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INVENTORY OF GREENHOUSE GAS EMISSIONS AND SINKS:

1990-2003

APRIL 15, 2005

U.S. Environmental Protection Agency

1200 Pennsylvania Ave., N.W.

Washington, DC 20460

U.S.A.

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All data tables of this document are available for the full time series 1990 through 2003, inclusive, at the internet site mentioned above.

FOR FURTHER INFORMATION

Contact Mr. Leif Hockstad, Environmental Protection Agency, (202) 343-9432, hockstad.leif@epa.gov.

Or Ms. Lisa Hanle, Environmental Protection Agency, (202) 343-9434, hanle.lisa@epa.gov.

For more information regarding climate change and greenhouse gas emissions, see the EPA web site at <http://www.epa.gov/globalwarming>.

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Preface

The United States Environmental Protection Agency (EPA) prepares the official *U.S. Inventory of Greenhouse Gas Emissions and Sinks* to comply with existing commitments under the United Nations Framework Convention on Climate Change (UNFCCC).[1] Under decision 3/CP.5 of the UNFCCC Conference of the Parties, national inventories for UNFCCC Annex I parties should be provided to the UNFCCC Secretariat each year by April 15.

In an effort to engage the public and researchers across the country, the EPA has instituted an annual public review and comment process for this document. The availability of the draft document is announced via Federal Register Notice and is posted on the EPA web site.[2] Copies are also mailed upon request. The public comment period is generally limited to 30 days; however, comments received after the closure of the public comment period are accepted and considered for the next edition of this annual report.

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[1] See Article 4(1)(a) of the United Nations Framework Convention on Climate Change <http://www.unfccc.int>.

[2] See <http://www.epa.gov/globalwarming/publications/emissions>.

7. Land-Use Change and Forestry

This chapter provides an assessment of the net greenhouse gas flux[1] resulting from forest lands, croplands, and settlements. IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) recommends reporting fluxes according to changes within and conversions between these land use types, as well as grassland and wetlands. However, consistent datasets are not available for the entire United States to allow results to be partitioned in this way. Therefore, greenhouse gas flux has been estimated for the following categories: 1) forest land remaining forest land 2) croplands remaining croplands, and 3) settlements remaining settlements. This categorization provides additional sources of information regarding N_2O emissions by major land use type.

It should be noted that other land-use and land-use change activities result in fluxes of non-CO_2 greenhouse gases to and from soils that are not comprehensively accounted for currently. These fluxes include emissions of CH_4 from managed forest soils, as well as CH_4 emissions from artificially flooded lands, which result from activities such as dam construction. Aerobic (i.e., non-flooded) soils are a sink for CH_4, so soil drainage can result in soils changing from a CH_4 source to a CH_4 sink, but if the drained soils are used for agriculture, fertilization and tillage disturbance can reduce the ability of soils to oxidize CH_4. The non-CO_2 emissions and sinks from these other land use and land-use change activities were not assessed due to scientific uncertainties about the greenhouse gas fluxes that result from these activities.

The greenhouse gas flux from forest land remaining forest land is reported using estimates of changes in forest carbon stocks and the application of nitrous oxide (N_2O) fertilizers to forest soils. Seven components of forest carbon stocks are analyzed: aboveground biomass, belowground biomass, dead wood, litter, soil organic carbon, harvested wood products in use, and harvested wood products in landfills. The estimated carbon dioxide (CO_2) flux from each of these forest components was derived from U.S. forest inventory data, using methodologies that are consistent with *LULUCF Good Practice Guidance* (IPCC 2003) and the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). In addition, this year, according to the new *LULUCF Good Practice Guidance* (IPCC 2003), N_2O emissions from fertilized forest soils are accounted for utilizing a default methodology.

Croplands remaining croplands emission estimates are a reflection of the changes in agricultural soil carbon stocks on both cropland and grazing land since the necessary datasets were not available to separate cropland and grassland fluxes. Changes in agricultural soil carbon stocks include mineral and organic soil carbon stock changes due to use and management of cropland and grazing land, and emissions of CO_2 due to the application of crushed limestone and dolomite to agricultural soils (i.e., soil liming). The methods used to estimate all three components of flux in agricultural soil carbon stocks are consistent with the *Revised 1996 IPCC Guidelines* and the *LULUCF Good Practice Guidance (IPCC 2003).*

Fluxes resulting from settlements remaining settlements include landfilled yard trimmings and food scraps, urban trees, and soil N_2O emissions from fertilization. Changes in yard trimming and food scrap carbon stocks in landfills are estimated using analysis of life-cycle greenhouse gas emissions and sinks associated with solid waste management (EPA 1998). Changes in carbon stocks in urban trees are estimated based on field measurements in ten U.S. cities and data on national urban tree cover, using a methodology consistent with the *LULUCF Good Practice Guidance* (IPCC 2003). Finally, this year, according to the new *LULUCF Good Practice Guidance* (IPCC 2003), N_2O emissions from fertilized settlement soils are accounted for according to a default methodology. Note that the chapter title “Land-Use Change and Forestry” has been used here to maintain consistency with the IPCC reporting structure for national greenhouse gas inventories; however, the chapter covers land-use activities, in addition to land-use change and forestry activities. Therefore, except in table titles, the term “land use, land-use change, and forestry” will be used in the remainder of this chapter.

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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.”

Unlike the assessments in other sectors, which are based on annual activity data, the flux estimates in this chapter, with the exception of those from wood products, urban trees, liming, and settlement and forest N_2O emissions, are based on periodic activity data 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. Because state surveys are collected at different times, using this data structure, the estimated CO_2 fluxes from forest carbon stocks differ at the national level from year to year. Agricultural soil carbon flux calculations are constant over multi-year intervals, with large discontinuities between intervals; however, fluxes after 1997 are inconsistent due to the method of accounting for the application of manure and sewage sludge amendments to mineral soils after 1997. 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 2003, the estimates of CO_2 flux from forests, agricultural soils, and landfilled yard trimmings and food scraps are based in part on modeled projections or extrapolation. Carbon dioxide flux from urban trees is based on neither annual data nor periodic survey data, but instead on data collected over the period 1990 through 1999. This flux has been applied to the entire time series.

Land use, land-use change, and forestry activities in 2003 resulted in a net carbon sequestration of 828 Tg CO_2 Eq. (226 Tg C) (Table 7-1and Table 7-2). This represents an offset of approximately 14 percent of total U.S. CO_2 emissions. Total land use, land-use change, and forestry net carbon sequestration declined by approximately 21 percent between 1990 and 2003. This decline was primarily due to a decline in the rate of net carbon accumulation in forest carbon stocks. Annual carbon accumulation in landfilled yard trimmings and food scraps also slowed over this period, as did annual carbon accumulation in agricultural soils. As described above, the constant rate of carbon accumulation in urban trees is a reflection of limited underlying data (i.e., this rate represents an average for 1990 through 1999).

Table 7-1: Net CO_2 Flux from Land-Use Change and Forestry (Tg CO_2 Eq.)

