux and the potential overlap with forest carbon are believed to be relatively minor (Nowak 2002). Because these are inestimable, they are not quantified as part of this analysis.

The results of the Tier 1 quantitative uncertainty analysis are summarized in Table 7-38. Net C flux from changes in C stocks in urban trees was estimated to be between -120.5 and -55.5 Tg CO$_2$ Eq. at a 95 percent confidence level. This indicates a range of 37 percent above and below the 2004 flux estimate of -88.0 Tg CO$_2$ Eq.

QA/QC and Verification

The net carbon flux resulting from urban trees was calculated using estimates of gross and net carbon 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 the 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 2002).

Recalculations Discussion

New estimates of urban area available in the 2000 U.S. Census have made it possible to develop estimates of net C flux in urban trees over the time series 1990 to 2004. Previous Inventory estimates relied solely on 1990 U.S. Census data, which were applied over the entire time series from 1990 to 2004. The new 2000 estimates were applied to the calculation of net C flux in that year. Additionally, 1990 and 2000 estimates were used as the basis for interpolating and extrapolating, respectively, estimates of urban area in the intervening years (1991 through 1999) and subsequent years (2001 through 2004). New 1990 estimates for urban area were also used in the current Inventory. Estimates used in previous Inventories did not include Alaska and Hawaii. Nowak et al. (in review) provide new 1990 estimates that include Alaska and Hawaii. Net C flux for the entire time series 1990 through 2004 was calculated based on these new estimates of urban area. These changes resulted in a change in emissions estimates for every year except 1990 and 1991. Estimates of net C flux from urban trees changed an average of 21 percent over the period from 1990 to 2003 relative to the previous report.

N$_2$O Fluxes from Soils (IPCC Source Category 5E1)

Of the fertilizers applied to soils in the United States, approximately 10 percent are applied to lawns, golf courses, and other landscaping occurring within settled areas. Application rates are less than those occurring on cropped soils, and, therefore, account for a smaller proportion of

Table 7-39: N$_2$O Fluxes from Soils in Settlements Remaining Settlements (Tg CO$_2$ Eq. and Gg)

Settlements Remaining Settlements: N$_2$O Fluxes from Soils	1990		1998	1999	2000	2001	2002	2003	2004
Tg CO$_2$ Eq.	5.6		6.2	6.2	6.0	5.8	6.0	6.2	6.4
Gg	18		20	20	19	19	19	20	21

total U.S. soil N_2O emissions per unit area. In 2004, N_2O emissions from this source were 6.4 Tg CO_2 Eq. (20.8 Gg). There was an overall increase of 15 percent over the period from 1990 through 2004 due to a general increase in the application of synthetic fertilizers. 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 7-39.

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 applied to turf grass annually through the application of synthetic commercial fertilizers and the amount of N in sewage sludge applied to non-agricultural land and in surface disposal of sewage sludge. Nitrogen applications to turf grass are assumed to be 10 percent of the total synthetic fertilizer used in the United States (Qian 2004). Total synthetic fertilizer applications were derived from fertilizer statistics (TVA 1991, 1992, 1993, 1994; AAPFCO 1995, 1996, 1997, 1998, 1999, 2000b, 2002, 2003, 2004, 2005) and a recent AAPFCO database (AAPFCO 2000a). Sewage sludge applications were derived from national data on sewage sludge generation, disposition, and nitrogen content (see Annex 3.11 for further detail). The IPCC default volatilization factor for synthetic fertilizer N applied (10 percent) was used to calculate the amount of unvolatilized N applied to turf grass through synthetic fertilizers (IPCC/UNEP/OECD/IEA 1997). The IPCC default volatilization factor for N excreted by livestock (20 percent)

was used to calculate the amount of unvolatilized N applied to non-agricultural land through sewage sludge applications and resulting from surface disposal of sewage sludge (IPCC/UNEP/OECD/IEA 1997).[16] The total amount of unvolatilized N resulting from these sources was multiplied by the IPCC default emission factor (1.25 percent) to estimate direct N_2O emissions. The volatilized and leached/runoff proportion, calculated with the IPCC default volatilization factors (10 or 20 percent, respectively, for synthetic or organic fertilizers) and leaching/runoff factor (30 percent), was 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 sector.

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 carbon 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 used here does not incorporate any of these variables and only accounts for variations in national fertilizer application rates. All settlement soils are treated equivalently under this methodology. Uncertainties exist in both the fertilizer application rates and the emission factors used to derive emission estimates.

The 95 percent confidence interval for the IPCC's default emission factor for synthetic fertilizer applied to soil ranges from 0.25 to 6 percent, according to Chapter 4 of IPCC (2000). While a Tier 1 analysis should be generated from a symmetrical distribution of uncertainty around the emission factor, an asymmetrical distribution was imposed here to account for the fact that the emission factor used

Table 7-40: Tier 1 Quantitative Uncertainty Estimates of N_2O Emissions from Soils in Settlements Remaining Settlements (Tg CO_2 Eq. and Percent)

Source	Gas	2004 Flux Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate			
			(Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Settlements Remaining Settlements: N_2O Fluxes from Soils	N_2O	6.5	0.4	37.6	-94%	+483%

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[16] Although the IPCC default factor of 20 percent is for the application of livestock manure, it is assumed to be a more accurate representation of volatilization for organic N additions when compared to the volatilization factor for synthetic N additions.

was not the mean of the range given by IPCC. Therefore, an upper bound of 480 percent and a lower bound of 80 percent were assigned to the emission factor. The uncertainty in the amount of synthetic fertilizer N applied to settlement soils was conservatively estimated to be 50 percent (Qian 2004). The results of the Tier 1 quantitative uncertainty analysis are summarized in Table 7-40. N_2O emissions from soils in Settlements Remaining Settlements in 2004 were estimated to be between 0.4 and 37.6 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 94 percent below to 483 percent above the 2004 emission estimate of 6.5 Tg CO_2 Eq.

Recalculations Discussion

The 2003 data were updated from the AAPFCO *Commercial Fertilizers 2004* report (2005). This change resulted in a one percent decrease in the emissions estimates for that year. The inclusion of N in sewage sludge applied to non-agricultural land and surface disposal of sewage sludge is new to the current Inventory. These changes resulted in an average change of about 1 percent over the period from 1990 to 2003.

Planned Improvements

The indirect N_2O emissions from fertilization of settlements, which are currently reported in the Agriculture chapter, will be reported here. In addition, the process-based model DAYCENT, which was used to estimate N_2O emissions from cropped soils this year, could also be used to simulate direct emissions as well as volatilization and leaching/runoff from settlements. DAYCENT has been parameterized to simulate turf grass. State-level settlement area data is available from the National Resource Inventory.

7.8. 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 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.

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