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# **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2001**

**April 15, 2003**

**U.S. Environmental Protection Agency  
1200 Pennsylvania Ave., N.W.  
Washington, DC 20460  
U.S.A.**

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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).<sup>1</sup> 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.<sup>2</sup> 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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<sup>1</sup> See Article 4(1)(a) of the United Nations Framework Convention on Climate Change <<http://www.unfccc.int>>.

<sup>2</sup> See <<http://www.epa.gov/globalwarming/emissions/national>>.

## 6. Land-Use Change and Forestry

This chapter provides an assessment of the net carbon dioxide (CO<sub>2</sub>) flux<sup>1</sup> caused by 1) changes in forest carbon stocks, 2) changes in carbon stocks in urban trees, 3) changes in agricultural soil carbon stocks, and 4) changes in carbon stocks in landfilled yard trimmings. Seven components of forest carbon stocks are analyzed: trees, understory vegetation, forest floor, down dead wood, soils, wood products in use, and landfilled wood products. The estimated CO<sub>2</sub> flux from each of these forest components was derived from U.S. forest inventory data, using methodologies that are consistent with the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). Changes in carbon stocks in urban trees were estimated based on field measurements in ten U.S. cities and data on national urban tree cover, using a methodology consistent with the *Revised 1996 IPCC Guidelines*. 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<sub>2</sub> 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 changes in agricultural soil carbon stocks are consistent with the *Revised 1996 IPCC Guidelines*. Changes in yard trimming carbon stocks in landfills were estimated using analysis of life-cycle greenhouse gas emissions and sinks associated with solid waste management (EPA 1998). 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.

Unlike the assessments in other chapters, which are based on annual activity data, the flux estimates in this chapter, with the exception of those from wood products, urban trees, and liming, 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 over five or ten year periods. The resulting annual averages are applied to years between surveys. As a result of this data structure, estimated CO<sub>2</sub> fluxes from forest carbon stocks (except the wood product components) and from agricultural soils (except the liming component) are constant over multi-year intervals, with large discontinuities between intervals. For the landfilled yard trimmings, 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 for the year 1997, the estimates of CO<sub>2</sub> flux from forests, agricultural soils, and landfilled yard trimmings are based in part on modeled projections. 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.

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<sup>1</sup> 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 6-1: Net CO<sub>2</sub> Flux from Land-Use Change and Forestry (Tg CO<sub>2</sub> Eq.)**

Sink Category	1990	1995	1996	1997	1998	1999	2000	2001
Forests	(982.7)	(979.0)	(979.0)	(759.0)	(751.7)	(762.7)	(755.3)	(759.0)
Urban Trees	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)
Agricultural Soils	(13.3)	(14.9)	(13.6)	(13.9)	(11.5)	(11.9)	(13.8)	(15.2)
Landfilled Yard Trimmings	(18.2)	(11.6)	(9.7)	(9.0)	(8.7)	(7.8)	(6.9)	(5.3)
<b>Total</b>	<b>(1,072.8)</b>	<b>(1,064.2)</b>	<b>(1,061.0)</b>	<b>(840.6)</b>	<b>(830.5)</b>	<b>(841.1)</b>	<b>(834.6)</b>	<b>(838.1)</b>

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

**Table 6-2: Net CO<sub>2</sub> Flux from Land-Use Change and Forestry (Tg C)**

Sink Category	1990	1995	1996	1997	1998	1999	2000	2001
Forests	(268)	(267)	(267)	(207)	(205)	(208)	(206)	(207)
Urban Trees	(16)	(16)	(16)	(16)	(16)	(16)	(16)	(16)
Agricultural Soils	(4)	(4)	(4)	(4)	(3)	(3)	(4)	(4)
Landfilled Yard Trimmings	(5)	(3)	(3)	(3)	(2)	(2)	(2)	(1)
<b>Total</b>	<b>(293)</b>	<b>(290)</b>	<b>(289)</b>	<b>(229)</b>	<b>(226)</b>	<b>(229)</b>	<b>(228)</b>	<b>(229)</b>

Note: 1 Tg C = 1 teragram carbon = 1 million metric tons carbon. Parentheses indicate net sequestration. Totals may not sum due to independent rounding. Shaded areas indicate values based on a combination of historical data and projections. All other values are based on historical data only.

Land use, land-use change, and forestry activities in 2001 resulted in a net sequestration of 838 Tg CO<sub>2</sub> Eq. (229 Tg C) (Table 6-1 and Table 6-2). This represents an offset of approximately 14 percent of total U.S. CO<sub>2</sub> emissions. Total land use, land-use change, and forestry net sequestration declined by approximately 22 percent between 1990 and 2001. 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 also slowed over this period, while annual carbon accumulation in agricultural soils increased. 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).

## Changes in Forest Carbon Stocks

For estimating carbon flux, carbon in forest ecosystems can be divided into the following five storage pools.

- Trees, including the roots, stems, branches, and foliage of living and standing dead trees.
- Understory vegetation, including shrubs and bushes, including the roots, stems, branches, and foliage.
- Forest floor, including fine woody debris, tree litter, and humus.

- Down dead wood, including logging residue and other coarse dead wood on the ground, and stumps and roots of stumps.
- Soil, including all organic material in soil.

Carbon is continuously cycled through and among these storage pools, and between forest ecosystems and the atmosphere as a result of biological processes in forests such as growth and mortality and anthropogenic activities such as harvesting, thinning, clearing, and replanting. As trees grow, carbon is removed from the atmosphere and stored in living tree biomass. As trees age, they continue to accumulate carbon until they reach maturity, at which point they are relatively constant carbon stores. As trees die and otherwise deposit litter and debris on the forest floor, decay processes release carbon to the atmosphere and also add carbon to the soil.

However, the net change in forest carbon is not equivalent to the net flux between forests and the atmosphere because timber harvests may not always result in an immediate flux of carbon to the atmosphere. Harvesting transfers carbon from one of the forest carbon storage pools to a “product pool.” Once in a product pool, the carbon is emitted over time as CO<sub>2</sub> if the wood product combusts or decays. The rate of emission varies considerably among different product pools. For example, if timber is harvested

for energy use, combustion results in an immediate release of carbon. Conversely, if timber is harvested and subsequently used as lumber in a house, it may be many decades or even centuries before the lumber is allowed to decay and carbon is released to the atmosphere. If wood products are disposed of in landfills, the carbon contained in the wood may be released years or decades later, or may be stored permanently in the landfill.