Sink Category	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Forest Land Remaining Forest Land	**(949.3)**	**(851.0)**	**(805.5)**	**(751.7)**	**(747.9)**	**(750.9)**	**(751.5)**	**(752.7)**
Changes in Forest Carbon Stocks	(949.3)	(851.0)	(805.5)	(751.7)	(747.9)	(750.9)	(751.5)	(752.7)
Cropland Remaining Cropland	**(8.1)**	**(7.4)**	**(4.3)**	**(4.3)**	**(5.7)**	**(7.1)**	**(6.2)**	**(6.6)**
Changes in Agricultural Soil Carbon Stocks	(8.1)	(7.4)	(4.3)	(4.3)	(5.7)	(7.1)	(6.2)	(6.6)
Settlements Remaining Settlements	**(84.7)**	**(71.6)**	**(71.2)**	**(70.0)**	**(68.9)**	**(68.9)**	**(68.8)**	**(68.7)**
Urban Trees	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)
Landfilled Yard Trimmings and Food Scraps	(26.0)	(12.9)	(12.5)	(11.4)	(10.2)	(10.3)	(10.2)	(10.1)
Total	**(1042.0)**	**(930.0)**	**(881.0)**	**(826.1)**	**(822.4)**	**(826.9)**	**(826.5)**	**(828.0)**

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

Table 7-2: Net CO_2 Flux from Land-Use Change and Forestry (Tg C)

Sink Category	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Forest Land Remaining Forest Land	**(259)**	**(232)**	**(220)**	**(205)**	**(204)**	**(205)**	**(205)**	**(205)**
Changes in Forest Carbon Stocks	(259)	(232)	(220)	(205)	(204)	(205)	(205)	(205)
Cropland Remaining Cropland	**(2)**	**(2)**	**(1)**	**(1)**	**(2)**	**(2)**	**(2)**	**(2)**
Changes in Agricultural Soil Carbon Stocks	(2)	(2)	(1)	(1)	(2)	(2)	(2)	(2)
Settlements Remaining Settlements	**(23)**	**(20)**	**(19)**	**(19)**	**(19)**	**(19)**	**(19)**	**(19)**
Urban Trees	(16)	(16)	(16)	(16)	(16)	(16)	(16)	(16)
Landfilled Yard Trimmings and Food Scraps	(7)	(4)	(3)	(3)	(3)	(3)	(3)	(3)
Total	**(284)**	**(254)**	**(240)**	**(225)**	**(224)**	**(226)**	**(225)**	**(226)**

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

Land use, land-use change, and forestry activities in 2003 resulted in a net flux of 6.4 Tg CO_2 Eq. of N_2O (20.7 Gg) (Table 7-3 and Table 7-4). Total N_2O emissions from the application of fertilizers to forests and settlements increased by approximately 14 percent between 1990 and 2003.

Table 7-3: Net N_2O Emissions from Land-Use Change and Forestry (Tg CO_2 Eq.)

Sink Category	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Forest Land Remaining Forest Land	**0.1**	**0.3**	**0.4**	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**
N_2O Fluxes from Soils	0.1	0.3	0.4	0.5	0.4	0.4	0.4	0.4
Settlements Remaining Settlements	**5.5**	**6.1**	**6.1**	**6.2**	**6.0**	**5.8**	**6.0**	**6.0**
N_2O Fluxes from Soils	5.5	6.1	6.1	6.2	6.0	5.8	6.0	6.0
Total	**5.6**	**6.4**	**6.5**	**6.6**	**6.3**	**6.2**	**6.4**	**6.4**

Note: Totals may not sum due to independent rounding.

Table 7-4: Net N_2O Emissions from Land-Use Change and Forestry (Gg)

Sink Category	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Forest Land Remaining Forest Land	**0.2**	**1.0**	**1.1**	**1.5**	**1.1**	**1.3**	**1.3**	**1.3**
N_2O Fluxes from Soils	0.2	1.0	1.1	1.5	1.1	1.3	1.3	1.3
Settlements Remaining Settlements	**17.9**	**19.8**	**19.8**	**19.9**	**19.3**	**18.7**	**19.4**	**19.4**
N_2O Fluxes from Soils	17.9	19.8	19.8	19.9	19.3	18.7	19.4	19.4
Total	**18.1**	**20.7**	**20.9**	**21.4**	**20.4**	**20.0**	**20.7**	**20.7**

Note: Totals may not sum due to independent rounding.

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, all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. This category includes live understory.
- Belowground biomass, all living biomass of coarse living roots greater than 2 mm diameter.
- Dead wood, including all non-living woody biomass either standing, lying on the ground (but not including litter), or in the soil.
- Litter, including 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 above 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 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 landfill.

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 *LULUCF Good Practice Guidance* (IPCC 2003) recommends reporting C stocks according to several land use types and conversions, specifically forest land remaining forest land, nonforest land becoming forest, and forest becoming non-forest. Currently, consistent datasets are not available for the entire United States to allow results to be partitioned in this way. Instead, net changes in all forest-related land, including non-forest land converted to forest and forests converted to non-forest are reported here.

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

Figure 7-1: 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.

Approximately 33 percent (303 million hectares) of the U.S. land area is forested (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 lands 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

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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 about 50 percent carbon by weight.

through 2003. 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 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 832 Tg CO$_2$ Eq. (227 Tg C) over the period 1990 through 2003 (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 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 21 percent between 1990 and 2003. This decline was primarily due to a decline in the estimated rate of sequestration in forest soils. Inventory derived estimates of soil C stocks are based solely on forest area and type. Thus, changes in soil C over time are directly the result of changes in total forest area or changes in forest type from forest inventory data.

Table 7-5. Net Annual Changes in Carbon Stocks (Tg CO$_2$ Eq. yr^{-1}) in Forest and Harvested Wood Pools

Carbon Pool	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Forest	**(739)**	**(638)**	**(599)**	**(537)**	**(537)**	**(537)**	**(537)**	**(537)**
Aboveground Biomass	(396)	(457)	(437)	(400)	(400)	(400)	(400)	(400)
Belowground Biomass	(77)	(89)	(85)	(78)	(78)	(78)	(78)	(78)
Dead Wood	(74)	(53)	(51)	(45)	(45)	(45)	(45)	(45)
Litter	(67)	(31)	(28)	(26)	(26)	(26)	(26)	(26)
Soil Organic Carbon	(125)	(8)	1	12	12	12	12	12
Harvested Wood	**(210)**	**(213)**	**(206)**	**(215)**	**(211)**	**(214)**	**(214)**	**(216)**
Wood Products	(48)	(58)	(52)	(62)	(59)	(59)	(59)	(60)
Landfilled Wood	(162)	(155)	(154)	(153)	(152)	(155)	(155)	(155)
Total Net Flux	**(949)**	**(851)**	**(806)**	**(752)**	**(748)**	**(751)**	**(751)**	**(753)**

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^{-1}) in Forest and Harvested Wood Pools

Carbon Pool	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Forest	**(202)**	**(174)**	**(163)**	**(146)**	**(146)**	**(146)**	**(146)**	**(146)**
Aboveground Biomass	(108)	(125)	(119)	(109)	(109)	(109)	(109)	(109)
Belowground Biomass	(21)	(24)	(23)	(21)	(21)	(21)	(21)	(21)
Dead Wood	(20)	(14)	(14)	(12)	(12)	(12)	(12)	(12)
Litter	(18)	(9)	(8)	(7)	(7)	(7)	(7)	(7)

Soil Organic Carbon	(34)	(2)	0	3	3	3	3	3
Harvested Wood	**(57)**	**(58)**	**(56)**	**(59)**	**(57)**	**(58)**	**(58)**	**(59)**
Wood Products	(13)	(16)	(14)	(17)	(16)	(16)	(16)	(16)
Landfilled Wood	(44)	(42)	(42)	(42)	(41)	(42)	(42)	(42)
Total Net Flux	**(259)**	**(232)**	**(220)**	**(205)**	**(204)**	**(205)**	**(205)**	**(205)**

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.

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 the average carbon density in forests by state, estimated for 2004.

