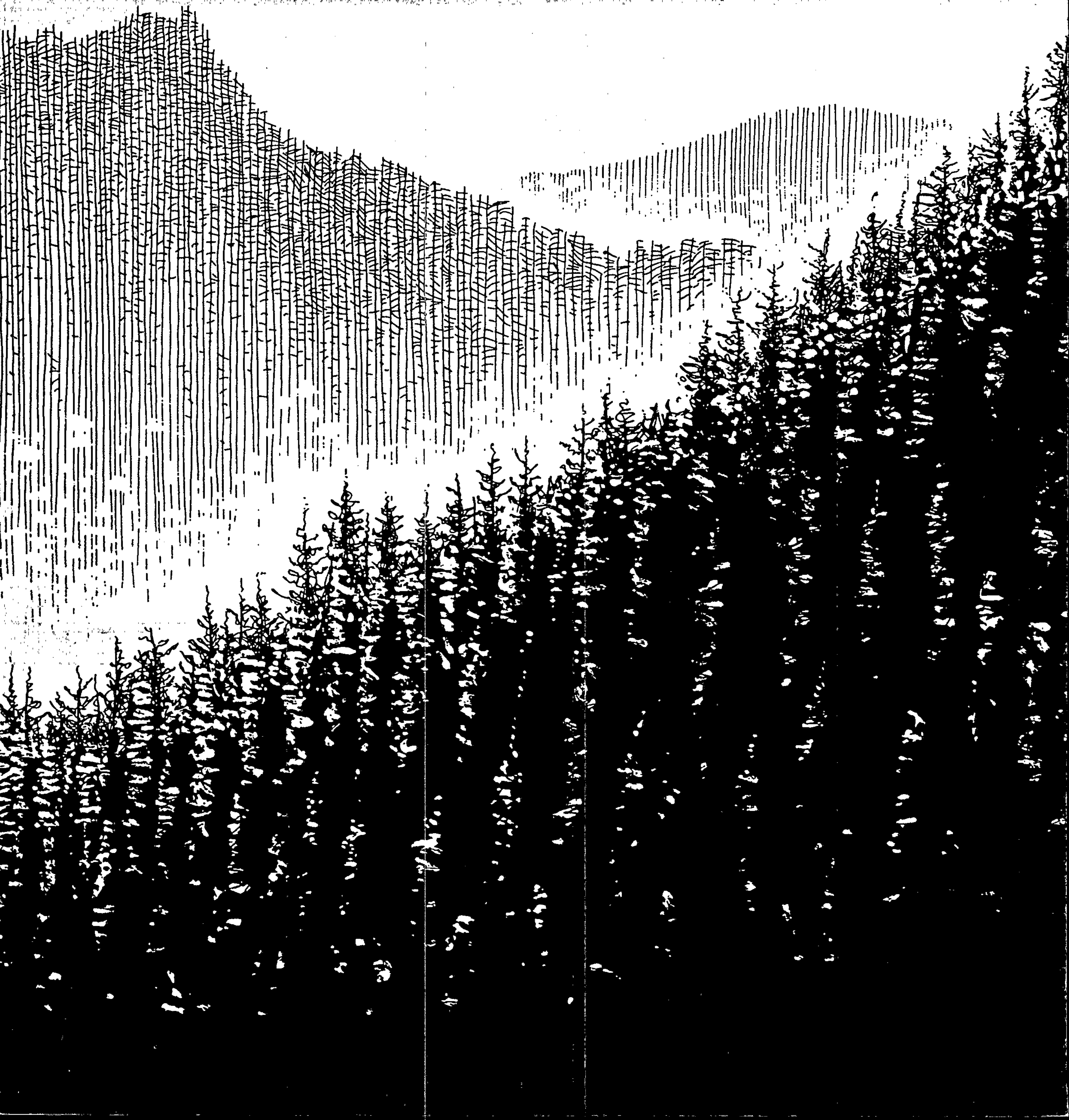
United States
Environmental Protection
Agency

Policy, Planning,
And Evaluation
(2122)

EPA 230-R-95-002
June 1995

EPA

Climate Change Mitigation Strategies In The Forest And Agriculture Sectors



Climate Change Mitigation Strategies in the Forest and Agriculture Sectors

U.S. Environmental Protection Agency
Office of Policy, Planning, and Evaluation
Climate Change Division
Washington, D.C., U.S.A.

June 1995

ACKNOWLEDGEMENTS

This report is the result of an extensive collaborative effort by a number of organizations and individuals. The work was sponsored and coordinated by the EPA Office of Policy, Planning, and Evaluation (OPPE), in Washington, DC. Richard Morgenstern, Maryann Froehlich, Dennis Tirpak, and Jane Leggett-Emil provided important guidance and support for the project. Kenneth Andrasko, William Hohenstein, and Steven Winnett provided technical guidance, coordination, and review throughout the project.

A number of individuals contributed to the design and coordination of the research, including: Thomas Murphy, Peter Beedlow, and Robert Dixon at the EPA Environmental Research Laboratory in Corvallis, OR; Rosemarie Russo, Lee Mulkey, and Tom Barnwell at the EPA Environmental Research Laboratory in Athens, GA; Courtney Riordan at the EPA Office of Research and Development; Andy Manale at the Water and Agricultural Policy Division of OPPE; Thomas Hamilton, Fred Kaiser, William Sommers and David Darr at the USDA Forest Service Research Office; Richard Haynes, John Mills, Judy Mikowski, and Del Thompson at the USDA Forest Service Pacific Northwest Research Station; Peter Ince and Ken Skog at the USDA Forest Service Forest Products Laboratory, Madison, WI; Carol Whitman and Gary Evans at the USDA Global Change Office; and Kate Heaton at the Bruce Company.

Studies for this analysis were conducted by: David Turner, Jeffrey Lee, Greg Koerper, and Jerry Barker at the EPA Environmental Research Laboratory in Corvallis, OR; Richard Haynes, Ralph Alig, and Eric Moore at the USDA Forest Service Pacific Northwest Research Station in Portland, OR; Richard Birdsey and Linda Heath at the USDA Forest Service in Washington DC; John Perez-Garcia at the Center for International Trade in Forest Products, University of Washington, Seattle, WA; Aziz Bouzaher, Derald Holtkamp, Randall Reese, and Jason Shogren at the Center for Agricultural and Rural Development, Iowa State University, Ames, IA; Anthony Donigian, Avinash Patwardhan, and Radha Chinnaswamy at AQUA TERRA Consultants, Mountain View, CA; Tom Barnwell and Robert Jackson at the EPA Environmental Research Laboratory in Athens, GA; Kevin Weinrich and Allen Rowell at Computer Sciences Corporation, Athens, GA; Vern Cole at the Natural Resources Ecology Laboratory, Fort Collins, CO; Bruce McCarl at Texas A&M University, College Station, TX; John (Mac) Callaway at RCG/Hagler Bailly, Boulder, CO; and Alice Cialella and Changsheng Li at the Bruce Company, Washington, DC.

Assistance in preparing this report synthesizing the study results was provided by Frances Sussman, David Reiner, Jeff Fiedler, Doug Keinath, Susan Barvenik, and Roger Schwabacher at ICF Incorporated, Washington, DC.

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EXECUTIVE SUMMARY

Human activities, particularly the use of fossil fuels for energy, increase atmospheric levels of greenhouse gases, which may induce changes in the earth's climate over the coming decades. While there remains considerable uncertainty about the rate and magnitude of possible climatic changes, the Intergovernmental Panel on Climate Change, under the auspices of the World Meteorological Organization and the United Nations Environmental Program, estimates that rising concentrations of greenhouse gases are likely to increase global temperatures by between 1.5°C and 4.5°C (2.7°F and 8.1°F) over the next century (IPCC 1992).

Together with temperature rise, related climatic changes, including rising sea level and altered storm patterns, are likely to have adverse impacts, such as loss of wetlands and coastal property, changes in water supply, and reductions in agricultural productivity in some areas. The U.S. Government is examining policies that may help reduce atmospheric concentrations of greenhouse gases, the most important of which is carbon dioxide (CO_2).