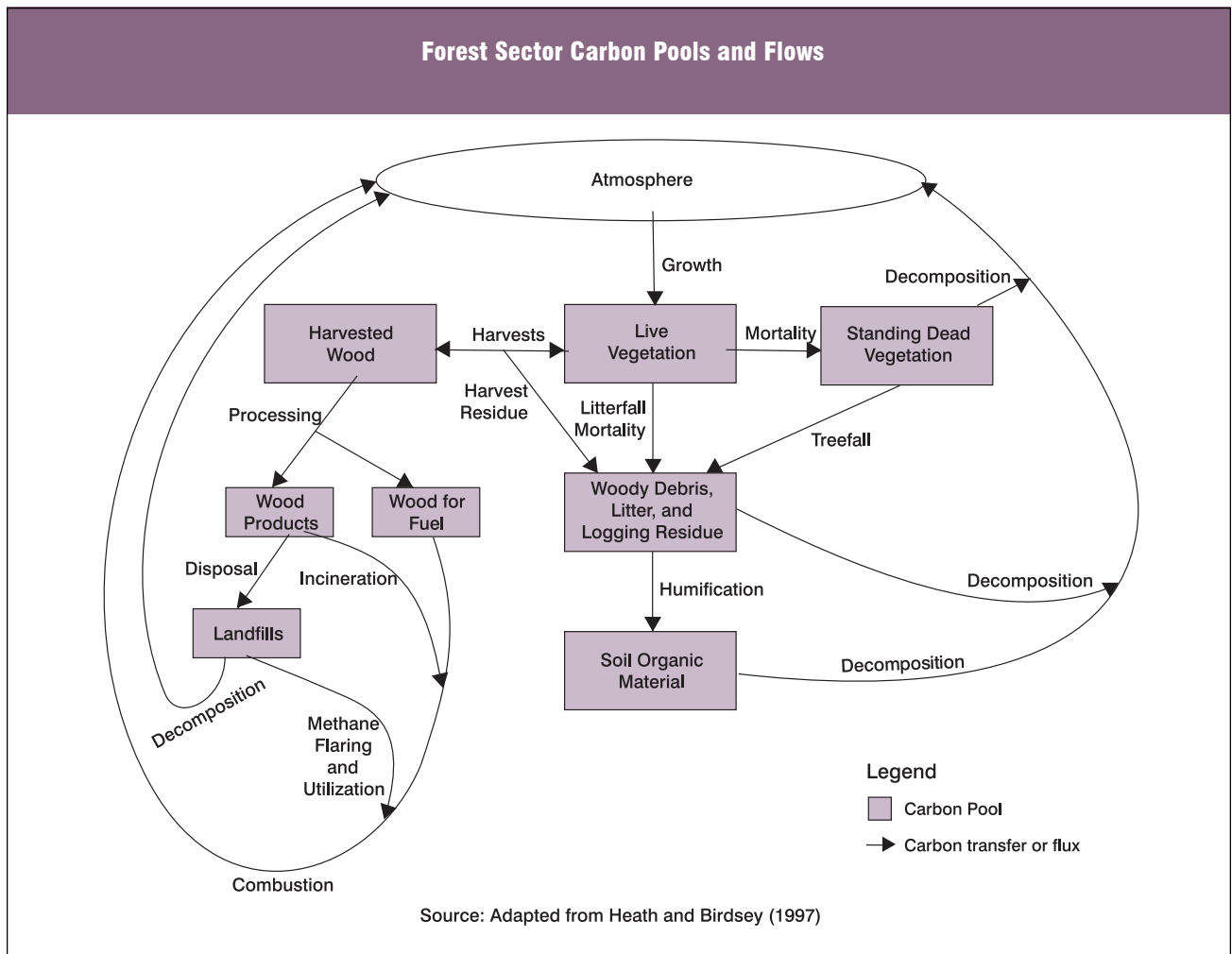
This section of the Land-Use Change and Forestry chapter quantifies the net changes in carbon stocks in five forest carbon pools and two harvested wood pools. The net change in stocks for each pool is estimated, and then the changes in stocks are summed over all pools to estimate total net flux.

Forest carbon storage pools, and the flows between them via emissions, sequestration, and transfers, are shown in Figure 6-1. In this figure, forest carbon storage pools are

represented by boxes, while flows between storage pools, and between storage pools and the atmosphere, are represented by arrows. 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 carbon from one pool to another, and that result in emissions to the atmosphere.

Approximately 33 percent (747 million acres) of the U.S. land area is forested (Smith et al. 2001). Between 1977 and 1987, forest land declined by approximately 5.9 million acres, and between 1987 and 1997, the area increased by about 9.2 million acres. These 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 carbon flux from forest land are management activities and the ongoing

Figure 6-1



impacts of previous land-use changes. These activities affect the net flux of carbon by altering the amount of carbon stored in forest ecosystems. For example, intensified management of forests can increase both the rate of growth and the eventual biomass density<sup>2</sup> of the forest, thereby increasing the uptake of carbon. Harvesting forests removes much of the aboveground carbon, but trees can grow on this area again and sequester carbon. The reversion of cropland to forest land through natural regeneration will cause increased carbon storage in biomass and soils. The net effect of both forest management and land-use change involving forests is captured in these estimates.

In the United States, improved forest management practices, the regeneration of previously cleared forest areas, and timber harvesting and use have resulted in an annual net uptake (i.e., net sequestration) of carbon during the period from 1990 through 2001. 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 are still affecting carbon fluxes from forests in the East. In addition to land-use changes in the early part of this century, carbon fluxes from Eastern forests have been affected by a trend toward managed growth on private land. Collectively, these changes have produced a near doubling of 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 carbon fluxes. Because most of the timber that is harvested from U.S. forests is used in wood products and much of the

discarded wood products are disposed of by landfilling, rather than incineration, significant quantities of this harvested carbon are transferred to long-term storage pools rather than being released to the atmosphere. The size of these long-term carbon storage pools has also increased over the last century.

Changes in carbon stocks in U.S. forests and harvested wood were estimated to account for an average annual net sequestration of 887 Tg CO<sub>2</sub> Eq. (242 Tg C) over the period 1990 through 2001 (Table 6-3 and Table 6-4).<sup>3</sup> The net sequestration is a reflection of net forest growth and increasing forest area over this period, particularly from 1987 to 1997, as well as net accumulation of carbon in harvested wood pools. The rate of annual sequestration, however, declined by 23 percent between 1990 and 2001. This was due to a greater increase in forest area between 1987 and 1997 than between 1997 and 2001. Most of the decline in annual sequestration occurred in the forest soil carbon pool. This result is due to the method used to account for changes in soil carbon after the conversion of land from forest to non-forest. Specifically, soil carbon stocks for each forest type are assumed to depend on land use and soil type and not to vary over time within forests. Therefore, as lands are converted from non-forest to forest, there is a substantial immediate increase in soil carbon stocks.

Table 6-5 presents the carbon stock estimates for forest and harvested wood storage pools. Together, the tree and forest soil pools account for over 80 percent of total carbon stocks. Carbon stocks in all pools, except forest floor, increased over time, indicating that during these periods, all storage pools, except forest floor, accumulated carbon (e.g., carbon sequestration by trees was greater than carbon removed from the tree pool through respiration, decay, litterfall, and harvest). Figure 6-2 shows 1997 forest carbon stocks, excluding harvested wood stocks, by the regions that were used in the forest carbon analysis. Figure 6-3 shows 1997 forest carbon stocks per hectare, by county, excluding harvested wood stocks, for all counties in the conterminous United States that have at least 5 percent of the county area in forest.

<sup>2</sup> The term “biomass density” refers to the weight of vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is about 50 percent carbon by weight.