Table 7-7. Carbon Stocks (Tg C) in Forest and Harvested Wood Pools

Carbon Pool	**1990**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Forest	**39,498**	**40,812**	**40,986**	**41,149**	**41,296**	**41,442**	**41,589**	**41,735**	**41,882**
Aboveground Biomass	14,114	14,928	15,053	15,172	15,281	15,390	15,499	15,608	15,717
Belowground Biomass	2,805	2,963	2,987	3,011	3,032	3,053	3,074	3,095	3,117
Dead Wood	2,444	2,572	2,587	2,600	2,613	2,625	2,638	2,650	2,662
Litter	4,496	4,598	4,606	4,614	4,621	4,628	4,636	4,643	4,650
Soil Organic Carbon	15,640	15,750	15,752	15,752	15,749	15,745	15,742	15,738	15,735
Harvested Wood	**1,915**	**2,307**	**2,365**	**2,421**	**2,480**	**2,537**	**2,595**	**2,654**	**2,713**
Wood Products	1,134	1,232	1,248	1,262	1,279	1,295	1,311	1,327	1,344
Landfilled Wood	781	1,074	1,117	1,159	1,200	1,242	1,284	1,327	1,369
Total Carbon Stock	**41,414**	**43,119**	**43,351**	**43,570**	**43,775**	**43,979**	**44,184**	**44,389**	**44,594**

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 2003 requires estimates of C stocks for 2003 and 2004.

Figure 7-2: Estimates of Net Annual Changes in Carbon Stocks for Major Carbon Pools (Tg C yr^{-1})

Note: Estimates for harvested wood are based on the same methodology and data as the previous U.S. Inventory (EPA 2004). Estimates for all pools are based on measured forest inventory data as described in the text. Total Net includes all forest pools: biomass, dead wood, litter, forest soils, wood products, and landfilled wood.

Figure 7-3: Average Carbon Density in the Forest Tree Pool in the Conterminous U.S. During 2004.

Methodology

The methodology described herein is consistent with *LULUCF Good Practice Guidance* (IPCC 2003) and the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). Estimates of net C flux from Land-Use Change and Forestry, including all pools except harvested wood, 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] 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 inventory 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]). However, over time individual state surveys gradually started to include reserved and less productive forest lands. 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 (Miles et al. 2001, Alerich et al. 2004), 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 each 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 design for all forestlands, including reserved and less productive lands. Inventories are assumed to represent stocks as of January 1 of the inventory year.

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 volume-to-biomass conversion factors for different types of forests as presented in 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).

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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).

[4] Forest land in the U.S. 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 U.S., which represented 79 percent of all forest lands over the same area (Smith et al. 2004b).

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 lands 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. Thus, the number of separate stock estimates for each state was one less than the number of available inventories. 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. Note that inventories are assumed to represent stocks as of January 1 of the inventory year; thus, stocks in 1989 and 1993 can be used to estimate flux for 1989 through 1992, for example. 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) and 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 2003, 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 of forest land (Miles et al. 2001). For larger areas, the uncertainty in area is concomitantly smaller. For volume data, the accuracy is targeted to be 5 percent for each 28,300 m^3 at the same confidence level. An analysis of uncertainty in growing stock volume data for timber producing lands was undertaken for five states: Florida, Georgia, North Carolina, South Carolina, and Virginia (Phillips et al. 2000). Nearly all of the uncertainty was found to be 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). Based on these accuracy guidelines and these results for the Southeastern United States, forest area and volume data for the conterminous United States are expected to be reasonably accurate, although estimates of small changes in growing stock volume may have substantial uncertainty.

In addition to uncertainty in growing stock volume, there is uncertainty associated with the estimates of C stocks in other ecosystem pools. 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, for example 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 (2000b) 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).

Recent studies have begun to quantify the uncertainty in national-level forest C budgets based on the methods adopted here. Smith and Heath (2000) and Heath and Smith (2000a) report on an uncertainty analysis they conducted on C sequestration in privately owned timberlands throughout the conterminous United States. These studies are not directly comparable to the estimates in this chapter because they used an older version of the FORCARB model and are based on older data. However, the relative magnitudes of the uncertainties are informative. For the period 1990 through 1999, the true mean C flux was estimated to be within 15 percent of the reported mean at the 80 percent confidence level. The corresponding true mean C stock estimate for 2000 was within approximately 5 percent of the reported mean value at the 80 percent confidence level. The relatively greater uncertainty in flux estimates compared to stock estimates is roughly similar to that found for estimates of growing stock volume discussed above (Phillips et al. 2000). In both analyses, there are greater relative uncertainties associated with smaller estimates of flux. Uncertainty in the estimates presented in this inventory may be greater than those presented by Heath and Smith (2000a) for several reasons. Most importantly, their analysis did not include uncertainty in growing stock volume data or uncertainties in stocks and fluxes of C from harvested wood.

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 2003 flux estimate for forest C stocks is estimated to be between (1,120.5) and (383.5) Tg CO_2 Eq. at a 95 percent confidence level (or 19 of 20 Monte Carlo Stochastic Simulations). This indicates a range of 49 percent below to 49 percent above the 2003 flux estimate of (752.7) Tg CO_2 Eq.

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

Source	**Gas**	**2003 Flux Estimate (Tg CO_2 Eq.)**	**Uncertainty Range Relative to 2003 Estimate[a]**			
			(Tg CO_2 Eq.)		**(%)**	
			Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Forests Remaining Forests: Changes in Forest Carbon Stocks	CO_2	(752.7)	(1,120.5)	(383.5)	-49%	+49%

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

QA/QC and Verification

As discussed above, the USDA Forest Service Forest Inventory and Analysis 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 Forest Inventory and Analysis 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 Forest Inventory and Analysis 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 Homepage).

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 Methods 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 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. Forest Inventory and Analysis data and some model projections are given in English units, but C stock estimates were developed using metric units. To avoid unit conversion errors, a standard conversion table in electronic form was used (Appendix B of Smith et al. 2001). Finally, C stock estimates were compared with previous inventory report estimates to assure 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 2003). Methods for estimating soil organic carbon are new for the current Inventory; differences are in the interpretation of STATSGO data and their relationship with FIA survey data as described by Amichev and Galbraith (2004)—see Annex 3.12 for additional information. Similar to that reported in the previous Inventory, estimates of forest C stocks and fluxes are based on forest inventory data from individual states rather than regions, and the data collected in states were assigned an average survey inventory plot date rather than simply assigned the year for which the database was compiled. However, the selection and compilation of survey data was implemented differently for the current Inventory, and there were some important differences in the underlying data.

Three differences in methods can affect the non-soil forest C estimates. First, the selection of the datasets representing individual state surveys was independent of last year’s selections. Both RPA and the newer FIADB datasets were considered, whereas last year only RPA data were used. The RPA data represent specific compilations of survey data and include some older data not currently available in the FIADB. Using both ensured the most recent data were used, yet older data were available as needed. Inventory data—even older surveys—are occasionally modified so that RPA and FIADB data of ostensibly the same survey may have some slight differences that can affect the C estimates. This is likely to have a very minor effect on recalculation of C stocks. Another minor change in method is that fluxes were separately determined from the original survey data for each state for each pool; in contrast, last year stocks were interpolated and summed to a national total for each year before flux was calculated. Finally, separate stocks and fluxes were determined for National Forest lands where, in the past, independent surveys were conducted at distinctly different times.

Pool definitions have changed for the current Inventory, as suggested by IPCC *LULUCF Good Practice Guidance* (IPCC 2003). In previous Inventories, the pools were trees, understory, forest floor, down dead wood, and forest soils. The forest soil pool is now soil organic carbon; forest floor is called litter. The previous tree pool included both above- and belowground biomass and mass of standing dead trees. The mass of standing dead trees was added to the down dead wood pool and is called dead wood. The remainder of the tree pool, live biomass, as well as the understory pool, was split into above- and belowground portions. The aboveground tree and understory pools were summed into the aboveground biomass pool; the belowground portions of these pools were added to create the belowground biomass pools.