Because vegetation and soil contain about three times as much carbon as the atmosphere, terrestrial ecosystems offer an opportunity to absorb and store (sequester) a significant additional amount of CO_2 from the atmosphere. One possible approach for slowing the increase in greenhouse gases concentrations in the atmosphere is to manage terrestrial ecosystems to conserve or sequester additional carbon.

Forest ecosystems represent an important opportunity for conserving and sequestering carbon because of their large accumulations of woody biomass. Creating new forests or restoring degraded ones can significantly increase carbon sequestration. Similarly, agricultural systems, which cover vast acreages, can be managed on a yearly basis to augment the large store of carbon in their soils.

The Office of Policy, Planning, and Evaluation at the U.S. Environmental Protection Agency, in collaboration with the U.S. Forest Service, is conducting an assessment of land use management policies that can contribute to stabilizing U.S. greenhouse gas emissions. This assessment analyzes potential greenhouse gas, economic, and other impacts of land use management policies. The assessment uses a number of different sectoral models, which have been, where feasible, linked to provide a comprehensive evaluation of the forest and agricultural sectors. Scenarios that represent the implementation of a number of policies are being analyzed using the assembled models. While much of this work is still ongoing, this study presents preliminary results of the following scenario analyses:

- Tree Planting on Marginal Crop and Pasture Land
- Conservation Reserve and Wetlands Reserve Programs
- Increased Use of Recycled Paper
- Reduced Harvest on National Forest Land
- Increased Use of Biomass Energy
- Modified Agricultural Tillage Practices
- Increased Use of Winter Cover Crops

TREE PLANTING ON MARGINAL CROP AND PASTURE LAND

Forestation policies that plant trees on marginal crop and pasture land increase the acreage devoted to forests in the U.S. These policies also increase the amount of carbon stored in U.S. forests.

- **Carbon Impacts.** A large-scale tree planting program of 12 million acres, costing $220 million annually for 10 years, would sequester an additional 6.8 million metric tons of carbon annually in 2000, and 16.7 million metric tons in 2010 (see Table ES-1). This accumulation would increase the size of the U.S. forest carbon pool by between almost 500 and 800 million metric tons of carbon by 2040, relative to the baseline, with approximately one-fourth of the total achieved by 2010.

- **Economic Impacts.** Since planting trees increases the wood available for harvest when the timber reaches maturity, future prices for timber are lower than in the absence of the tree planting program. Stumpage prices fall most in the South, creating benefits for consumers and losses for owners of timber. Lower prices for U.S. timber result in a significant decrease in imports of Canadian lumber by the year 2040.

- **Other Impacts.** Tree planting on marginal lands can reduce soil erosion, protect watersheds, and conserve biodiversity.

CONSERVATION RESERVE AND WETLANDS RESERVE PROGRAMS

One policy option using existing programs to sequester carbon is to extend current and planned contracts under the Conservation Reserve Program (CRP), thereby preventing the loss of forested land that would otherwise revert to cropland. Other options would expand both the CRP and the Wetlands Reserve Program (WRP) with tree-planted areas.

- **Carbon Impacts:**

  • Enrolling 40 million acres under the CRP and maintaining this acreage would result in an annual carbon accumulation of 11.6 million metric tons in 2000, and 7.9 million metric tons in 2010. This would increase the size of the U.S forest carbon pool by almost 200 million metric tons in 2015 and nearly 350 million metric tons by 2035, compared to the likely reversion of CRP lands after 1995.

  • Expanding the CRP to 50 million acres by planting an additional 10 million acres with trees would result in an annual carbon accumulation of 31.5 million metric tons in 2000, and 15.9 million metric tons in 2010 (see Table ES-1), and would more than double the incremental carbon stored relative to the base case. The total carbon pool on these lands would increase by over 1,100 million metric tons by 2035.

  • Expanding the WRP to five million acres would result in an annual carbon accumulation of 2.2 million metric tons in 2000, and 4.4 million metric tons in 2010. The forest carbon pool would increase by almost 200 million metric tons by 2035.

- **Economic Impacts.** Net economic returns increase for crop producers, but decrease significantly for livestock producers. The net result of changes in income and in government payments is a decline in combined agriculture and livestock industry returns of about $350 million to $450 million per year. Under the CRP scenarios, consumers are generally worse off with slightly lower consumption and higher retail prices, resulting in about a 2 percent increase in total consumer expenditures.

INCREASED USE OF RECYCLED PAPER

By decreasing the demand for harvested wood, increased paper recycling has the potential to increase standing biomass and, thus, enlarge the forest carbon pool. In this scenario, the utilization rate for recycled wastepaper increases to 45% by 2000 and remains constant through 2040.

- **Carbon Impacts.** Increased use of recycled paper would result in an annual carbon accumulation of 13.5 million metric tons in 2000, and 15.6 million metric tons in 2010 (see Table ES-1). The forest carbon pool would increase by an additional 400 to 600 million metric tons by 2040, an amount comparable to that of large scale tree planting programs.

- **Economic Impacts.** Because additional recycling reduces the demand for pulpwood, stumpage prices and revenues for producers decline over time under this scenario. Declining revenues occur predominantly in the softwood markets in the South, which produce the bulk of the paper pulp for markets that switch to recycled fiber. Lower U.S. timber prices reduce softwood lumber imports from Canada, which drop roughly to 36 percent below base case levels by 2040.

REDUCED HARVEST ON NATIONAL FOREST LAND

Harvest reductions in this scenario result from eliminating harvest of old growth volumes in the Pacific Northwest, protecting spotted owl habitat in Washington, Oregon and California, protecting the red cockaded woodpecker in the South, eliminating below cost timber sales, and eliminating harvesting in existing roadless areas.

- **Carbon Impacts.** Decreases in National Forest harvest would be mostly offset by increased harvests by other landowners, or in other regions. Overall there is little change in the total timber inventory and, hence, in the total carbon stored on U.S. timberland. Offsetting harvests in other countries could, however, increase carbon storage in U.S. forests over base case levels. Carbon losses in those other countries might be greater than the carbon savings realized in the U.S.

- **Economic Impacts.** Because timber inventories are reduced, softwood lumber prices increase, prompting a slight decrease in consumption of 16% and an increase in Canadian imports of 10% by 2040. Higher prices also increase the use of more energy-intensive, non-wood substitute products. Analysis of international trade linkages suggests that higher prices increase harvests in countries other than the U.S. This result could lead to economic surplus gains of $1.4 billion to timber producers worldwide and a net welfare loss of almost $100 million for U.S. producers.

INCREASED USE OF BIOMASS ENERGY

Under this scenario, energy supplied by fuelwood from existing forests increases from 3.1 Quads in 2000 to 5.4 Quads in 2030, to meet levels of bioenergy supply contained in the National Energy Strategy (NES).

- **Carbon Impacts.** Increasing the production of energy from biomass has three distinct effects on CO_2 emissions: *(1)* CO_2 is released when the wood is combusted to produce energy; *(2)* carbon is sequestered during the growth or regrowth of forests harvested for biofuels; and *(3)* carbon emissions are "avoided" when fossil fuel combustion is displaced by bioenergy. Removing wood for biofuels initially has the effect of reducing the carbon inventory on the forest base. Over time, however, regrowth on harvested lands replaces the biomass carbon. Increased use of biomass energy results in an annual forest carbon accumulation of -7.3 million metric tons in 2000, and -17.8 million metric tons in 2010 (see Table ES-1). The real benefit to the atmosphere occurs as wood displaces fossil fuels. Avoided fossil fuel emissions are 2.6 million metric tons in 2000, and 7.5 million metric tons in 2010. Combined net carbon impacts equal -4.7 million metric tons in 2000, and -10.3 million metric tons in 2010.