<sup>3</sup> This average annual net sequestration is based on the entire time series (1990 through 2001), rather than the abbreviated time series presented in Table 6-3 and Table 6-4. Results for the entire time series are presented in Annex O.

**Table 6-3: Net Changes in Carbon Stocks in Forest and Harvested Wood Pools, and Total Net Forest Carbon Flux (Tg CO<sub>2</sub> Eq.)**

Carbon Pool	1990	1995	1996	1997	1998	1999	2000	2001
<b>Forest</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(546.3)</b>	<b>(546.3)</b>	<b>(546.3)</b>	<b>(546.3)</b>	<b>(546.3)</b>
Trees	(469.3)	(469.3)	(469.3)	(447.3)	(447.3)	(447.3)	(447.3)	(447.3)
Understory	(11.0)	(11.0)	(11.0)	(14.7)	(14.7)	(14.7)	(14.7)	(14.7)
Forest Floor	(25.7)	(25.7)	(25.7)	29.3	29.3	29.3	29.3	29.3
Down Dead Wood	(55.0)	(55.0)	(55.0)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)
Forest Soils	(212.7)	(212.7)	(212.7)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)
<b>Harvested Wood</b>	<b>(209.0)</b>	<b>(205.3)</b>	<b>(205.3)</b>	<b>(212.7)</b>	<b>(205.3)</b>	<b>(216.3)</b>	<b>(209.0)</b>	<b>(212.7)</b>
Wood Products	(47.7)	(55.0)	(55.0)	(58.7)	(51.3)	(62.3)	(58.7)	(58.7)
Landfilled Wood	(161.3)	(150.3)	(150.3)	(154.0)	(154.0)	(154.0)	(150.3)	(154.0)
<b>Total Net Flux</b>	<b>(982.7)</b>	<b>(979.0)</b>	<b>(979.0)</b>	<b>(759.0)</b>	<b>(751.7)</b>	<b>(762.7)</b>	<b>(755.3)</b>	<b>(759.0)</b>

Note: Parentheses indicate net carbon “sequestration” (i.e., accumulation into the carbon pool minus emissions or stock removal from the carbon pool). The sum of the net stock changes in this table (i.e., total net flux) is an estimate of the actual net flux between the total forest carbon pool and the atmosphere. Shaded areas indicate values based on a combination of historical data and projections. Forest values are based on periodic measurements; harvested wood estimates are based on annual surveys. Totals may not sum due to independent rounding.

**Table 6-4: Net Changes in Carbon Stocks in Forest and Harvested Wood Pools, and Total Net Forest Carbon Flux (Tg C)**

Carbon Pool	1990	1995	1996	1997	1998	1999	2000	2001
<b>Forest</b>	<b>(211)</b>	<b>(211)</b>	<b>(211)</b>	<b>(149)</b>	<b>(149)</b>	<b>(149)</b>	<b>(149)</b>	<b>(149)</b>
Trees	(128)	(128)	(128)	(122)	(122)	(122)	(122)	(122)
Understory	(3)	(3)	(3)	(4)	(4)	(4)	(4)	(4)
Forest Floor	(7)	(7)	(7)	8	8	8	8	8
Down Dead Wood	(15)	(15)	(15)	(16)	(16)	(16)	(16)	(16)
Forest Soils	(58)	(58)	(58)	(15)	(15)	(15)	(15)	(15)
<b>Harvested Wood</b>	<b>(57)</b>	<b>(56)</b>	<b>(56)</b>	<b>(58)</b>	<b>(56)</b>	<b>(59)</b>	<b>(57)</b>	<b>(58)</b>
Wood Products	(13)	(15)	(15)	(16)	(14)	(17)	(16)	(16)
Landfilled Wood	(44)	(41)	(41)	(42)	(42)	(42)	(41)	(42)
<b>Total Net Flux</b>	<b>(268)</b>	<b>(267)</b>	<b>(267)</b>	<b>(207)</b>	<b>(205)</b>	<b>(208)</b>	<b>(206)</b>	<b>(207)</b>

Note: 1 Tg C = 1 Tg carbon = 1 million metric tons carbon. This table has been included to facilitate comparison with previous U.S. Inventories. Parentheses indicate net carbon “sequestration” (i.e., accumulation into the carbon pool minus emissions or harvest from the carbon pool). The sum of the net stock changes in this table (i.e., total net flux) is an estimate of the actual net flux between the total forest carbon pool and the atmosphere. Shaded areas indicate values based on a combination of historical data and projections. Forest values are based on periodic measurements; harvested wood estimates are based on annual surveys. Totals may not sum due to independent rounding.

**Table 6-5: U.S. Forest Carbon Stock Estimates (Tg C)**

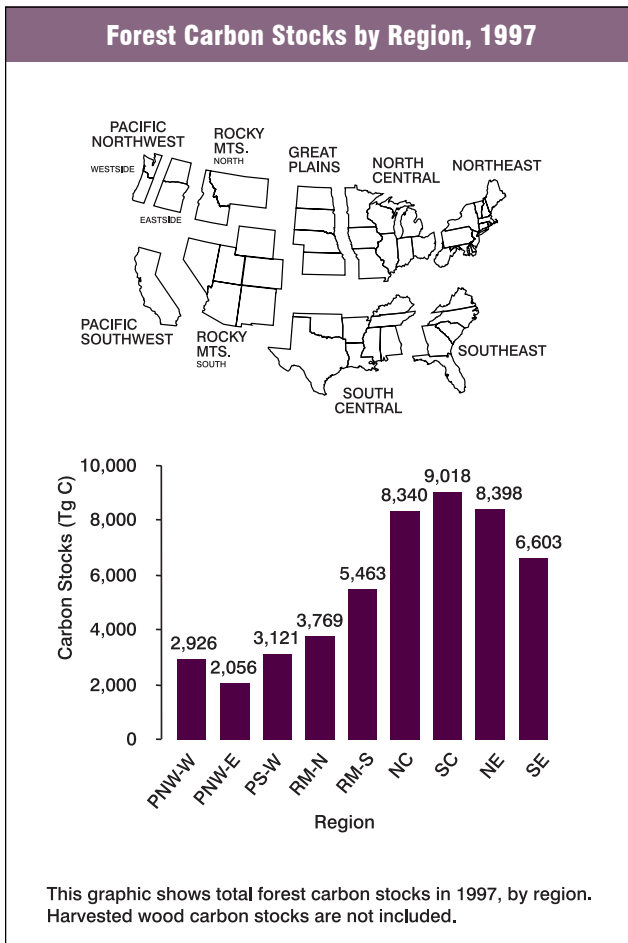
Carbon Pool	1987	1997	2002
<b>Forest</b>	<b>47,595</b>	<b>49,695</b>	<b>50,440</b>
Trees	15,168	16,449	17,059
Understory	448	473	493
Forest Floor	4,240	4,306	4,266
Down Dead Wood	2,058	2,205	2,285
Forest Soils	25,681	26,262	26,337
<b>Harvested Wood</b>	<b>1,920</b>	<b>2,478</b>	<b>2,767</b>
Wood Products	1,185	1,319	1,398
Landfilled Wood	735	1,159	1,369
<b>Total Forest Carbon Stocks</b>	<b>49,515</b>	<b>52,173</b>	<b>53,207</b>

Note: Forest carbon 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. Shaded areas indicate values based on a combination of historical data and projections. All other estimates are based on historical data only. Totals may not sum due to independent rounding. Note that the stock is listed for 2002 because stocks are defined as of January 1 of the listed year.