Two changes in the use of data are also likely to affect the recalculation of C. The equations used to estimate tree C from forest inventory data have been revised slightly; the net effect is that total tree C (live plus standing dead trees, which are part of both the biomass and dead wood pools as summarized here) calculated for the 2002 RPA database (Smith et al. 2004b) was 0.3 percent greater with the new set of equations relative to those used last year. Perhaps the largest effect on C recalculations is that for the previous Inventory the final C stocks were modeled. This year, however, values are simply extrapolated. The principal reason for eliminating the projections was the difficulty in establishing projections consistent with the available forest inventory data.

Overall, these changes resulted in an average annual increase of 103.3 Tg CO_2 Eq. (16 percent) in forest carbon stocks for the period 1990 through 2002.

Planned Improvements

The Forest Inventory and Analysis program has adopted a new annualized design, such that a portion of each state will be surveyed each year (Gillespie 1999). The annualized survey also includes measuring attributes that are needed to estimate C in various pools, such as soil C and forest floor C, on a subset of the plots. During the next several years, the use of annual data, including new data on soil and forest floor C stocks, and new data on non-timberlands, will improve the precision and accuracy of estimates of forest C stocks and fluxes.

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.

N_2O Fluxes from Soils (IPCC Source Category 5.A.1)

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_2O) emissions from forest soils for 2003 were almost 7 times higher than the baseline year (1990). The trend toward increasing N_2O emissions is a result of an increase in fertilized area of pine plantations in the southeastern United States. Total 2003 forest soil N_2O emissions are roughly equivalent to 3.3 percent of the total forest soil carbon flux, and 0.07 percent of the total sequestration in standing forests, and are summarized in Table 7-9.

Table 7-9. N_2O Fluxes from Soils in Forests Remaining Forests (Tg CO_2 Eq. and Gg)

Forests Remaining Forests: N_2O Fluxes	**1990**		**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**

from Soils									
Tg CO_2 Eq.	0.06		0.30	0.35	0.47	0.35	0.39	0.39	0.39
Gg	0.19		0.96	1.14	1.50	1.14	1.26	1.26	1.26

Methodology

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_2O emissions from fertilizer applications to forests were based on the area of pine plantations receiving fertilizer in the southeastern United States and estimated application rates (North Carolina Sate Forest Nutrition Cooperative 2002). Not accounting for fertilizer applied to non-pine plantations is justified because fertilization is routine for pine forests but rare for hardwoods (Binkley et al. 1995). For each year, the area of pine receiving N fertilizer was multiplied by the midpoint of the reported range of N fertilization rates (150 lbs. N per acre). Data for areas of forests receiving fertilizer outside the southeastern United States were not available, so N additions to non-southeastern forests are not included here; 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 and 2003, 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 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 2003 emission estimate of 0.4 Tg CO_2 Eq.

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

IPCC Source Category	Gas	Year 2003 Emissions (Tg CO_2 Eq.)	Uncertainty (%)	Uncertainty Range Relative to 2003 Emission Estimate (Tg CO_2 Eq.)

				Lower Bound	**Upper Bound**
Forests Remaining Forests: N_2O Fluxes from Soils	N_2O	0.4	96 to 483%	0.01	2.3

Recalculations Discussion

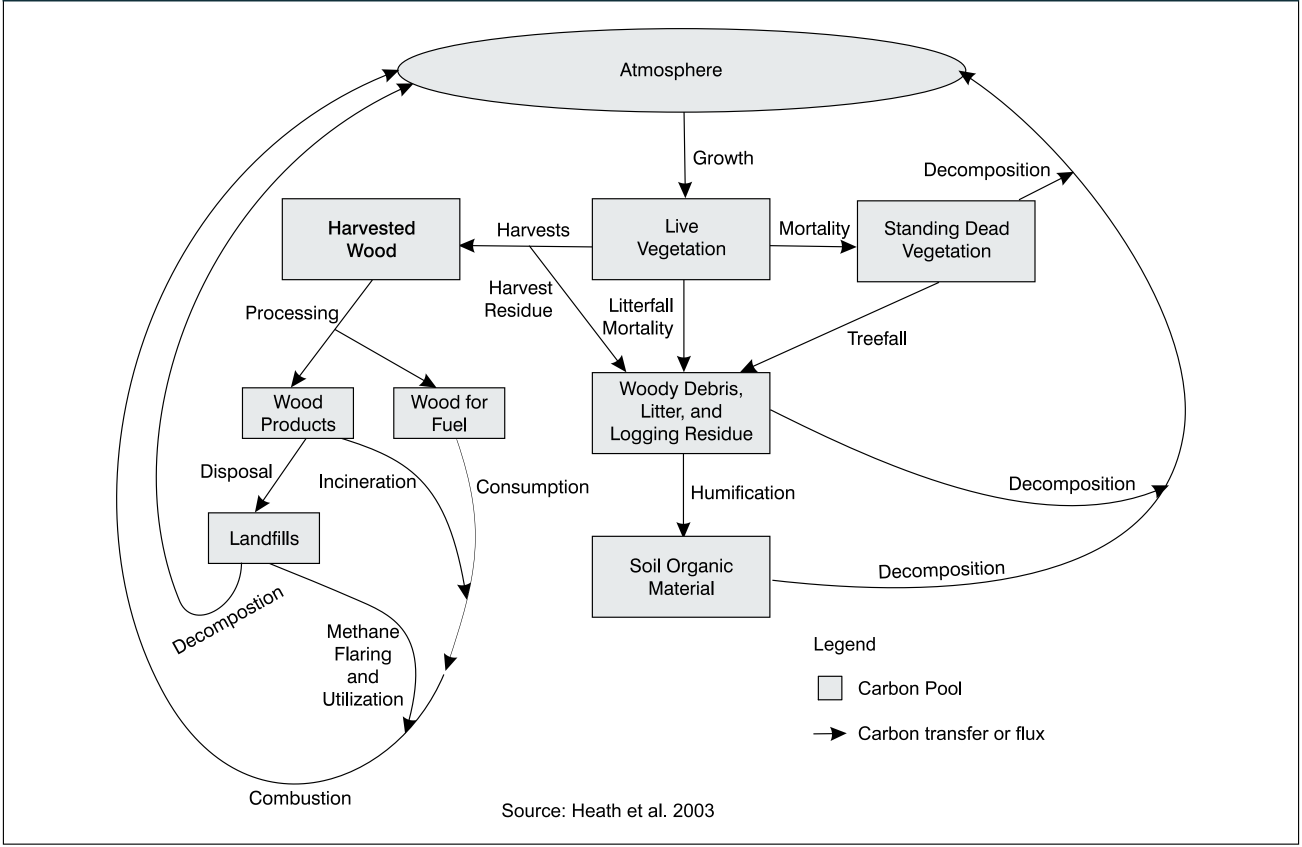
The current Inventory reports N_2O emissions from soils in forested areas separately for the first time. In previous Inventories, N_2O emissions from this source were implicitly included with N_2O emissions from agricultural soils. The net effect of separating forest soils from agricultural soils for the current Inventory is to reduce emissions reported from the agricultural sector by a very small amount. However, because the methods for reporting that source have changed significantly this year, it is impossible to isolate the magnitude of change caused by this recalculation alone on the overall differences in N_2O emissions from agricultural soils. The 2003 direct emission estimate for N_2O from forest soils amounts to an offset of total forest carbon sequestration of approximately 0.5 percent (including standing forests and wood products).

7.2. Land Converted to Forest Land (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 lands are 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 quantify CO_2 or N_2O fluxes from land converted to forest land at this time.