COMBINED FOREST POLICY SCENARIOS

Because policies can have offsetting economic impacts, there are benefits to jointly implementing forest sector policies. Combining scenarios presents an opportunity to evaluate the carbon, timber, and economic consequences of a coordinated forest sector strategy to sequester carbon. The combined scenarios are:

- Reduced Harvest and Increased Wastepaper Recycling (Combination 1)
- Combination 1 with Increased Production of Energy from Biomass (Combination 2)
- Combination 2 with Large-scale Tree Planting (Combination 3)

The combined scenarios are projected to have the following effects.

- **Carbon Impacts.** The carbon impact of the combination 1 scenario is similar to that of the increased paper recycling scenario; 10.6 million metric tons of carbon are accumulated annually in 2000 and 13.0 million metric tons are accumulated annually in 2010. In addition:

  • Adding the biomass energy scenario (combination 2) reduces carbon significantly, even when avoided fossil fuel emissions are taken into account. Net annual carbon accumulation equals 6.8 million metric tons in 2000, and 3.7 million metric tons in 2010.

  • Adding large-scale tree planting to this scenario (combination 3) illustrates the benefits of combining a bioenergy strategy with plantations established to grow biofuel stocks. Net annual carbon accumulation for combination 3 rises to 12.7 million metric tons in 2000 and 18.5 million metric tons in 2010.

- **Economic Impacts.** Combining increased recycling with reduced harvests on public lands creates offsetting impacts on timber prices. Stumpage prices for combination 1 are higher than for the recycled fiber scenario and lower than the harvest reduction scenario. Because of the strong influence of additional recycling, prices are lower than in the base case. In addition:

  • Adding a large biomass energy program that draws on existing resources in the forest sector increases prices over the first scenario, creating economic gains for stumpage suppliers in the combination 2 scenario.

  • Introducing large-scale tree planting reduces prices, relative to combination 2. Because combination 3 includes the reduced harvest scenario and biomass energy scenario, however, which draw down the timber inventory, prices are above those for the tree planting scenario alone.

  Thus, the presence of multiple activities in the combined scenarios reduces the adverse economic impacts of individual scenarios.

MODIFIED AGRICULTURAL TILLAGE PRACTICES

It is estimated that agricultural soils store 1.5 trillion metric tons of carbon, or roughly twice the amount of carbon in the atmosphere. Under this scenario, tillage practices on highly erodible lands were changed to reduced-till and no-till practices in order to meet soil conservation targets.

- **Carbon Impacts.** Changing agricultural practices, that continue the trend towards conservation tillage, would result in average annual soil organic carbon accumulations of up to 2.5 million metric tons above base case levels (see table ES-1). Estimated soil carbon accumulation rates are very sensitive to projected crop yields. Soil carbon impacts on individual areas of the U.S. can differ significantly from national averages due to variation in dominant crop rotations, other production practices, climate, and soil conditions.

- **Economic Impacts.** Economic impacts depend primarily on assumptions about short term crop yield decreases due to unfamiliarity with the new tillage practices. Without yield adjustments, net returns (gross revenues less variable costs) under the low conservation scenario increase by $0.67 per acre, or 0.8 percent. Net returns under the more aggressive high conservation scenario increase by $4.06 per acre, or 5.4 percent. With yield adjustments for implementing conservation tillage practices, net returns decrease by $3.02 per acre or (3.4 percent) for the low conservation scenario, and decrease by $2.93 per acre or (3.3 percent) for the high conservation scenario.

- **Other Impacts.** As an additional benefit, soil erosion decreases by 20 to 30 percent with increased use conservation tillage practices.

INCREASED USE OF WINTER COVER CROPS

This scenario introduces winter cover crops to areas with favorable conditions (areas with proper climate, crop rotations, and length of growing season), thereby increasing total biomass production and associated soil carbon accumulation on agricultural lands over the course of the year.

- **Carbon Impacts.** Although lands targeted for winter cover crops account for only 5 to 10 percent of the total land area in the study region, there are significant increases in the level of soil organic carbon. Increased planting of winter cover crops results in an average annual soil organic carbon accumulations of up to 3.5 million metric tons above base case levels (see Table ES-1).

- **Economic Impacts.** Average net economic returns to farms decreased by slightly over 1 percent as a result of these cover crop policies.

- **Other Impacts.** Some cover crops, such as hairy vetch, have the additional benefit of fixing nitrogen in the soil.

Table ES-1
Annual Carbon Accumulation for the Forest and Agriculture Sector Scenarios, Decadal Intervals (million metric tons)

	2000	2010	2020	2030
Tree Planting on Marginal Crop and Pasture Land				
12 million acres, optimal distribution	6.8	16.7	19.4	13.0
6 million acres, optimal distribution	4.1	9.6	10.8	6.2
4 million acres, historic distribution	3.5	6.5	7.5	5.5
Conservation and Wetlands Reserve Programs				
40 million acres in CRP	11.6	7.9	7.7	7.2
50 million acres in CRP	31.5	15.9	34.5	31.6
5 million acres of Wetlands Forest	2.2	4.4	7.0	4.6
Increased Use of Recycled Paper	13.5	15.6	10.0	4.4
Increased Energy from Biomass				
Forest Carbon	*-7.3*	*-17.8*	*-29.6*	*-21.1*
Avoided Fossil Fuel Emissions	*2.6*	*7.5*	*13.2*	*27.5*
Net Carbon Flux	-4.7	-10.3	-16.4	6.4
Combined Forest Policy Scenarios				
Combination 1: NF harvest reduction and recycling	10.6	13.0	8.8	3.7
Combination 2: Combination 1 and biomass energy				
Forest Carbon	*4.2*	*-3.8*	*-23.8*	*-24.2*
Avoided Fossil Fuel Emissions	*2.6*	*7.5*	*13.2*	*27.5*
Net Carbon Flux	6.8	3.7	-10.6	3.3
Combination 3: Combination 2 and tree planting				
Forest Carbon	*10.1*	*11.0*	*-6.6*	*-12.7*
Avoided Fossil Fuel Emissions	*2.6*	*7.5*	*13.2*	*27.5*
Net Carbon Flux	12.7	18.5	6.6	14.8
Modified Tillage Practices	2.5	2.5	2.5	2.5
Winter Cover Crops	3.5	3.5	3.5	3.5

1. Introduction

Rising atmospheric levels of greenhouse gases, which are the result of anthropogenic sources of emissions, are likely to induce changes in the earth's climate over the coming decades. Greenhouse gas-induced climate change, which is projected to result in rising global average temperatures and rising sea levels, may have associated impacts on energy demand, water resource quality, coastal property and ecosystems, and the commercial forestry and agriculture sectors. There remains considerable uncertainty about the rate and magnitude of possible climate change, as well as about the physical impacts associated with such change. There is, however, an emerging consensus that policies to stabilize or reduce emissions of greenhouse gases — which include carbon dioxide (CO_2) and other radiatively important trace gases, such as methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) — should be explored (see Box 1-1).

The vegetation and soil in terrestrial ecosystems contain about three times as much carbon as is in the atmosphere, and play a major role in the movement of CO_2 and other greenhouse gases into and out of the atmosphere. For example, carbon may be released to the atmosphere as CO_2 or CH_4 when trees or other vegetation are harvested or decay, or when soils are tilled. Thus, increasing the amount of standing biomass, or changing cultivation practices, can increase the size of the carbon sink and decrease concentrations of greenhouse gases in the atmosphere. One proposed approach, therefore, for slowing the increase in atmospheric CO_2 is to manage terrestrial ecosystems to conserve or sequester (remove and store) carbon.

Forest ecosystems present particularly significant opportunities for carbon conservation and sequestration because of their large accumulations of woody biomass. In 1990, U.S. forests recaptured approximately 9 percent of the CO_2 emitted in the U.S. from the combustion of fossil fuels (USEPA 1994). Strategies in the forest and agriculture sectors have the technical potential to recapture a significantly greater portion of U.S. CO_2 emissions in the future.