## Methodology

The methodology described herein is consistent with the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). The IPCC identifies two approaches for developing estimates of net carbon flux or stock change from Land-Use Change and Forestry: 1) using average annual statistics on land use, land-use change, and forest management activities, and applying carbon density and flux rate data to these activity estimates to derive total flux values; or 2) using carbon stock estimates derived from periodic inventories of forest stocks, and measuring net changes in carbon stocks over time. The latter approach was employed because the United States conducts periodic surveys of national forest stocks. In addition, the IPCC identifies two approaches to accounting for carbon emissions from

Figure 6-2



harvested wood: 1) assuming that all of the harvested wood replaces wood products that decay in the inventory year so that the amount of carbon in annual harvests equals annual emissions from harvests; or 2) accounting for the variable rate of decay of harvested wood according to its disposition (e.g., product pool, landfill, combustion). The latter approach was applied for this Inventory using estimates of carbon stored in wood products and landfilled wood.<sup>4</sup> The use of direct measurements from forest surveys to estimate the forest pools, and the use of data on wood products and landfilled wood to estimate the harvested wood pool is likely

<sup>4</sup> The product estimates in this study do not account for carbon stored in imported wood products. However, they do include carbon stored in exports, even if the logs are processed in other countries (Heath et al. 1996).

<sup>5</sup> As explained in the paragraphs below, the 1987 and 1997 “inventories” referred to here are actual forest inventories (i.e., datasets based on field surveys), while the 2002 “inventory” is a projection derived from the historical field data and a linked system of forest sector models. A national (field-based) forest inventory has not been completed for 2002.

<sup>6</sup> Forest land in the United States includes all land that is at least 10 percent stocked with trees of any size. Timberland is the most productive type of forest land, growing at a rate of 20 cubic feet per acre per year or more. In 1997, there were about 503 million acres of timberlands, which represented 67 percent of all forest lands (Smith and Sheffield 2000). Forest land classified as timberland is unreserved forest land that is producing or is capable of producing crops of industrial wood. The remaining 33 percent of forest land is classified as reserved forest land, which is forest land withdrawn from timber use by statute or regulation, or other forest land, which includes forests on which timber is growing at a rate less than 20 cubic feet per acre per year.

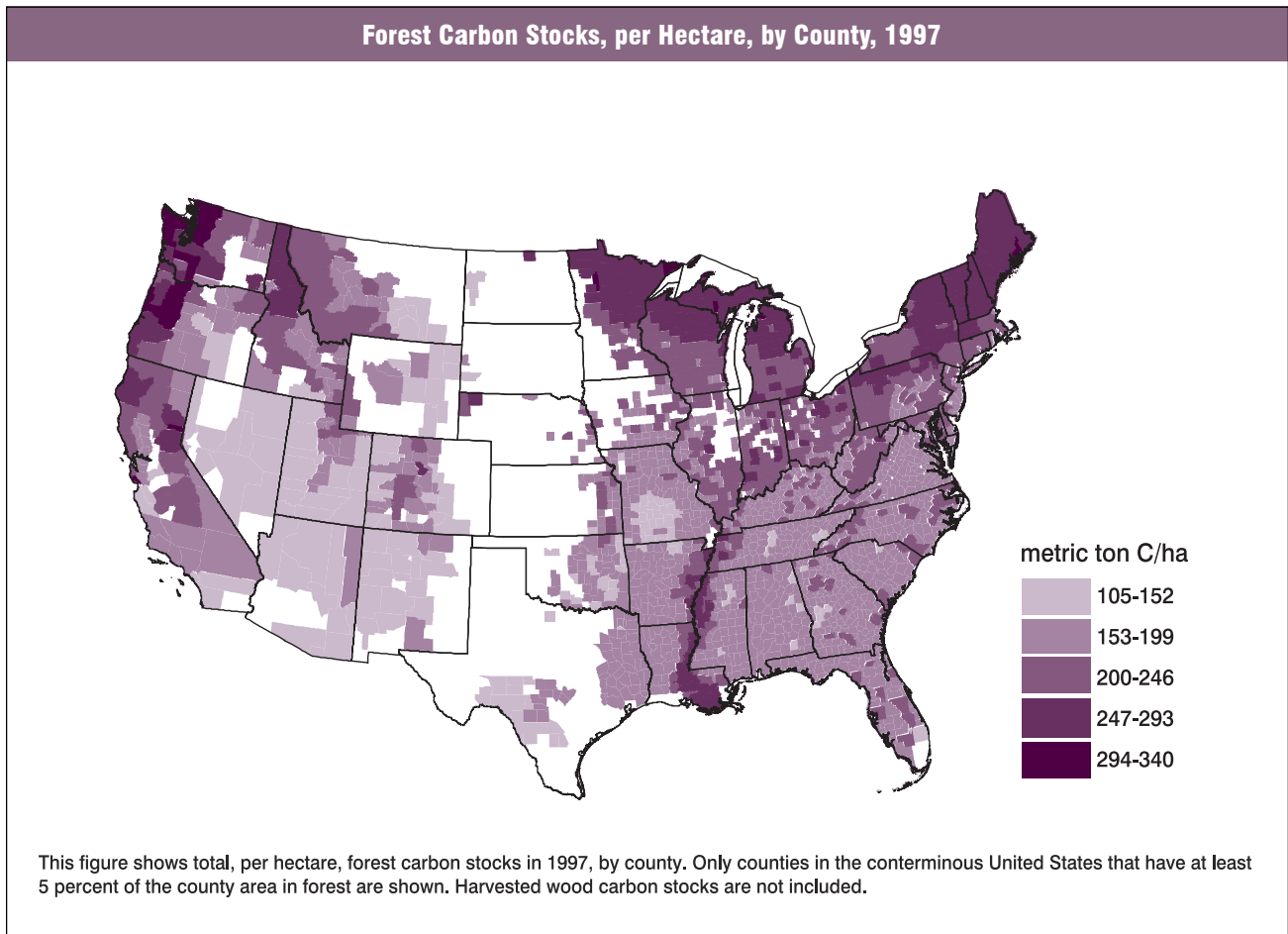
to result in more accurate flux estimates than the alternative IPCC methodologies. Due to differences in data sources, different methods were used to calculate the carbon flux in forests and in harvested wood products. Therefore these methods are described separately below.