Figure 7-1

Forest Sector Carbon Pools and Flows



Source: Heath et al. 2003

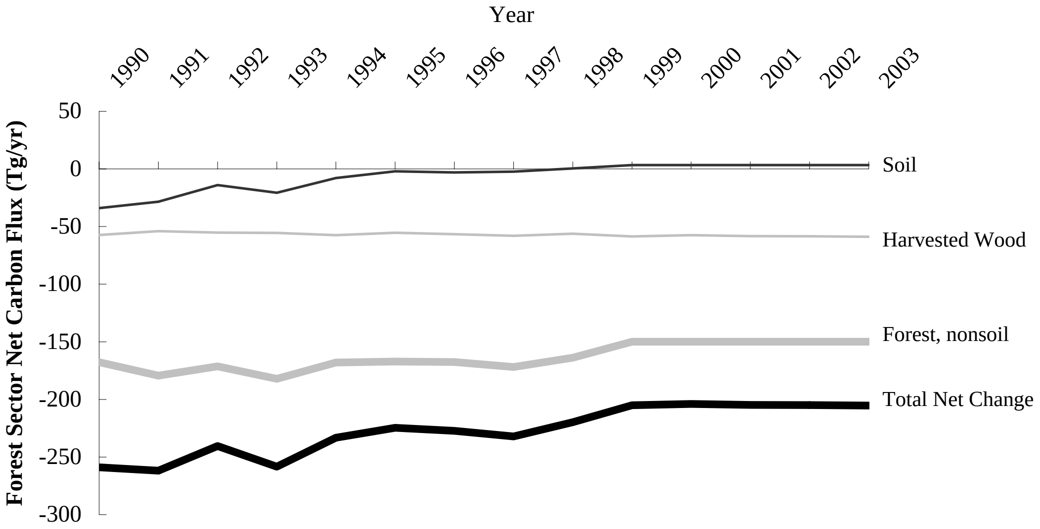
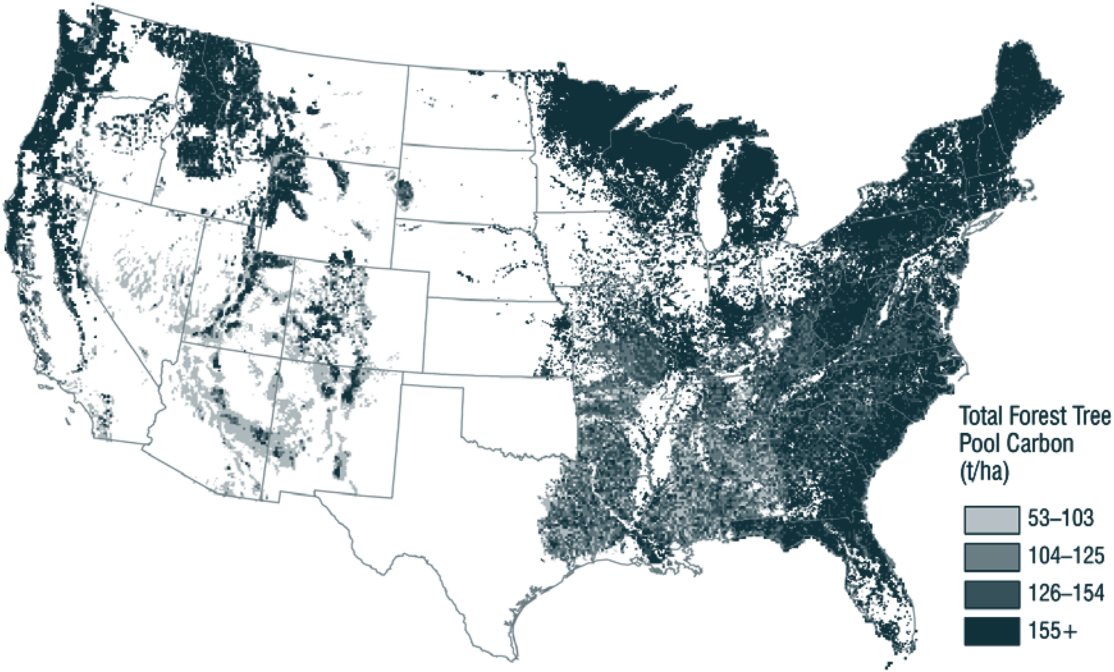


Figure 7-2: Estimates of Net Annual Changes in Carbon Stocks for Major Carbon Pools

Figure 7-3

Average Carbon Density in the Forest Tree Pool in the Conterminous U.S. During 2004



Note: Estimates are based on forest inventory data as described in the text.

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3.12. Methodology for Estimating Net Carbon Stock Changes in Forest Lands Remaining Forest Lands

This annex expands on the methodology used to calculate net changes in carbon (C) stocks in forest ecosystems and in harvested wood products. Some of the details of C conversion factors and procedures for calculating net CO_2 flux for forests are provided below; more detailed descriptions of selected topics may be found in the cited references.

Carbon Stocks and Net Changes in Forest Ecosystem Carbon Stocks

C stocks were estimated at the inventory plot level for each C pool within each state in the conterminous U.S. based on availability of inventory data. Forest survey data in the United States were obtained from USDA Forest Service, Forest Inventory and Analysis (FIA) Resources Planning Act Assessment (RPA) databases or the individual state surveys in the FIADB, version 1.7. More complete information about these data is available at an FIA Internet site (<http://ncrs2.fs.fed.us/4801/fiadb/index.htm>). All FIADB surveys used for C stock estimates were obtained from this site on or before August 10, 2004.

The first step in developing C estimates was to identify separate inventory surveys for each state and associate each with an average year for field collection of data. Most inventory databases provide the year in which the data were collected. If data were collected over a number of years, an average value is assigned. A few surveys had missing or incorrect values for year of field data; in some cases it was possible to obtain this information from the regional FIA units, otherwise the year was inferred from other data. Some overlap exists between the RPA and FIADB inventories because the RPA summaries were compiled from the FIADB. Such overlaps are identified and adjusted to avoid duplication. Older surveys for some states, particularly in the West, have National Forest System lands surveyed at different times than other forestlands in the state. For this reason, C stocks for National Forests were separately estimated from other forests to account for differences in average year. The inventories used for each state as well as average year identified for each are provided in Table 3-111.

For each inventory summary 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). Coefficients of the model are applied to the survey data at the scale of the FIA inventory plots; the results are estimates of C density (Mg per hectare) for a number of separate C pools. C stocks and fluxes for Forests Remaining Forests are reported in pools following IPCC LULUCF *Good Practice Guidance* (2003). FORCARB2 estimates C density for live trees, standing dead trees, understory vegetation, down dead wood, forest floor, and soil organic matter. All non-soil pools except forest floor can be separated into aboveground and belowground components. FORCARB2's live tree and understory C pools are pooled as biomass in this Inventory. Similarly, standing dead trees and down dead wood are pooled as dead wood in this Inventory. Definitions of forest floor and soil organic matter in FORCARB2 correspond to litter and forest soils, respectively in IPCC LULUCF Good Practice Guidance (2003).

The tree C pools in FORCARB2 include aboveground and belowground (coarse root) C mass of live trees. Separate estimates are made for whole-tree and aboveground-only biomass. Thus, the belowground portion is determined as the difference between the two estimates. Tree C estimates are based on Smith et al. (2003) and are functions of plot level growing stock volume of live trees, forest type, and region. C mass of wood is approximately 50 percent of dry weight (IPCC/UNEP/OECD/IEA 1997). The minimum-sized tree included in FIA data is one-inch diameter (2.54 cm) at diameter breast height (1.3 meter); this represents the minimum size included in the tree C pools.