The Office of Policy, Planning, and Evaluation at the U.S. Environmental Protection Agency, in collaboration with the U.S. Forest Service, is conducting an assessment of land use management policies that can contribute to stabilizing U.S. greenhouse gas emissions. A broad set of policies in the agriculture and forest sectors that could potentially increase the capacity of terrestrial carbon storage include:

Box 1-1
Actions to Mitigate Climate Change

In 1992, the United Nations Conference on Environment and Development (UNCED) formulated the Framework Convention on Climate Change, which has since been signed by the U.S. and at least 160 other countries. On Earth Day 1993, President Clinton announced that the U.S. would participate in climate change mitigation efforts and, in October 1993, released the U.S. Climate Change Action Plan (CCAP), which has as its goal returning U.S. emissions of greenhouse gases to 1990 levels by the year 2000.

Emissions of greenhouse gases are generally measured in million metric tons of carbon equivalent (MMTCE). MMTCE provides a consistent measure to compare emissions of different greenhouse gases that accounts for the relative global warming input of each gas. In 1990, U.S. net greenhouse gas emissions equalled 1,444 MMTCE. Of this total, 1,233 MMTCE (85 percent) were net carbon released as CO_2 emissions, 162 MMTCE (11 percent) were methane (CH_4), 30 MMTCE (2 percent) were N_2O, and 19 MMTCE (1 percent) were HFCs or PFCs.

In the absence of the CCAP, the Administration projects that net greenhouse gas emissions would grow to 1,568 MMTCE by 2000. Under the CCAP, which includes measures to reduce various sources of emissions as well as increase carbon sequestration by forests, the Administration estimates net greenhouse gas emissions of 1,459 MMTCE. This estimate reflects reductions by the year 2000 of 109 MMTCE, or 7 percent of estimated emissions in the year 2000.

Sources: USEPA 1994; USDOS 1994

- enlarging the acreage of trees by encouraging rural and urban tree planting and adopting long term fire management strategies;

- increasing the rate of tree growth on existing forest land by improving timber management practices or using improved seedling stock;

- using biomass-based fuels, which reduce carbon emissions from fossil fuels, and do not themselves have a net impact on long-term atmospheric carbon;

- increasing utilization rates for recycled paper, thereby reducing demand for pulpwood and maintaining and increasing timber inventories;

- conserving standing primary and old-growth forests as stocks of biomass by restricting harvesting or setting aside land;

- reducing soil disturbances by modifying tillage practices and thereby increasing soil organic carbon; and

- planting winter cover crops to increase biomass on agricultural lands.

This document summarizes the results of a number of studies conducted over the last three years to examine forestry and agricultural policies, including many of those described above, and their implications for carbon storage and emissions of greenhouse gases (see Box 1-2). Understanding not only the greenhouse gas implications but also the socioeconomic effects of these policies requires answering a series of key questions:

- To what extent can the policy or program sequester or offset greenhouse gas emissions?

- How much will the policy or program cost the government?

- What are the economic and social impacts on the forest and agriculture sectors nationally and regionally?

- How effective are the policies or programs when combined?

- What are the impacts of these domestic policies on global trade, and of global trade on these policies?

The results of the studies reported in this document build on a body of literature, both scientific and policy-analytic. Past analyses of the potential impacts of domestic forest and agriculture management practices have concentrated on one or two of a multitude of factors — an individual policy, effects on soil carbon, or program cost. This study evaluates the full range of economic implications and quantifies the likely physical effects for a variety of potential strategies. Together with the past literature, the studies reported here represent an initial step towards building the volume of information necessary to comprehensively assess viable policy options in the forest and agriculture sectors for reducing/offsetting greenhouse gas emissions.

This study has assembled a set of models which, collectively, evaluate the impacts of various forest and agriculture sector strategies designed to reduce or sequester carbon emissions. Following a brief description (in Section 2) of carbon processes, land use change, and the scenarios examined, Section 3 presents the models used in the study. Sections 4, 5, and 6 present the results of the scenario analyses. Section 7 concludes with a brief discussion of research directions.

Box 1-2
Studies Conducted for this Assessment

The Forest Sector Carbon Budget of the United States: Carbon Pools and Flux Under Alternative Policy Options. May 1993. Edited by D.P. Turner, J.J. Lee, G.J. Koerper, and J.R. Barker, U.S. EPA Environmental Research Laboratory at Corvallis, Oregon. EPA report EPA/600/3-93/093. Supplemented by additional scenario analyses.

Alternative Simulations of Forestry Scenarios Involving Carbon Sequestration Options: Investigation of Impacts on Regional and National Timber Markets. August 1994. Report prepared by R.W. Haynes, R.J. Alig, and E. Moore, USDA Forest Service, PNW Station, General Technical Report PNW-GTR-355.

Carbon Sequestration Impacts of Alternative Forestry Scenarios. April 1993. Report prepared by R.A. Birdsey and L.S. Heath, USDA Forest Service. Supplemented by additional scenario analyses.

Global Forestry Impacts of Reducing Softwood Supplies from North America. July 1993. Working Paper 43 prepared by J.M. Perez-Garcia, Center for International Trade in Forest Products at the University of Washington.

An Analysis of Proposed Domestic Climate Warming Mitigation Program Impacts on International Forest Products Markets. July 1994. Working Paper 50 prepared by J.M. Perez-Garcia, Center for International Trade in Forest Products at the University of Washington.

Economic and Resource Impacts of Policies to Increase Organic Carbon in Agricultural Soils. May 1993. Report prepared by A. Bouzaher, D.J. Holtkamp, R. Reese, and J. Shogren, Center for Agricultural and Rural Development at Iowa State University.

Long Term Economic Consequences of Alternative Carbon Reducing Conservation and Wetlands Reserve Programs: A BLS Analysis. May 1993. Report prepared by R. Reese, A. Bouzaher, and J. Shogren, Center for Agricultural and Rural Development at Iowa State University.

Assessment of Alternative Management Practices and Policies Affecting Soil Carbon in Agroecosystems of the Central United States. April 1994. Report prepared by A.S. Donigian, A.S. Patwardhan, and R. Chinnaswamy, AQUA TERRA Consultants; T.O. Barnwell, Jr. and R.B. Jackson, IV, U.S. EPA Environmental Research Laboratory at Athens, Georgia; K.B. Weinrich and A.L. Rowell, Computer Sciences Corporation; and C.V. Cole, Natural Resources Ecology Laboratory. EPA/600/R-94/067.

Planting Trees on Agricultural Lands: The Costs and Economic Impacts of CRP Reversion. December 14, 1994. Report prepared by J.M. Callaway, RCG/Hagler Bailly and B.F. McCarl, Texas A&M University.

Carbon Sequestration and N_2O Emissions from Soils: A Model Simulation Study for Seven Agricultural Sites in the Central U.S. Using the DNDC model. October 7, 1993. Draft report prepared by C. Li and A. Cialella, The Bruce Company.