### Forest Carbon Stock Change

The overall approach was to sample the forest carbon at one time, sample the forest carbon again several years later, and then subtract the two estimates to calculate the net change in carbon stocks. Three periodic inventories (sampling times) were used: 1987, 1997, and 2002.<sup>5</sup> For each periodic inventory, each carbon pool was estimated using coefficients from the FORCARB model, as described below. The carbon pools included live and dead standing trees, understory vegetation, forest floor, and soil. These estimates were summed to calculate total carbon stocks at each time period. Data sources and methods for estimating each carbon pool are described briefly below and more fully in Annex O.

The starting point for estimating forest carbon stock change was to obtain data on the area and growing stock volume for forest lands. For 1987 and 1997, such data were available from periodic inventories conducted by the USDA Forest Service Forest Inventory and Analysis program (Smith et al. 2001, Frayer and Furnival 1999). In the past, the Forest Inventory and Analysis program did not conduct detailed surveys of all forest land, but instead focused on timber producing land, which is called timberland. In addition, some reserved forest land and some other forest land were surveyed.<sup>6</sup> With the introduction of the new annualized inventory design (Gillespie 1999), all forest lands will feature the same type of detailed information. In order to include all forest lands, estimates were made for timberlands and then were extrapolated for non-timberland forests.

Figure 6-3



The Forest Inventory and Analysis program has conducted consistent forest surveys based on extensive statistically based sampling of much of the forest land in the United States since 1952. Historically, these were conducted periodically, state-by-state within a region. One state within a region would be surveyed, and when finished, another state was surveyed. Eventually (every 5 to 14 years, depending on the state), all states within a region would be surveyed, and then states would be resurveyed. The Forest Inventory and Analysis program has adopted a new annualized design, so that a portion of each state will be surveyed each year (Gillespie 1999); however, data are not yet available for all states. The annualized survey also includes a plan to measure attributes that are needed to estimate carbon in various pools, such as soil carbon and forest floor carbon. Currently, some of these pools must be estimated based on other measured characteristics. Characteristics that were measured in the 1987 and 1997

surveys include individual tree diameter and species, and forest type and age of the plot. For more information about forest inventory data and carbon stock change, see Birdsey and Heath (2001).

Historically, 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. Growing stock is a classification of timber inventory that includes live trees of commercial species meeting specified standards of quality (Smith et al. 2001). Timber products output refers to the production of industrial roundwood products such as logs and other round timber generated from harvesting trees, and the production of bark and other residue at processing mills. Utilization factors relate inventory volume to the volume cut or destroyed when producing roundwood (May 1998). Growth, harvests, land-use change, and other estimates of change are derived from repeated surveys.

For the 2002 periodic inventory, data were not available from the Forest Inventory and Analysis program. Therefore, areas, volumes, growth, land-use changes, and other forest characteristics were projected with a system of models representing the U.S. forest sector (see Haynes 2002, also see Annex O).

Based on the measured or projected periodic survey data, estimates were made of the total biomass and carbon in trees on timberlands and other forest lands. For timberlands, total biomass and carbon in standing trees were calculated from the growing stock volume. Calculations were made using biomass conversion factors for each forest type and region presented in Smith et al. (in press). For non-timberlands, biomass and carbon in standing trees were estimated based on average carbon estimates derived from similar timberlands. Reserved forests were assumed to contain the same average carbon densities as timberlands of the same forest type, region, and owner group. These averages were multiplied by the areas of non-timberland forests and then aggregated for a national total. Average carbon stocks were derived for other forest land by using average carbon stocks for Timberlands, which were multiplied by 50 percent to simulate the effects of lower productivity.

Understory carbon was estimated from inventory data using equations presented in Birdsey (1992). Forest floor carbon was estimated from inventory data using the equations presented in Smith and Heath (2002). Down dead wood was estimated using a procedure similar to that used for estimating carbon in understory vegetation, as described in Annex O. Data on the carbon content of soils were obtained from the national STATSGO spatial database. These data were combined with spatial data from the Forest Inventory and Analysis program on the location of U.S. forest lands to estimate soil carbon in all forest lands.

Once carbon pools were estimated as described above for each periodic inventory (1987, 1997, and 2002), the pools were summed together to create total forest carbon stock estimates. Average annual carbon stock changes were then calculated by subtracting carbon stocks at the end of a time period from those at the beginning of the time period, and then dividing by the number of years in the time period.

## Harvested Wood Products Carbon Stock Change

Estimates of carbon stock changes in wood products and wood discarded in landfills were based on the methods described in Skog and Nicholson (1998). These methods utilize two harvested wood carbon storage pools: wood products in use, and wood discarded in landfills. Annual historical estimates and projections of detailed product production were used to divide consumed roundwood into product, wood mill residue, and pulp mill residue. Rates of decay for wood products and for wood in landfills were estimated and applied to the respective pools. The results were aggregated to produce national estimates. To account for imports and exports, the production approach was used, meaning that carbon in exported wood was included using the same disposal rates as in the United States, while carbon in imported wood was not included. Over the period 1990 through 2001, carbon in exported wood accounted for an average of 22 Tg CO<sub>2</sub> Eq. storage 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 26 Tg CO<sub>2</sub> Eq. per year in 1990 to 47 Tg CO<sub>2</sub> Eq. per year in 2001.

## Data Sources

The estimates of forest carbon stocks used in this Inventory to calculate forest carbon fluxes are based largely on areas, volumes, growth, harvests, and utilization factors derived from the forest inventory data collected by the USDA Forest Service Forest Inventory and Analysis program. Compilations of these data for 1987 and 1997 are given in Waddell et al. (1989) and Smith et al. (2001), with trends discussed in the latter citation. The timber volume data used here include timber volumes on forest land classified as timberland, as well as on some reserved forest land and other forest land. Timber volumes on forest land in Alaska, Hawaii, and the U.S. territories are not sufficiently detailed to be used here. Also, timber volumes on non-forest land (e.g., urban trees, rangeland) are not included. The timber volume data include estimates by tree species, size class, and other categories. The forest inventory data are used to derive estimates of carbon stocks as described above in the methodology section and in Annex O. Estimates of soil carbon are based on data from the STATSGO database (USDA 1991). Carbon stocks in wood products in use and wood products stored in landfills are 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 NAPAP (Ince 1994) and TAMM/ATLAS (Haynes 2002, Mills and Kincaid 1992) models. The carbon conversion factors and decay rates for harvested carbon removed from the forest are taken from Skog and Nicholson (1998).

## Uncertainty

This section discusses uncertainties in the carbon sequestration estimates, given the methods and data used. There are sampling and measurement errors associated with the forest survey data that underlie the forest carbon estimates. These surveys are based on a statistical sample designed to represent the wide variety of growth conditions present over large territories. Although newer inventories are being conducted annually in every state, many of the data currently used were collected over more than one year in a state, and data associated with a particular year may actually have been collected over several previous years. Thus, there is uncertainty in the year associated with the forest inventory data. In addition, the forest survey data that are currently available generally exclude timber stocks on most forest land in Alaska, Hawaii, and U.S. territories. However, net carbon fluxes from these stocks are believed to be minor. The assumptions that were used to calculate carbon stocks in reserved forests and other forests in the conterminous United States also contribute to the uncertainty. Although the potential for uncertainty is large, the sample design for the forest surveys contributes to limiting the error in carbon flux. Estimates from sampling at different times on permanent plots are correlated, and such correlation reduces the uncertainty in estimates of carbon flux. For example, in a study on the uncertainty of the forest carbon budget of private Timberlands of the United States, Smith and Heath (2000) estimated that the uncertainty of the flux decreased more than three-fold when the correlation coefficient increased from 0.5 to 0.95.