A second, but minor, component of biomass is understory vegetation. Understory vegetation is defined in FORCARB2 as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than one-inch diameter, measured at breast height. In this Inventory, it is assumed that 10 percent of understory C mass is belowground. This general root-to-shoot ratio (0.11) is near the lower range of temperate forest values provided in IPCC LULUCF Good Practice Guidance (2003) and was selected based on two general assumptions: ratios are likely to be lower for light-limited understory vegetation as compared with larger trees, and a greater proportion of all root mass will be less than 2 mm diameter. C density estimates are based on Birdsey (1996) and were applied at the inventory plot level (Smith et al. 2004a).

Dead wood includes the FORCARB2 pools of down dead wood and standing dead trees. Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter, at transect intersection, that are not attached to live or standing dead trees. Down dead wood includes stumps and roots of harvested trees. Ratio estimates of down dead wood to live tree biomass were developed by FORCARB2 simulations and applied at the plot level (Smith et al. 2004a). The standing dead tree C pools in FORCARB2 include aboveground and belowground (coarse root) mass. Again, separate estimates are made for whole-trees and aboveground-only portions so belowground mass is based on the difference between the two estimates. Estimates are based on Smith et al. (2003) and are functions of plot level growing stock volume of live trees, C density of live trees, forest type, and region

Estimates of litter and soil organic carbon (SOC) are not based on C density of trees. Litter C is the pool of organic C (litter, duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on equations of Smith and Heath (2002) and applied at the plot level. Estimates of SOC are based on the national STATSGO spatial database (USDA 1991). Soil C estimates provided with the 2003 Inventory (EPA 2003) were also based on STATSGO data, but the current methods differ from previous summaries. Estimates presented here are based on the general approach described by Amichev and Galbraith (2004). In their procedure, SOC was calculated for the conterminous U.S. using the STATSGO database, and data gaps were filled by representative values from similar soils. Links to region and forest type groups were developed with the assistance of the USDA Forest Service FIA Geospatial Service Center by overlaying FIA forest inventory plots on the soil C map.

A historical focus of the FIA program was to provide information on timber resources of the U.S. For this reason, some forest lands, which were less productive or reserved (i.e., land where harvesting was prohibited by law), were less intensively surveyed. This generally meant that forest type and area were identified but measurements were not collected on individual tree measurements. However, all annualized surveys initiated since 1998 have followed a new national plot design for all forestlands (Miles et al. 2001, Alerich et al. unpublished <http://ncrs2.fs.fed.us/4801/fiadb/index.htm>). The practical effect that this evolution in inventories has had on estimating forest C stocks from 1990 through the present is that some older surveys of lands do not have the stand level values for merchantable volume of wood or stand age, which are necessary inputs to FORCARB2. The data gaps present in the surveys collected before 1998 have been filled by assigning regional average C densities calculated from later, complete, inventories. This has had the effect of generating an estimate for C stock with no net change in C density on those lands with gaps in past surveys.

The FORCARB2 C pools were configured to form the IPCC (2003) recommended storage pools. Aboveground portions of live trees and understory vegetation were pooled to form the aboveground biomass pool; similarly, belowground portions were pooled to form belowground biomass. Standing dead trees and down dead wood were pooled to dead wood. The forest floor estimate corresponds to the litter pool. Average C density values for forest ecosystem C pools according to region and forest types within regions are provided in Table 3-112. Note that C densities reflect the surveys included in the 2002 RPA inventory summary, not potential maximum C storage. Thus, C densities are affected by the distribution of stand sizes within a forest type, which can range from regenerating to mature stands. A large proportion of young stands is likely to reduce the regional average for C density in forest types managed for timber production, such as Southern pines.

The overall approach for determining forest C stocks and stock change was to estimate forest C stocks based on data from two forest surveys conducted several years apart (Table 3-111). C stocks were calculated separately for each state based on inventories available since 1990 and for the most recent inventory prior to 1990. Thus, the number of separate stock estimates for each state was one less than the number of available inventories. 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. Summed fluxes and stocks are in Table 3-113 and Table 3-114, respectively.

Carbon in Harvested Wood Products

Estimates of C stock changes in wood products and wood discarded in landfills were based on the methods described by Skog and Nicholson (1998) which were based in turn on earlier efforts using similar approaches (Heath et al. 1996, Row and Phelps, 1996). C stocks in wood products in use and wood products stored in landfills were estimated from 1910 onward based on several sets of historical data from the USDA Forest Service. These data include estimates of wood product demand, trade, and consumption (USDA 1964, Ulrich 1989, Howard 2001). Annual historical estimates and model projections of the production of wood products were used to divide consumed roundwood into wood product, wood mill residue, and pulp mill residue. To estimate the amount of time products remain in use before disposal, wood and paper products were divided into 21 categories, each with an estimated product half-life (Skog and Nicholson 1998). After disposal, the amount of waste that is burned was estimated. For products entering dumps or landfills, the proportion of C emitted as CO_2 or CH_4 was estimated using the estimated maximum proportion of wood and paper converted to CO_2 or CH_4 in landfills for 5 product types. By following the fate of C from the wood harvested in each year from 1910 onward, the change in C stocks in wood products and landfills, and the amount of C emitted to the atmosphere with and without energy recovery were estimated for each year through 2003. 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. From 1990 through 2002, the amount of C in exported wood averaged 6 Tg C per year, with little variation from year to year. For comparison, imports (which were not included in the harvested wood net flux estimates) increased from 7.2 Tg C per year in 1990 to 13 Tg C per year in 2002. Skog and Nicholson (1998) go into further detail in their description of this methodology. Summaries of net fluxes and stocks for harvested wood in products and landfills are in Table 3-113 and Table 3-114.

Table 3-111. Source of Forest Inventory and Average Year of Field Survey Used to Estimate Statewide Carbon Stocks.

State[a]	Source of Inventory Data[b]	Average Year Assigned to Inventory[c]
Alabama	1997 RPA	1990
	FIADB, cycle 7	1999
	FIADB, cycle 4	2002
Arizona, NFS	1987 RPA	1985
	FIADB, cycle 2	1995
	FIADB, cycle 3	2002
Arizona, all other	1997 RPA	1985
	FIADB, cycle 2	1996
	FIADB, cycle 3	2002
Arkansas	1987 RPA	1978
	FIADB, cycle 1	1995
	FIADB, cycle 3	2001
California, NFS	1987 RPA	1980
	1997 RPA	1991
	2002 RPA	1997
California, all other	1987 RPA	1982
	1997 RPA	1994
Colorado, NFS	1997 RPA	1984
	2002 RPA	1990
Colorado, all other[d]	2002 RPA	1982
Connecticut	1997 RPA	1985
	FIADB, cycle 4	1998
Delaware	1997 RPA	1986
	FIADB, cycle 4	1999
Florida	1987 RPA	1987
	1997 RPA	1994
Georgia	1987 RPA	1982
	1997 RPA	1996
Idaho, NFS	1987 RPA	1982
	2002 RPA	1993
Idaho, all other	1987 RPA	1981
	2002 RPA	1990
Illinois	1997 RPA	1985
	FIADB, cycle 4	1997
	FIADB, cycle 5	2002
Indiana	1987 RPA	1987
	FIADB, cycle 4	1997
	FIADB, cycle 5	2000
Iowa	2002 RPA	1989