2. BACKGROUND: THE CARBON CYCLE, HISTORIC LAND USE CHANGE, AND MITIGATION STRATEGIES

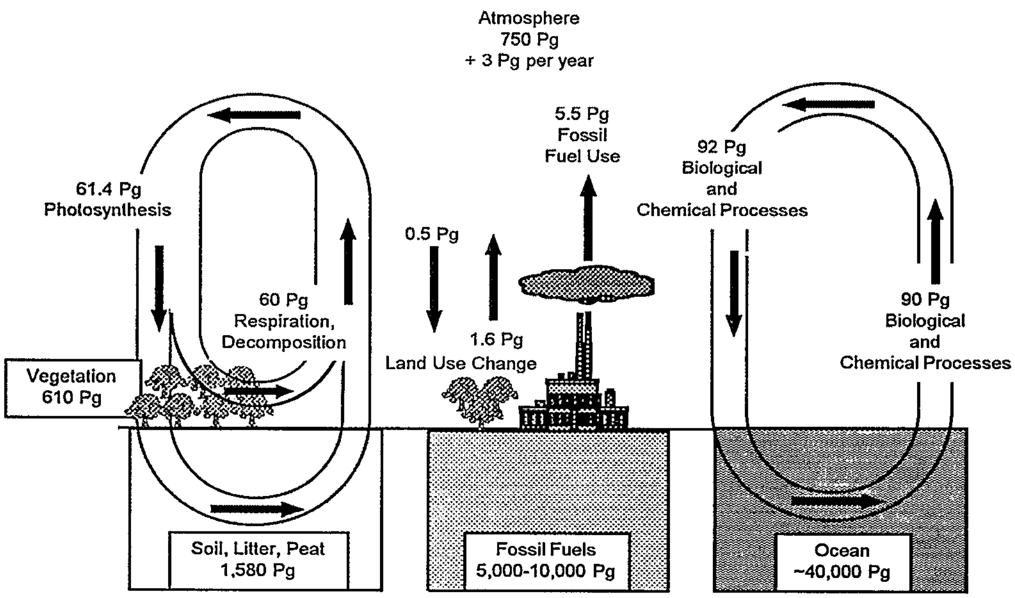
Rising levels of atmospheric CO_2 may increase global temperatures through the "greenhouse" effect, which in turn may raise sea level and have serious domestic and international implications for human health, ecosystems, productive resources, and coastal areas. The atmospheric concentration of CO_2 has risen from approximately 275 parts-per-million (ppm) in pre-industrial times to 350 ppm today, and is currently increasing at a rate of approximately 1.5 ppm per year. Projections suggest that the global average temperature will warm by 1.5 °C to 4.5 °C (2.7 °F to 8.1 °F) by the first half of the next century (IPCC 1992).

The potential consequences of increasing atmospheric carbon levels are serious enough that governments are considering programs to stabilize or reduce anthropogenic emissions. Increasing forest carbon sequestration can play an important role in these efforts. To develop effective policy options, an understanding of the global carbon cycle, and how anthropogenic carbon emissions may affect it, is necessary. This section presents background information on the role of terrestrial ecosystems in the global carbon cycle, describes how historic land-use changes have determined the current status of U.S. forests, and presents the policy scenarios that are evaluated in this report.

2.1 The Global Carbon Cycle and Carbon Sector Budgets

The global carbon cycle is the movement of carbon among the atmosphere, terrestrial biosphere, and ocean. Current estimates suggest that the oceans store by far the largest amount of carbon — roughly 40,000 billion metric tons of carbon (see Figure 2-1). Soil is the next largest reservoir, or pool, followed by the vegetation and the atmospheric carbon reservoirs, which are about equal in magnitude. Although the terrestrial biosphere (vegetation and soils) stores much less carbon than do the oceans, the amount of carbon that cycles annually between the terrestrial biosphere and the atmosphere is similar to that which cycles between the oceans and the atmosphere. Together, the combined annual flux between these two pools and the atmosphere is about 20 percent of the total atmospheric carbon pool.

Figure 2-1. The Global Carbon Cycle



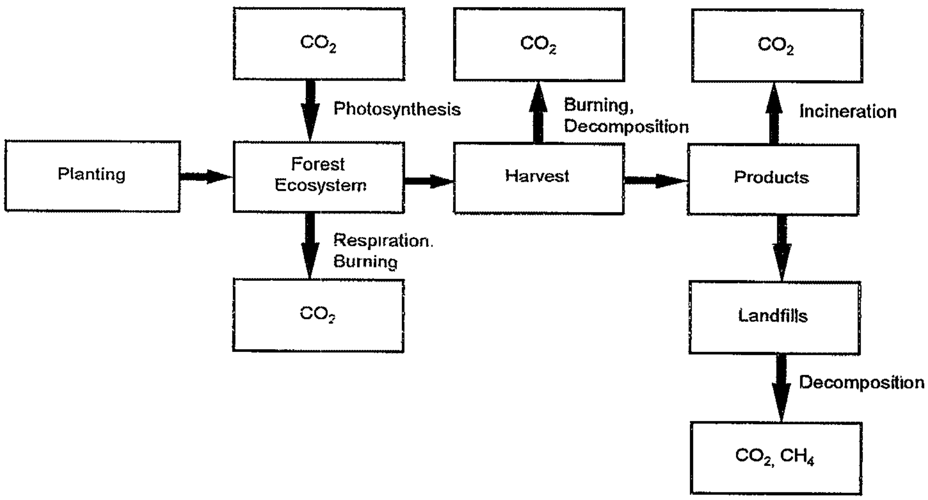
Sources: IPCC 1994; IPCC 1992; Schneider 1989

From the perspective of possible global climate change, the concern is that more carbon, primarily in the form of CO_2, is accumulating in the atmosphere than is being removed through plant photosynthesis and other biological processes. It is estimated that the atmosphere is gaining about 3 billion metric tons of carbon annually. The two principal sources of atmospheric CO_2 increases are fossil fuel combustion and deforestation, which contribute 5.5 billion and 1.1 billion metric tons of carbon, respectively, worldwide. Further, trends suggest that rates of anthropogenic emissions of CO_2 from these two sources are rising. Terrestrial vegetation is an important component of the carbon cycle, and policies designed to enhance its capacity as a carbon pool, or reduce its emissions of greenhouse gases, can potentially have a significant impact on atmospheric levels of CO_2.

FOREST SECTOR CARBON BUDGET[1]

A carbon budget is a bookkeeping system for tracking the amount of carbon in various reservoirs ("pools") and the amount of carbon transferred among the reservoirs and the atmosphere ("fluxes"). The forest sector carbon budget has three major pools: the organic matter of forest ecosystems, the products derived from forests, and products that are landfilled, incinerated, or otherwise discarded (see Figure 2-2). The main uptake of carbon into forests is through photosynthesis, the fixation of atmospheric CO_2 by green plants. Carbon loss from forests occurs primarily from burning and from the harvest of wood by humans. The net flux of carbon from the atmosphere to the forest is the difference between carbon uptake from photosynthesis and carbon release from respiration by all forest organisms, including decomposers. The "net accumulation" of carbon by forest ecosystems is the net flux minus carbon removed by harvest and burning. Detailed forest sector inventories developed periodically by the U.S. Forest Service provide an accurate basis for estimating forest carbon storage. The analyses conducted for this report model the impacts of various policies on forest inventories over time and estimate the associated changes in carbon storage.

Figure 2-2. The Forest Sector Carbon Budget



Source: Turner, et al. 1993

Unlike the forests, there are no systematic inventories of the product and disposal pools, or of the net annual transfer of material into or out of these pools. Some products, such as furniture and lumber for housing, are a relatively long-lived store for carbon. Once these and other products, such as newspaper and paper packaging, enter disposal pools, much of the material decays and the carbon is emitted to the atmosphere in the form of greenhouse gases. The length of time over which material decays depends on the type of material and on factors specific to the landfill. In some cases, a portion of the carbon may effectively be permanently stored in the landfill. Transfers of harvested

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[1] This section is based primarily on Turner, et al. 1993.

forest biomass into product and disposal pools can, therefore, have a significant impact on the timing and magnitude of carbon accumulation in the entire forest sector.

Agriculture

Vegetation and soil in the agricultural sector also store carbon. Soil organic matter, in the form of live crops in the ground, crop residues, and other dead and decaying plant material and soil micro-fauna, account for the carbon found in agricultural soils. Soil carbon accumulation is determined by the balance of biomass inputs from primary production (e.g., crop residue) and carbon loss from decomposition and erosion (Donigian, et al. 1994). Thus, agricultural management practices such as crop selection, crop residue treatment (e.g., burning, removal), and tillage, have a large impact on soil carbon accumulation. For example, tilling soil during the planting season disturbs some of the soil organic matter and promotes decomposition, releasing CO_2 into the atmosphere. Management practices that increase production, such as introducing winter cover crops into an annual crop rotation, can also increase soil carbon accumulation.