Additional sources of uncertainty come from the models used to estimate carbon storage in specific ecosystem components, such as forest floor, understory vegetation, and soil. Extrapolation of the results of site-specific ecosystem studies to all forest lands introduces uncertainty because such studies may not adequately represent regional or national averages. Uncertainty also arises 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 the impacts of forest management activities, including harvest, on soil carbon are not well understood. For example, while Johnson and Curtis (2001) found little or no net change in soil carbon 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 was such that the usefulness of the studies may be limited in determining harvesting effects on soil carbon. Soil carbon impact estimates need to be very precise because even small changes in soil carbon may sum to large differences over large areas. This analysis assumes that soil carbon density for each forest type stays constant over time. As more information becomes available, the effects of changes in land use will be better accounted for in estimates of soil carbon.

Recent studies have begun to quantify the uncertainty in national-level carbon budgets based on the methods adopted here. Smith and Heath (2000) and Heath and Smith (2000a) report on an uncertainty analysis they conducted on carbon sequestration in private timberlands. These studies are not strictly comparable to the estimates in this chapter because they used an older version of the FORCARB model, which was based on older data and produced decadal estimates. However, the magnitudes of the uncertainties should be instructive. Their results indicate that the carbon flux of private timberlands, not including harvested wood, was approximately the average carbon flux (271 Tg CO<sub>2</sub> Eq. per year) ±15 percent at the 80 percent confidence level for the period 1990 through 1999. The flux estimate included the tree, soil, understory vegetation, and forest floor components only. The uncertainty in the carbon inventory of private timberlands for 2000 was approximately 5 percent at the 80 percent confidence level. These estimates did not include all uncertainties, such as the ones associated with public timberlands, and reserved and other forest land, but they did include many of the types of uncertainties listed previously. Because of these additional factors, uncertainty is expected to be greater in estimates for all forest lands.

# ANNEX O

## Methodology for Estimating Net Changes in Forest Carbon Stocks

This annex presents a discussion of the methodology used to calculate net changes in carbon stocks in trees, understory, forest floor, down dead wood, forest soils, wood products and landfilled wood. More detailed discussions of selected topics may be found in the references cited in this annex.

The details of carbon conversion factors and procedures for calculating net CO<sub>2</sub> flux for forests are given in three steps. In addition, the USDA Forest Service forest sector modeling projection system is described briefly.

### Step 1: Estimate Forest Carbon Stocks and Net Changes in Forest Carbon Stocks

#### Step 1a: Obtain Forest Inventory Data

Forest survey data in the United States by broad forest type and region for 1987 and 1997 were obtained from USDA Forest Service, Forest Inventory and Analysis estimates of forest resources, published in Waddell et al. (1989) and Smith et al. (2001). The Forest Inventory and Analysis data include: (1) growing stock volume per acre by forest type (referred to hereinafter as “growing stock volumes”); and (2) area by timberland and other forest land, for general forest types by region (referred to hereinafter as “forest areas”). For 2001, the same variables were obtained from model results as described in Haynes (2002). (See Forest Sector Modeling Projection System below). This information was combined with separate estimates of carbon density (carbon mass per unit area) to estimate carbon stocks.

#### Step 1b: Estimate Carbon in Living and Standing Dead Trees

To estimate live tree biomass, equations that convert forest tree volumes to total live tree dry biomass (Smith et al. in press) were applied to the growing stock volumes by forest type and region (obtained in Step 1a). Tree biomass includes aboveground biomass and belowground biomass of coarse roots. The minimum sized tree is one-inch diameter at diameter breast height (1.3 meter). Trees less than one-inch diameter are counted as carbon in understory vegetation. Biomass estimates were divided by two to obtain estimates of carbon in living trees (i.e., it was assumed that dry biomass is 50 percent carbon). Standing dead tree biomass was calculated by applying equations that estimate biomass for standing dead trees (Smith et al., in press) from growing stock volumes. Again, standing dead tree biomass was divided by two to estimate carbon in standing dead trees. Table O-1 lists the average living and standing dead tree carbon densities by forest type, as calculated by applying the equations to the 1997 data.

**Table O-1: Average U.S. Carbon Densities of Forest Components\* (Metric Tons C/ha)**

Region <sup>a</sup> /Forest Type	Live and Standing Dead Tree Carbon	Forest Floor Carbon	Soil Organic Carbon <sup>b</sup>
<b>Eastern</b>			
White-red-jack pine	77.1	13.8	196.1
Spruce-fir	59.8	40.2	192.9
Longleaf-slash pine	42.4	9.2	136.3
Loblolly-shortleaf pine	49.3	9.1	91.7
Oak-pine	57.3	11.6	82.3
Oak-hickory	76.3	6.6	85.0
Oak-gum-cypress	86.0	6.0	152.2
Elm-ash-cottonwood	67.6	23.0	118.1
Maple-beech-birch	82.5	28.0	139.5
Aspen-birch	56.0	7.6	237.0
Other forest types	1.8	2.1	99.6
Nonstocked	3.7	3.5	99.6

**Western**

Douglas-fir	110.8	30.7	89.6
Ponderosa pine	66.3	20.3	70.4
Western white pine	69.2	25.8	68.3
Fir-spruce	113.0	37.4	137.5
Hemlock-Sitka spruce	152.4	34.1	157.1
Larch	97.0	30.2	65.6
Lodgepole pine	67.8	23.9	62.7
Redwood	186.6	26.9	85.8
Hardwoods	89.0	9.9	79.5
Other forest types	55.4	28.2	90.1
Pinyon-juniper	20.8	21.1	56.3
Chaparral	17.5	25.7	58.7
Nonstocked	18.1	24.4	90.1

\* Based on 1997 data for major forest types of the conterminous United States.

<sup>a</sup>Eastern United States is defined as states east of, and including, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Western United States includes the remaining conterminous states.

<sup>b</sup>Soil includes both mineral soils and organic soils (i.e., histosols); carbon densities are to a depth of 1 meter.

**Step 1c: Estimate Carbon in Understory Vegetation**

To estimate carbon in understory vegetation, equations based on Birdsey (1992) were applied to the database that was used to produce the compiled forest statistics in Smith et al. (2001). Understory vegetation is defined as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than one-inch diameter, measured at breast height. A ratio of understory carbon to live tree carbon was calculated, and multiplied by 100 to calculate the percentage of carbon in the understory relative to that in live trees. These percentages were then averaged for each forest type in each region. This percentage was multiplied by the live tree carbon data in 1987 and 1997 to calculate understory carbon. These percentages are given in Table O-2. This procedure was used instead of applying the Birdsey equations directly, because detailed databases are not available for inventory years prior to 1987. Using estimated average values results in consistent historical carbon estimates for all survey years.