	FIADB, cycle 4	2001
Kansas	1987 RPA	1987
	FIADB, cycle 4	1994
	FIADB, cycle 5	2002
Kentucky	2002 RPA	1987
	FIADB, cycle 4	2001
Louisiana	1987 RPA	1984
	2002 RPA	1991
	FIADB, cycle 3	2002
Maine	1987 RPA	1983
	FIADB, cycle 4	1995
	FIADB, cycle 5	2000
Maryland	1997 RPA	1986
	FIADB, cycle 5	1999
Massachusetts	1997 RPA	1985
	FIADB, cycle 4	1997
Michigan	1987 RPA	1987
	FIADB, cycle 5	1992
	FIADB, cycle 6	2001
Minnesota	2002 RPA	1989
	FIADB, cycle 12	2000
Mississippi	1987 RPA	1977
	2002 RPA	1993
Missouri	2002 RPA	1988
	FIADB, cycle 5	2001
Montana, NFS	1987 RPA	1987
	2002 RPA	1995
	FIADB, cycle 2	2003
Montana, all other	2002 RPA	1988
	FIADB, cycle 2	2003
Nebraska	1987 RPA	1987
	FIADB, cycle 3	1994
	FIADB, cycle 4	2002
Nevada, NFS	1987 RPA	1984
	2002 RPA	1996
Nevada, all other	1987 RPA	1980
	1997 RPA	1989
New Hampshire	1997 RPA	1983
	FIADB, cycle 5	1996
	FIADB, cycle 6	2003
New Jersey	1997 RPA	1987
	FIADB, cycle 4	1998
New Mexico, NFS	1987 RPA	1985
	FIADB, cycle 2	1997
New Mexico, all other	1997 RPA	1987
	FIADB, cycle 2	1999
New York	1987 RPA	1987
	FIADB, cycle 5	2002
North Carolina	1987 RPA	1984
	1997 RPA	1990
North Dakota	1987 RPA	1987
	FIADB, cycle 3	1994
	FIADB, cycle 4	2001
Ohio	1987 RPA	1987
	FIADB, cycle 5	2001
Oklahoma	1987 RPA	1986
	2002 RPA	1991
Oregon, eastern NFS	1987 RPA	1987
	2002 RPA	1994
	FIADB, cycle 5	2001
Oregon, eastern all other	1987 RPA	1977
	1997 RPA	1992

	FIADB, cycle 5	2001
Oregon, western NFS	1987 RPA	1987
	2002 RPA	1995
	FIADB, cycle 5	2001
Oregon, western all other	1997 RPA	1988
	FIADB, cycle 5	2001
Pennsylvania	2002 RPA	1989
	FIADB, cycle 5	2001
Rhode Island	1997 RPA	1985
	FIADB, cycle 4	1998
South Carolina	1987 RPA	1986
	1997 RPA	1992
	FIADB, cycle 3	2000
South Dakota, NFS	1997 RPA	1985
	2002 RPA	1999
	FIADB, cycle 5	2001
South Dakota, all other	1987 RPA	1985
	FIADB, cycle 4	1995
	FIADB, cycle 5	2002
Tennessee	1997 RPA	1989
	FIADB, cycle 6	1998
	FIADB, cycle 4	2001
Texas	1987 RPA	1985
	2002 RPA	1992
	FIADB, cycle 3	2002
Utah	1987 RPA	1977
	2002 RPA	1993
	FIADB, cycle 2	2001
Vermont	1997 RPA	1983
	FIADB, cycle 5	1997
Virginia	1987 RPA	1986
	1997 RPA	1991
	FIADB, cycle 3	1999
Washington, eastern NFS	1987 RPA	1987
	2002 RPA	1995
	FIADB, cycle 5	2002
Washington, eastern all other	1987 RPA	1980
	2002 RPA	1991
	FIADB, cycle 5	2002
Washington, western NFS	1987 RPA	1987
	2002 RPA	1995
	FIADB, cycle 5	2002
Washington, western all other	2002 RPA	1989
	FIADB, cycle 5	2002
West Virginia	2002 RPA	1988
	FIADB, cycle 5	2000
Wisconsin	1987 RPA	1987
	FIADB, cycle 5	1995
	FIADB, cycle 6	2001
Wyoming, NFS	1997 RPA	1984
	2002 RPA	1997
	FIADB, cycle 2	1999
Wyoming, all other	2002 RPA	1983
	FIADB, cycle 2	2001

[a] Inventories for 11 western states were separated into National Forest System (NFS) and all other forestlands (all other). Oregon and Washington were also divided into eastern and western forests (east or west of the crest of the Cascade Mountains).

[b] FIADB is version 1.7 as available on Internet August 10, 2004.

[c] Rounded to the nearest year

[d] Assume no change in Colorado non-NFS forestland

Table 3-112. Average Carbon Density (Mg/ha) by Carbon Pool and Forest Area (1000 ha) for Forest Types Based on the Inventory in the 2002 RPA Database.

Region (States) Forest Types	Above-ground Biomass	Below-ground Biomass	Dead Wood	Litter	SOC	Forest Area
			Carbon Density (Mg/ha)			(1000 ha)
Northeast						
(CT,DE,MA,MD,ME,NH,NJ,NY,PA,RI,VT,WV)						
White-red-jack pine	69.7	14.3	8.0	13.3	78.1	2,615
Spruce-fir	46.9	9.9	10.9	32.4	98.0	3,373
Loblolly-shortleaf pine	46.3	9.4	5.7	12.5	77.5	591
Oak-pine	66.6	13.1	8.7	27.2	66.9	987
Oak-hickory	71.1	13.5	9.5	7.9	53.1	10,394
Elm-ash-cottonwood	49.8	9.6	7.5	23.7	111.7	1,104
Maple-beech-birch	65.2	12.5	9.9	26.5	69.6	13,477
Aspen-birch	44.6	8.7	6.8	8.9	87.4	1,663
Minor types and nonstocked	51.3	9.8	7.7	6.6	100.2	208
Northern Lake States						
(MI,MN,WI)						
White-red-jack pine	42.1	8.8	6.0	12.0	120.8	1,739
Spruce-fir	37.3	7.9	7.0	31.3	261.8	3,561
Oak-hickory	68.7	13.0	10.5	8.1	97.1	2,479
Elm-ash-cottonwood	47.8	9.2	8.4	24.4	179.9	1,847
Maple-beech-birch	67.5	13.0	10.7	25.9	134.3	5,738
Aspen-birch	43.2	8.3	8.7	8.4	146.1	5,514
Minor types and nonstocked	6.2	1.1	3.7	4.8	206.3	135
Northern Prairie States						
(IA,IL,IN,KS,MO,ND,NE,OH,SD)						
White-red-jack pine	54.3	11.3	8.6	11.6	61.5	75
Loblolly-shortleaf pine	35.6	7.4	5.6	12.0	36.5	325
Ponderosa pine	43.9	9.3	6.8	14.2	48.5	529
Oak-pine	45.7	8.9	6.5	24.5	38.6	586
Oak-hickory	61.7	11.7	8.4	7.6	47.2	8,405
Elm-ash-cottonwood	66.9	12.6	10.4	24.1	84.0	1,675
Maple-beech-birch	54.5	10.3	7.6	24.3	70.7	3,080
Aspen-birch	55.3	10.4	8.9	8.7	71.0	116
Minor types and nonstocked	31.0	5.8	7.4	8.2	65.3	390
South Central						
(AL,AR,KY,LA,MS,OK,TN,TX)						
Longleaf-slash pine	43.5	8.9	5.2	11.2	55.5	1,249
Loblolly-shortleaf pine	44.2	9.0	5.2	10.5	41.9	11,563
Oak-pine	47.3	9.2	6.6	9.3	41.7	7,599
Oak-hickory	54.3	10.2	7.3	5.9	38.6	21,787
Oak-gum-cypress	65.7	12.4	9.3	6.3	52.8	6,835
Elm-ash-cottonwood	59.7	11.3	8.5	5.8	49.9	765
Minor types and nonstocked	33.0	6.1	3.3	6.1	54.7	1,210
Southeast						
(FL,GA,NC,SC,VA)						
White-red-jack pine	78.6	15.8	9.6	12.4	52.4	264
Longleaf-slash pine	35.2	7.2	3.9	9.7	110.0	4,362
Loblolly-shortleaf pine	43.3	8.9	4.8	9.4	72.9	9,427
Oak-pine	48.5	9.5	4.7	9.1	61.4	4,598
Oak-hickory	68.0	12.8	6.3	6.2	45.3	11,081
Oak-gum-cypress	68.2	13.1	7.2	6.4	158.0	5,585
Elm-ash-cottonwood	59.9	11.5	6.5	5.9	95.7	338
Minor types and nonstocked	79.4	15.1	7.4	7.6	76.8	183
Pacific Northwest, Westside						
(Western OR and WA)						
Douglas-fir	122.2	25.5	16.4	31.6	94.8	5,309
Fir-spruce	161.2	34.0	55.7	37.2	62.1	950
Hemlock-Sitka spruce	129.8	27.3	35.6	34.4	116.3	2,292
Hardwoods	93.3	18.2	14.8	8.6	95.7	2,075
Minor types and nonstocked	50.8	10.3	9.5	19.0	65.1	425
Pacific Northwest, Eastside						