2.2 Historic Land Use Change: U.S. Forests[2]

The history of the conversion of original forest to its current state is important for a complete understanding of trends and modelling projections of carbon flux and storage. In 1630, the continental U.S. had about 822 million acres of forest land, characterized by a high proportion of very large trees and in approximate equilibrium with respect to growth and mortality. With the exception of pockets in the western U.S., most of the pre-settlement forest has now been cleared and developed, or replaced with agricultural land or successional forest. Productive forest land (see Box 2-1) is estimated at 537 million acres, with another 200 million acres of urban and marginal forest land (now called other forest) (Haynes, et al. 1994). A division of the continental U.S. into three regions — North, South, and West — broadly captures differences in the use and management of the pre-settlement forest lands. Current and historic carbon storage on these lands reflects the different land use patterns in each region (see Figure 2-3).[3]

Box 2-1
Definition of Timberland and Woodland

Forest land in the U.S. is differentiated between timberland, reserved timberland, and other forest. *Timberland* is forest land that is producing or is capable of producing crops of industrial wood and that is not withdrawn from timber utilization by statute or administrative regulation. (Note: areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)

Reserved timberland refers to land having the productive capacity of timberland but which is withdrawn from timber utilization by statute or administrative regulation.

Other forest land ("woodland") includes forest land other than timberland and reserved timberland. It includes available and reserved unproductive forest land, which is incapable of producing 20 cubic feet per acre per year of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness.

Source: Turner, et al. 1993

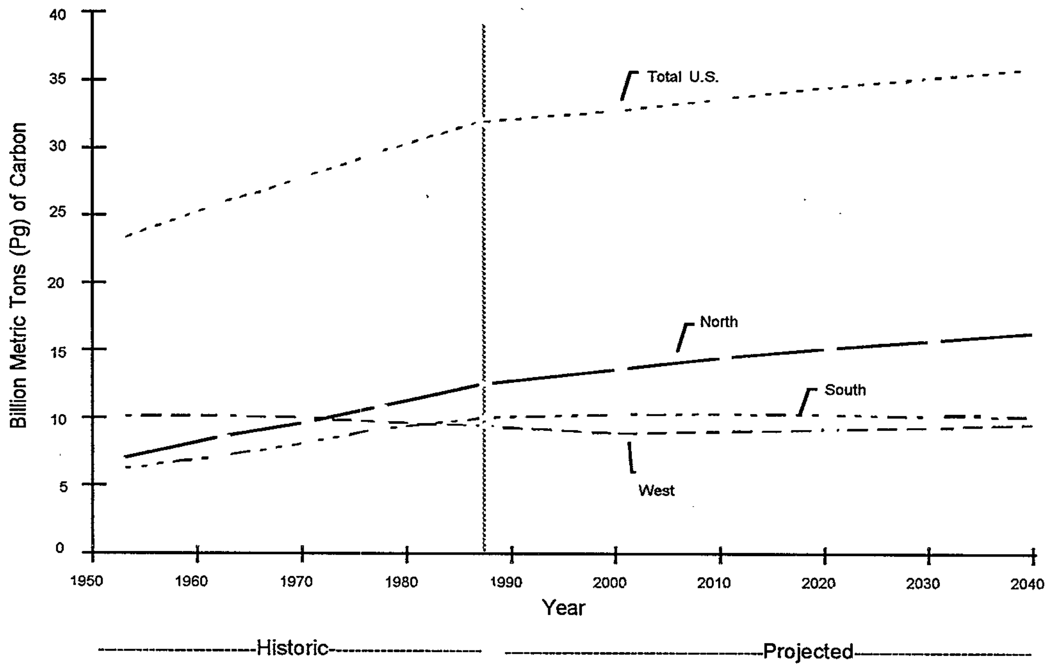
Northern Region

By the end of the 19th century, virtually all northern forests had been cleared for agricultural use or heavily logged for timber products, with the exception of extreme northern

[2] This section is based primarily on Birdsey and Heath 1993.

[3] In terms of the regions identified subsequently in Figure 4-2, the West is composed of the Pacific Northwest and Southwest and the Rocky Mountains; the North combines the Northeast and the North Central; and the South contains the Southeast and South Central.

Figure 2-3. Carbon Storage on U.S. Timberland, by Region



Source: Birdsey and Heath 1993

areas of Maine and the Great Lakes States and some inaccessible areas in the Appalachian mountains. Beginning in the mid-nineteenth century and accelerating in the 20th century, marginal agricultural land reverted to forest and produced a dense stocking of trees, with much of the area now covered by trees in the 25 to 65 year age classes. These forest lands of mixed species are in the middle of a period of rapid growth that can be sustained for several more decades before reaching a period of declining growth. In the near future, therefore, forest biomass is expected to continue to increase.

SOUTHERN REGION

As in the North, only scattered fragments of pre-settlement forest remain. The current forest has been regenerated either naturally or artificially on marginal cropland, pasture, or cutover forest land, and many areas are being cut for the third time and regenerated to a fourth timber stand. The intensively managed southern forests have the youngest age class distribution in the U.S., with a large proportion in the 25 to 45 year age classes. Because of intensive management and a continuing shift of industrial timber supply to the South, most of these forests are not expected to reach biological maturity before further harvest and regeneration. Forest biomass is expected to remain constant or decline slightly over time.

WESTERN REGION

Although the West has not experienced the major land use shifts characteristic of other regions, forest disturbance has dominated the landscape as the original forests have been logged and converted to second-growth forests. The remaining old-growth in the West comprises less than 2 percent of the pre-settlement forest. Both private and public western forests have a relatively flat age-class distribution, but with a large component of older forest classes. It is expected that western public forest lands will be increasingly reserved from timber cutting, producing a long-term net gain in forest biomass on public lands. As harvesting shifts from public to private lands, forest biomass on private lands will correspondingly decline.

2.3 Historic Land Use Change: Agriculture

The extensive conversion of land to agriculture, which began just after the turn of the century, resulted in substantial decreases in soil organic carbon relative to native ecosystems. Traditional agricultural practices involved increased disturbance of soil, reduced plant cover during fallow periods, and the removal or burning of crop residues, which minimized carbon inputs and promoted organic matter decomposition (Donigian, et al. 1994). These practices led to an estimated 47% decrease in soil organic carbon between 1907 and 1950. This release represents the second largest anthropogenic source contributing to historical increases in CO_2, after fossil fuel combustion (Post, et al. 1990).

Following this period of decline, soil organic carbon remained fairly constant for the next two decades as modern crop management practices were developed. These management practices have decreased the level and intensity of tillage, and have increased the amount of crop residues that are returned to the soil. Soil carbon models that reflect changes in agricultural practices indicate that soil organic carbon levels have been steadily increasing since 1970, although this trend has yet to be confirmed at a national or regional level (Donigian, et al. 1994).

2.4 Overview of Scenarios

There are a number of trends in the forest and agriculture sectors, as well as potential new programs, that could increase the next accumulation of carbon in forest and agricultural ecosystems. The scenarios considered in this report, which are summarized in Box 2-2, represent a range of plausible trends, new programs, or expanded existing programs. Three of these scenarios (large-scale tree planting, and tree planting on conservation or wetlands reserve program lands) increase the amount of carbon stored on U.S. forest land by increasing the acreage of standing trees.[4] Two additional scenarios expand the forest carbon pool by reducing harvesting on existing stands (reduced National Forest harvest and increased wastepaper recycling). A sixth scenario increases the use of wood for biofuels, and additional scenarios combine policies.

In the agriculture sector, modifying existing agricultural practices can increase soil organic carbon levels. Employing tillage practices that do not disturb the soil as much as conventional tillage, and planting winter cover crops, can in some cases increase carbon sequestration in agricultural soils, and provide other benefits such as reduced erosion or increased nitrogen fixation.

3. Methodology

This report analyzes potential economic, greenhouse gas, and other impacts of land use management policies. The assessment uses a number of different sectoral models, which have been, where feasible, linked to provide a comprehensive evaluation of the forest and agricultural sectors (see Box 3-1). The relationships among these models are illustrated in Figures 3-1 and 3-2.

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[4] The Conservation Reserve Program provides incentives to remove highly erodible land from agricultural production by paying for conversion costs, and providing rental payments over 10 year contracts. The WRP provides incentives to restore and protect wetlands that have been fully or partially converted to agricultural production, by paying for conversion costs and compensating owners for the land value.