**Table O-2: Ratios of Understory and Down Dead Wood Carbon to Live Tree Carbon\* (Percent)**

Region/Forest Type	Ratio of Understory Carbon to Live Tree Carbon	Ratio of Down Dead Wood Carbon to Live Tree Carbon
<b>Northeast</b>		
White-red-jack pine	2.5	10.8
Spruce-fir	2.6	13.3
Longleaf-Slash pine	2.5	10.8
Loblolly-shortleaf pine	2.5	10.8
Oak-pine	2.8	12.9
Oak-hickory	2.4	10.9
Oak-gum-cypress	2.6	11.1
Elm-ash-cottonwood	2.6	11.1
Maple-beech-birch	1.9	11.1
Aspen-birch	2.7	13.6
Other Forest Types	8.9	3.8
Nonstocked	8.9	3.8
<b>North Central</b>		
White-red-jack pine	1.8	9.8
Spruce-fir	2.2	17.4
Longleaf-Slash pine	2.4	7.4
Loblolly-shortleaf pine	2.4	7.4
Oak-pine	1.9	7.2
Oak-hickory	2.3	9.6
Oak-gum-cypress	2.3	9.6
Elm-ash-cottonwood	2.2	10.8
Maple-beech-birch	2.2	10.8
Aspen-birch	2.8	13.3
Other Forest Types	5.5	4.1
Nonstocked	5.5	4.1

<b>Southeast</b>		
White-red-jack pine	6.8	23.9
Spruce-fir	6.8	23.9
Longleaf-Slash pine	6.8	23.9
Loblolly-shortleaf pine	6.8	23.9
Oak-pine	5.2	28.0
Oak-hickory	4.4	24.2
Oak-gum-cypress	2.2	21.8
Elm-ash-cottonwood	2.2	21.8
Maple-beech-birch	4.4	24.2
Aspen-birch	2.2	21.8
Other Forest Types	11.9	2.0
Nonstocked	11.9	2.0
<b>South Central</b>		
White-red-jack pine	5.9	18.6
Spruce-fir	5.9	18.6
Longleaf-Slash pine	5.9	18.6
Loblolly-shortleaf pine	5.9	18.6
Oak-pine	4.4	17.3
Oak-hickory	3.7	15.0
Oak-gum-cypress	2.2	15.7
Elm-ash-cottonwood	2.2	15.7
Maple-beech-birch	3.7	15.0
Aspen-birch	2.2	15.7
Other Forest Types	16.9	1.7
Nonstocked	16.9	1.7
<b>Pacific Northwest Eastside of Cascades</b>		
Douglas-fir	1.6	10.0
Ponderosa Pine	2.5	12.6
Western White Pine	1.6	10.0
Fir-Spruce	1.1	15.7
Hemlock-Sitka spruce	1.6	10.0
Larch	1.6	10.0
Lodgepole pine	2.6	21.3
Redwood	1.9	25.8
Other hardwoods	1.4	8.9
Unclassified & other	2.5	12.6
Pinyon-Juniper	10.7	3.7
Chaparral	9.7	2.1
Nonstocked	9.7	2.1
<b>Pacific Northwest Westside of Cascades</b>		
Douglas-fir	2.0	11.9
Ponderosa Pine	2.5	18.1
Western White Pine	2.5	18.1
Fir-Spruce	1.0	13.7
Hemlock-Sitka spruce	1.0	13.7
Larch	2.0	11.9
Lodgepole pine	1.7	16.4
Redwood	2.0	11.9
Other hardwoods	4.5	3.9
Unclassified & other	1.7	16.4
Pinyon-Juniper	20.2	3.7
Chaparral	14.2	3.0
Nonstocked	14.2	3.0
<b>Rocky Mountain, Northern</b>		
Douglas-fir	2.6	19.2
Ponderosa Pine	2.4	19.6
Western White Pine	2.2	9.7
Fir-Spruce	1.7	14.8
Hemlock-Sitka spruce	2.0	18.7
Larch	2.2	9.7
Lodgepole pine	2.4	19.6

Redwood	2.2	9.7
Other hardwoods	1.9	14.2
Unclassified & other	2.2	9.7
Pinyon-Juniper	16.1	3.2
Chaparral	16.1	3.2
Nonstocked	16.1	3.2
<b>Rocky Mountain, Southern</b>		
Douglas-fir	2.8	19.4
Ponderosa Pine	4.1	21.6
Western White Pine	2.8	19.4
Fir-Spruce	2.2	17.4
Hemlock-Sitka spruce	2.8	19.4
Larch	2.8	19.4
Lodgepole pine	3.1	12.8
Redwood	2.8	19.4
Other hardwoods	9.2	26.7
Unclassified & other	10.7	3.3
Pinyon-Juniper	9.8	3.9
Chaparral	9.8	3.9
Nonstocked	2.6	15.2
<b>Pacific Southwest</b>		
Douglas-fir	2.3	15.5
Ponderosa Pine	2.6	15.2
Western White Pine	2.2	11.5
Fir-Spruce	2.6	15.2
Hemlock-Sitka spruce	2.6	15.2
Larch	4.6	10.8
Lodgepole pine	2.6	15.2
Redwood	4.4	9.7
Other hardwoods	2.8	11.5
Unclassified & other	9.9	3.1
Pinyon-Juniper	15.3	3.5
Chaparral	15.3	3.5
Nonstocked	2.5	10.8

\* Based on data from 1997. Regions are defined in Figure 6-2 of the Land-Use Change and Forestry Chapter.

#### **Step 1d: Estimate Carbon in Forest Floor**

Forest floor carbon is the pool of organic carbon (litter, duff, humus, and small woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. To estimate carbon in the forest floor, equations developed by Smith and Heath (in press) were applied to the dataset described in Step 1a. Table O-1 shows the average forest floor carbon densities by forest type, as calculated based on the 1997 data.

#### **Step 1e: Estimate Carbon in Down Dead Wood**

Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter that are not attached to trees. Down dead wood includes stumps and roots of harvested trees. To estimate carbon in down dead wood, a procedure similar to estimating carbon in understory vegetation was used. Down dead wood was estimated in the projections by using decay rates applied to logging residue, along with equations that estimate the amount of down dead wood from causes other than harvesting. The percentage of down dead wood carbon relative to that in live trees was calculated. As for the understory carbon, average values of down dead wood were derived for each forest type in each region. This percentage was multiplied by the live tree carbon data from the dataset described in step 1a to calculate the total amount of carbon in down dead wood. These percentages are given in Table O-2. This procedure was used because detailed databases are not available for older data. By using this procedure, carbon estimates from historical data are consistent with carbon estimates from current Forest Inventory and Analysis data.

### Step 1f: Estimate Forest Soil Carbon

To estimate the amount of carbon in forest soils, data for soils from the surface down to a depth of 1 meter were obtained from the STATSGO spatial database (USDA 1991). Then a spatial data set delineating forest types throughout the conterminous United States (Powell et al. 1993) was overlaid onto the soil carbon data from STATSGO. An estimate of the average amount of carbon in the soil was then calculated for each forest type. Estimates included both mineral soils and organic soils.<sup>1</sup> Coarse roots were included with tree carbon estimates rather than with soils. The soil carbon estimates are given in Table O-1. These estimates were multiplied by the area of forest land in each forest type for all years. Thus, any change in soil carbon is a reflection of changes in the area of forest land or changes in forest type.