(Eastern OR and WA)						
Douglas-fir	72.0	15.0	9.7	36.6	94.8	2,200
Ponderosa pine	41.6	8.7	9.4	23.2	50.7	2,858
Fir-spruce	100.5	21.2	36.5	38.2	62.1	1,361
Hemlock-Sitka spruce	89.0	18.7	25.4	38.9	116.3	624
Larch	85.9	17.9	11.6	36.3	45.1	137
Lodgepole pine	42.2	8.8	9.2	22.6	52.0	1,047
Hardwoods	59.9	11.4	9.4	28.8	68.3	190
Pinyon-juniper	39.4	8.0	4.6	21.1	46.9	1,049
Minor types and nonstocked	34.5	7.0	7.3	25.1	77.0	301
Pacific Southwest						
(CA)						
Douglas-fir	118.1	24.7	14.6	37.3	40.1	366
Ponderosa pine	77.1	15.8	17.8	23.3	41.3	2,823
Fir-spruce	117.0	24.7	43.0	38.6	51.9	870
Lodgepole pine	95.4	19.7	22.2	27.3	35.2	401
Redwood	131.4	27.3	19.0	58.2	53.8	371
Hardwoods	77.7	14.8	11.1	31.0	27.0	6,164
Other softwood types	110.1	22.9	25.7	39.9	49.8	2,432
Pinyon-juniper	41.0	8.2	4.5	21.1	26.3	1,135
Chaparral	60.2	11.3	7.1	17.3	25.6	870
Minor types and nonstocked	29.8	5.9	6.3	19.8	41.6	850
Rocky Mountains, North						
(ID,MT)						
Douglas-fir	70.7	14.9	18.4	36.7	38.8	5,939
Ponderosa pine	39.2	8.2	8.3	22.9	34.3	2,191
Fir-spruce	66.2	14.0	27.4	36.9	44.1	3,802
Hemlock-Sitka spruce	82.1	17.4	32.6	36.4	46.1	639
Larch	58.5	12.4	22.9	35.8	34.2	409
Lodgepole pine	55.7	11.9	17.7	23.3	37.2	3,611
Hardwoods	34.8	6.6	10.9	27.2	54.8	555
Other softwood types	47.6	10.1	14.0	39.3	31.4	622
Minor types and nonstocked	30.2	6.1	5.1	21.1	42.3	418
Rocky Mountains, South						
(AZ,CO,NM,NV,UT,WY)						
Douglas-fir	62.5	13.3	17.5	37.8	30.9	2,212
Ponderosa pine	36.5	7.7	7.6	23.4	24.1	4,271
Fir-spruce	68.2	14.5	26.7	38.4	31.5	3,984
Lodgepole pine	53.9	11.6	19.8	24.1	27.0	2,336
Hardwoods	36.1	6.8	9.3	28.3	45.3	4,828
Other softwood types	28.5	5.9	8.0	38.6	27.9	1,409
Pinyon-juniper	28.5	5.9	3.4	21.1	19.7	18,403
Minor types and nonstocked	7.2	1.2	3.9	17.5	24.1	849

Table 3-113. Net Annual Changes in Carbon Stocks (Tg C yr^{-1}) in Forest and Harvested Wood Pools, 1990-2003

Carbon Pool	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Forest	(202)	(208)	(185)	(203)	(176)	(169)	(171)	(174)	(163)	(146)	(146)	(146)	(146)	(146)
Live, aboveground	(108)	(118)	(114)	(118)	(113)	(122)	(122)	(125)	(119)	(109)	(109)	(109)	(109)	(109)
Live, belowground	(21)	(23)	(22)	(23)	(22)	(24)	(24)	(24)	(23)	(21)	(21)	(21)	(21)	(21)
Dead Wood	(20)	(20)	(20)	(21)	(20)	(14)	(13)	(14)	(14)	(12)	(12)	(12)	(12)	(12)
Litter	(18)	(18)	(15)	(20)	(14)	(8)	(9)	(9)	(8)	(7)	(7)	(7)	(7)	(7)
Soil Organic Carbon	(34)	(28)	(14)	(21)	(8)	(2)	(3)	(2)	0	3	3	3	3	3
Harvested Wood	(57)	(54)	(55)	(56)	(57)	(55)	(57)	(58)	(56)	(59)	(57)	(58)	(58)	(59)
Wood Products	(13)	(11)	(13)	(15)	(17)	(15)	(15)	(16)	(14)	(17)	(16)	(16)	(16)	(16)
Landfilled Wood	(44)	(43)	(43)	(41)	(41)	(41)	(41)	(42)	(42)	(42)	(41)	(42)	(42)	(42)
Total Net Flux	(259)	(262)	(240)	(258)	(233)	(225)	(227)	(232)	(220)	(205)	(204)	(205)	(205)	(205)

Table 3-114. Carbon Stocks (Tg C) in Forest and Harvested Wood Pools, 1990-2004

Carbon Pool	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Forest	39,489	39,700	39,908	40,093	40,296	40,472	40,641	40,812	40,986	41,149	41,296	41,442	41,589	41,735	41,882
Live, aboveground	14,114	14,222	14,340	14,453	14,572	14,685	14,807	14,928	15,053	15,172	15,281	15,390	15,499	15,608	15,717
Live, belowground	2,805	2,826	2,849	2,871	2,894	2,916	2,940	2,963	2,987	3,011	3,032	3,053	3,074	3,095	3,117
Dead Wood	2,444	2,464	2,485	2,505	2,526	2,545	2,559	2,572	2,587	2,600	2,613	2,625	2,638	2,650	2,662
Litter	4,496	4,514	4,532	4,547	4,567	4,581	4,589	4,598	4,606	4,614	4,621	4,628	4,636	4,643	4,650
Soil Organic Carbon	15,640	15,674	15,702	15,716	15,737	15,745	15,747	15,750	15,752	15,752	15,749	15,745	15,742	15,738	15,735
Harvested Wood	1,915	1,973	2,027	2,082	2,137	2,195	2,250	2,307	2,365	2,421	2,480	2,537	2,595	2,654	2,713
Wood Products	1,134	1,147	1,158	1,171	1,186	1,202	1,217	1,232	1,248	1,262	1,279	1,295	1,311	1,327	1,344
Landfilled Wood	781	825	868	911	952	992	1,033	1,074	1,117	1,159	1,200	1,242	1,284	1,327	1,369
Total Carbon Stock	41,414	41,673	41,934	42,175	42,433	42,667	42,891	43,119	43,351	43,570	43,775	43,979	44,184	44,389	44,594