Box 2-2
Summary of Scenarios

Increasing Forest Carbon Storage

Afforestation — Tree planting on marginal crop and pasture land. Two alternative funding levels for tree planting programs are analyzed ($110 million and $220 million annually for 10 years, or about 6 to 12 million acres).

Conservation Reserve Program (CRP) — Expanding and maintaining the current CRP plans, thereby increasing forestland acreage above the current program. Two alternative proposals are analyzed (a 40 million acre CRP and a 50 million acre CRP).

Wetland Reserve Program (WRP) — Introducing a 5 million acre reserve of wetlands targeted to re-establish bottomland hardwood forest stands on suitable agricultural lands.

Increased Recycling — The utilization rate for recycled paper increases to 45 percent of total fiber production in the year 2000 and remains constant through 2040.

Reduced National Forest Harvest — Harvest on National Forests declines relative to the base case to reflect additional reserved timberland and set-asides.

Wood Energy (biofuels) — Fuelwood consumption for biofuels increases as described in the National Energy Strategy.

Combination Scenario 1 — Combines reduced National Forest harvest with recycling.

Combination Scenario 2 — Combines reduced National Forest harvest, recycling, and biofuels.

Combination Scenario 3 — Combines reduced National Forest harvest, recycling, biofuels, with $220 million in annual funding over 10 years for tree planting programs.

Strategies in the Agriculture Sector

Modified Tillage Practices — Increased use of Reduced Till and No-Till practices on agricultural land.

Winter Cover Crops — Introduce winter cover crops where climate, crop rotations, and length of growing season allow.

For the forest sector, changes in forest inventory on private timberlands are estimated by linking an economic model (TAMM), which estimates tree harvest volume by region, to a forest inventory model (ATLAS), which tracks forest age class distribution by forest type and productivity class. TAMM ensures that the economic consequences of implementing the various policy options are allowed to affect the carbon budget. The resulting forest inventory at any point in time is run through two alternative carbon models (FCM and FORCARB), to estimate total forest carbon. The model HARVCARB is used to estimate changes in the amount of carbon in forest products and in disposal pools from material harvested from 1990 to 2040.

The basic forest sector analyses using TAMM/ATLAS and the carbon models are supplemented in several ways. First, because tree planting on marginal crop and pasture land may affect prices and production in the agriculture sector, additional results from two models of the U.S. agricultural sector, ASM and BLS, provide insights into the potential impacts of tree planting policies. Second, because the U.S. exports and imports raw timber and forest products, policies to expand the U.S. timber inventory can affect world markets. The CINTRAFOR global trade model is used to evaluate these

Box 3-1
Summary of Key Models Used for this Assessment

Forest Sector Models

Timberland Assessment Market Model (TAMM) — economic model of the U.S. forest sector, developed by the U.S. Forest Service.

Aggregate TimberLand Assessment System (ATLAS) — forest inventory change model for private timberland in the U.S., developed by the U.S. Forest Service and linked to TAMM.

North American Pulp and Paper (NAPAP) model — sectoral model of demand, supply and technology for the pulp and paper sector of U.S. and Canada, developed by the U.S. Forest Service.

Forest Carbon Models (FCM and FORCARB) — models of the carbon contained in forest ecosystems, developed by the U.S. Environmental Protection Agency and the U.S. Forest Service, respectively.

HARVCARB — model of post-harvest carbon, tracing the flows of carbon through processing, use, and disposal, developed at the Institute for Forest Analysis, Planning, and Policy.

CINTRAFOR Global Trade Model (CGTM) — global forest sector model, developed by the International Institute for Applied Systems Analysis (IIASA) and the University of Washington's Center for International Trade in Forest Products (CINTRAFOR).

Agriculture Sector Models

Basic Linked Systems (BLS) — model linking 34 national and regional models to simulate world agricultural production and trade, developed by Iowa State University's Center for Agricultural and Rural Development (CARD).

Resource Adjustment Modeling System (RAMS) — model of regional agricultural production, developed by Iowa State University's Center for Agricultural and Rural Development (CARD).

Denitrification and Decomposition (DNDC) Model — model of carbon and nitrogen dynamics in agricultural soils, developed by the Bruce Company and the University of New Hampshire.

CENTURY - model of the dynamics of soil organic matter in agricultural lands and grasslands, developed by Colorado State University in collaboration with Michigan State University.

Agriculture Sector Model (ASM) — model of the U.S. agriculture sector, developed at the Agricultural Economics Department of Texas A&M University.

impacts. Last, to analyze the impacts of increased waste paper recycling, the NAPAP model provides detail on the North American pulp and paper sector.

To evaluate the economic and carbon impacts of change in agricultural practices, the analysis combines models of agricultural production, agricultural markets, and physical processes (such as the dynamics of carbon and nitrogen in soils). A detailed regional model (RAMS) of agricultural production methods is used to evaluate the impacts on production of alternative crops, tillage practices, and rotations. This regional production model is linked to two models (DNDC and CENTURY) of the physical processes in agricultural soils to capture soil dynamics, fluctuations in the levels of soil organic carbon, and changes in nitrous oxide emissions. Finally, the impacts of these policies on

Figure 3-1. Forest Sector Models

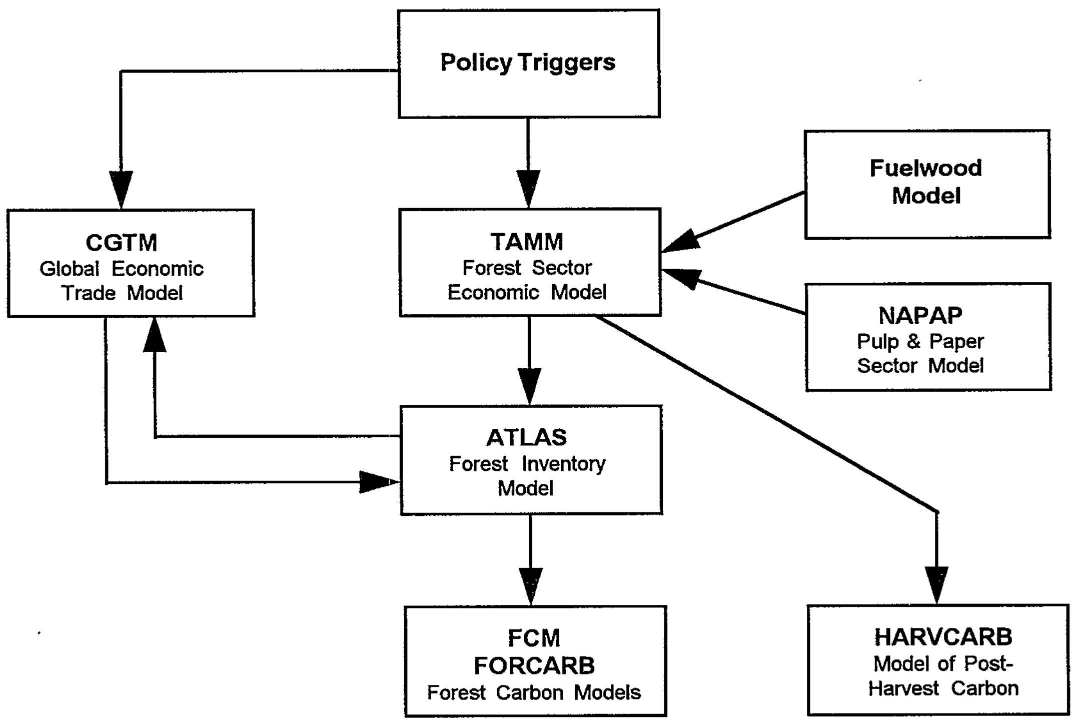
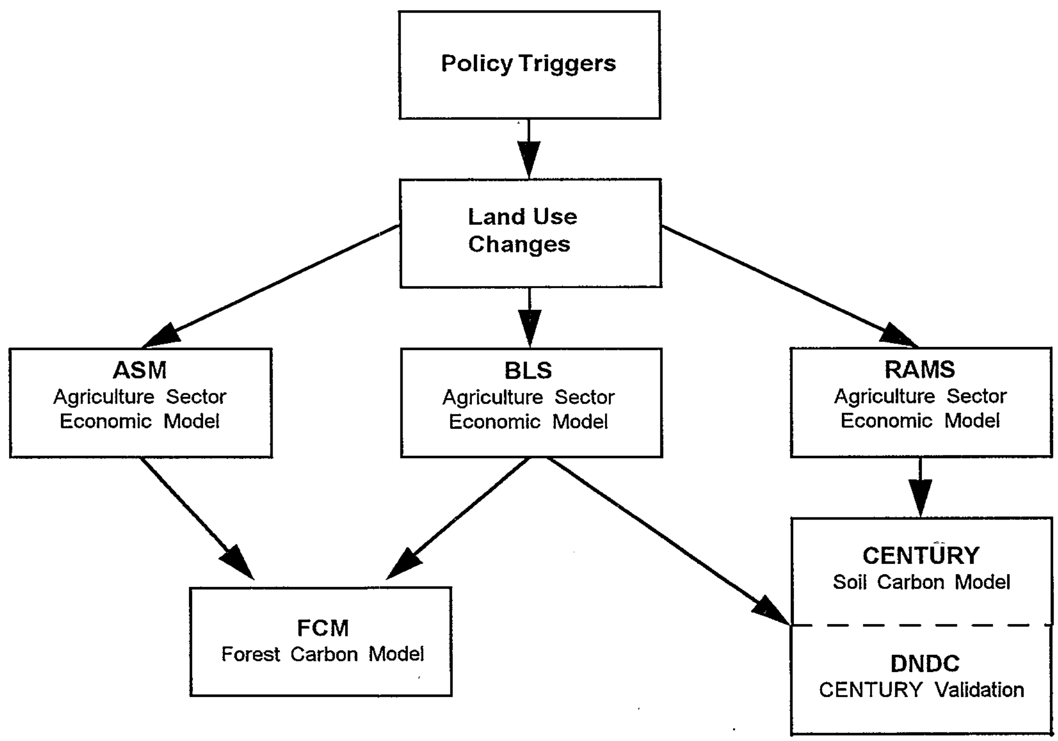