### Step 1g: Calculate Net Carbon Stock Changes

After calculation of all forest carbon stocks, the final step was to calculate the average annual net carbon stock change for each forest carbon pool for the years from 1990 through 2001. The net annual stock change for each pool for 1987 through 1997 was derived by subtracting the 1987 stock from the 1997 stock, and dividing by the number of years between estimates (10 years). The stocks, by definition, correspond to the stock as of January 1 of the given year. The net annual stock changes for 1997 through 2001 were derived in the same way using the 1997 and 2002 stocks. The procedure for estimating carbon stocks in 2002 is described below under the heading “Forest Sector Modeling Projection System.”

### Step 2: Estimate Harvested Wood Carbon Fluxes

The first step in estimating stocks and fluxes of harvested wood (i.e., wood products and landfilled wood) was to compile historical data on: the production of lumber, plywood and veneer, pulp and other products; product and log imports and exports; and fuelwood (in terms of million cubic feet of roundwood equivalent beginning in the year 1900, as described in Skog and Nicholson 1998). Data were obtained from USDA (1964), Ulrich (1989), and Howard (2001). Projected values for wood products and roundwood use were obtained from the models used for the USDA Forest Service 2000 Resource Planning Act Assessment (Haynes 2002, Ince 1994, see “Forest Sector Modeling Projection System” below). Roundwood products include logs, bolts, and other round timber generated from harvesting trees for industrial or consumer use. The harvested wood-to-carbon conversion factors presented by Skog and Nicholson (1998) were applied to annual estimates and projections to estimate the amount of carbon in roundwood and wood products. The amount of roundwood consumed was categorized according to product such as lumber, railroad ties, and paper, because the length of time that carbon remains in these products differs substantially. The dynamics of carbon loss through decay or through disposal of the product is summarized as the half-life of each product (Skog and Nicholson 1998). The resulting estimates were applied to products to derive the net carbon change in wood products and landfills. Note that, unlike forest carbon stock estimates, carbon in harvested wood products estimates are derived as a carbon stock change. In other words, the annual roundwood production is a change variable already before it is converted to carbon.

### Step 3: Sum the Results from Step 1 and Step 2 for the Total Net Flux from U.S. Forests

In the final step, net changes in forest carbon stocks are added to net changes in harvested wood carbon stocks, to obtain estimates of total net forest flux (see Table O-3).

**Table O-3: Net CO<sub>2</sub> Flux from U.S. Forest Carbon Stocks (Tg CO<sub>2</sub> Eq.)**

Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
<b>Forests</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(773.7)</b>	<b>(546.3)</b>	<b>(546.3)</b>	<b>(546.3)</b>	<b>(546.3)</b>	<b>(546.3)</b>
Trees	(469.3)	(469.3)	(469.3)	(469.3)	(469.3)	(469.3)	(469.3)	(447.3)	(447.3)	(447.3)	(447.3)	(447.3)
Understory	(11.0)	(11.0)	(11.0)	(11.0)	(11.0)	(11.0)	(11.0)	(14.7)	(14.7)	(14.7)	(14.7)	(14.7)
Forest Floor	(25.7)	(25.7)	(25.7)	(25.7)	(25.7)	(25.7)	(25.7)	29.3	29.3	29.3	29.3	29.3
Down Dead Wood	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)
Forest Soils	(212.7)	(212.7)	(212.7)	(212.7)	(212.7)	(212.7)	(212.7)	(55.0)	(55.0)	(55.0)	(55.0)	(55.0)

<sup>1</sup> Organic soils, otherwise known as histosols, are soils that develop in wetland areas and have greater than 20 to 30 percent organic matter by weight depending on clay content.

<b>Harvested Wood</b>	<b>(209.0)</b>	<b>(198.0)</b>	<b>(202.8)</b>	<b>(203.9)</b>	<b>(210.5)</b>	<b>(205.3)</b>	<b>(205.3)</b>	<b>(212.7)</b>	<b>(205.3)</b>	<b>(216.3)</b>	<b>(209.0)</b>	<b>(212.7)</b>
Wood Products	(47.7)	(40.7)	(46.6)	(54.6)	(60.9)	(55.0)	(55.0)	(58.7)	(51.3)	(62.3)	(58.7)	(58.7)
Landfilled Wood	(161.3)	(157.3)	(156.2)	(149.2)	(149.6)	(150.3)	(150.3)	(154.0)	(154.0)	(154.0)	(150.3)	(154)
<b>Total</b>	<b>(982.7)</b>	<b>(971.7)</b>	<b>(976.4)</b>	<b>(977.5)</b>	<b>(984.1)</b>	<b>(979.0)</b>	<b>(979.0)</b>	<b>(759.0)</b>	<b>(751.7)</b>	<b>(762.7)</b>	<b>(755.3)</b>	<b>(759.0)</b>

Note: Parentheses indicate net carbon "sequestration" (i.e., accumulation into the carbon pool minus emissions or stock removal from the carbon pool). The sum of the net stock changes in this table (i.e., total net flux) is an estimate of the actual net flux between the total forest carbon pool and the atmosphere. Lightly shaded areas indicate values based on a combination of historical data and projections. Forest values are based on periodic measurements; harvested wood estimates are based on annual surveys. Totals may not sum due to independent rounding.

## Forest Sector Modeling Projection System

The modeling projection system is a set of models that has been used for the USDA Forest Service, Resource Planning Act Assessment since the late 1980s (Figure O-1). The models include an area change model (Alig 1985), a timber market model (TAMM; Adams and Haynes 1980), a pulp and paper model (NAPAP; Ince 1994) and an inventory model (ATLAS; Mills and Kincaid 1992). Many of these models are econometric models, designed to project the demand and supply and prices in the forest sector. Results of the projection include timber volume, forest areas, harvests, and primary product production. For a description of the assumptions and results of the modeling system, see Haynes (2002).

The FORCARB model (Plantinga and Birdsey 1993, Heath and Birdsey 1993, and Heath et al. 1996) uses data on timber volume, forest areas, and harvests from the modeling system to estimate carbon in trees using biometrical relationships between carbon and live tree volume. FORCARB estimates carbon in all other forest ecosystem components, producing carbon density estimates similar to those in Table O-1 and Table O-2. The model WOODCARB (Skog and Nicholson 1998) uses harvested roundwood product statistics, along with end-use, decay rate, and duration information to estimate carbon in harvested wood.

Figure O-1 illustrates the connections between the various models, data inputs, and data outputs that comprise the forest sector modeling projection system. Names of model authors are in parentheses in each model box to facilitate identification of model citations. Data that are external to the models are marked with double lines.

### Figure O-1: Forest Sector Modeling Projection System

**Figure 0-1: Forest Sector Modeling Projection System**