Figure 3-2. Agriculture Sector Models



agricultural markets are evaluated using a general equilibrium model (BLS) which accounts for the linkages between agricultural markets and the non-agricultural markets, regional and international feedbacks related to trade, and impacts on different commodities, including the major cash crops and livestock.

3.1 Forest Sector Models

The **Timber Assessment Market Model (TAMM)** is a model of the U.S. forest sector developed by the U.S. Forest Service, which provides an integrated structure for examining the behavior of regional prices, consumption, and production in stumpage and product markets (Adams and Haynes 1980; Haynes and Adams 1985). It is designed to provide long-term projections of price, consumption, and production trends and to simulate the effects of alternative forest policies and programs. TAMM includes six lumber and plywood demand regions and eight product and stumpage supply regions within the contiguous U.S. Projections under TAMM are dependent on exogenous inputs from other models: pulp fiber requirements (from the NAPAP model described below), and trade and fuelwood projections. The background assumptions for any TAMM model run include projections of future forest products markets (based on forecasts of the major determinants of product demand, and of timber and product supply). On the demand side, the major determinants are future growth in aggregate economic activity, as measured by gross national product (GNP), and in certain key end-uses for forest products, such as new residential construction and the repair or alteration of existing dwellings. It is important to note that TAMM does not account for changes in managerial behavior in response to price signals and likely overestimates any adverse economic impacts due to tree planting or reduced harvests (Winnett, et al. 1993). TAMM also does not account for forests that are managed for non-commodity values.

The **Aggregate TimberLand Assessment System (ATLAS)** projects inventories for all private timberland in the U.S. (Mills and Kincaid 1992). Developed by the U.S. Forest Service, ATLAS is an age-based, yield table model that projects acres by detailed strata for time intervals consistent with the inventory stand-age classes. In the model, the inventory is represented by acreage cells classified by region, ownership, management type, management intensity, and age class. Inputs to the model include estimates of harvest, acreage shifts, management alternatives, and growth parameters. A major attribute of the model is that it can simulate shifts in management intensities and the consequent changes in yields. It can also account for both partial harvests and thinning.

The **North American Pulp and Paper (NAPAP)** sector model uses linear programming to solve for market equilibrium in spatially specific markets. NAPAP represents technological options as economic choices via activity analysis, with production capacity modeled for many competing production processes. The pulp and paper sector is modeled as eight demand regions for 14 categories of final products and five supply regions, which together provide sufficient detail to capture market equilibria for all principal commodities of the pulp and paper sector in North America (U.S. and Canada). The model includes estimates of regional supply functions for manufacturing inputs; regional demand functions for commodity outputs; technological coefficients describing production possibilities in terms of inputs per unit of product output in various production processes for each commodity; other manufacturing costs by process; transportation costs for various commodities and regions; regional production capacities for the various processes; regional constraints on recovery of paper for recycling; import and export *ad valorem* taxes; and monetary exchange rates (between U.S. and Canada).

The **CINTRAFOR Global Trade Model (CGTM)** is a global forest sector model developed by the International Institute for Applied Systems Analysis (IIASA) and the University of Washington's Center for International Trade in Forest Products (CINTRAFOR). CGTM provides forecasts of production, consumption, prices, and trade for eight different forest product commodities, in 43 timber supply regions and 33 demand regions (Perez-Garcia 1993, Cardellichio et al. 1989). Forecasts of market behavior are subject to regional constraints including resource availability and production capacity.

CGTM searches for a spatial (or global) equilibrium, which is the point where the amount supplied by several log and commodity markets equals the amount demanded by all consumers.

The **Forest Carbon Model (FCM)**, developed by the U.S. Environmental Protection Agency, is used to generate estimates of forest carbon from the inventories generated by the TAMM/ATLAS analyses (Turner, et al. 1993). The yield tables in ATLAS are used as the basis for constructing stand-level carbon budgets. Carbon pool size per unit area per age class is estimated for living tree biomass, woody debris, understory vegetation, forest floor, and soil components of the forest. Separate stand-level carbon budgets are prepared for each of 422 yield tables supplied by the USDA Forest Service. Carbon storage at the regional and national level is then determined by coupling these stand-level carbon budgets to forest inventory data on the areal extent and stocking volume of each age class within each inventory type. The set of stand-level carbon budgets provides the foundation for the FCM (see Box 3-2).

A separate forest carbon model, **FORCARB**, developed by the U.S. Forest Service, is alternatively linked to TAMM/ATLAS for some of the analyses (Birdsey 1992a, 1992b). Growing stock inventories by age class and area are derived from the ATLAS model and grouped into 248 "management units," defined by region, owner, species, and site quality. The growing stock inventories are treated as "snapshots" of the forest at particular times and converted to tree (living tree and standing dead trees), soil, forest floor, and understory carbon. Removals of growing stock for each management unit are converted to estimates of harvested carbon.

The model **HARVCARB** is used to examine the distribution and transfer of post-harvest carbon quantities predicted by the TAMM/ATLAS analyses of policy alternatives (Row and Phelps 1990). The model traces the flow of forest harvest carbon through five phases of processing, use, and disposal: from trees to roundwood logs; through processing into forest products; into uses in construction, manufacturing, and paper products; to discarded products; and finally, to landfills, incinerators, and back to the atmosphere. HARVCARB reports emissions on both a carbon (i.e., mass) basis and carbon-equivalent (i.e., climate impact) basis. The latter result, which accounts for the generation and release of methane from landfilled forest products, and the greater climate impact of methane relative to carbon dioxide, is used in this report. HARVCARB was developed at the Institute for Forest Analysis, Planning, and Policy.

Box 3-2
Estimating Forest Carbon: FCM and FORCARB

Both the FCM and FORCARB models use the volume of merchantable wood (trees that are large enough to contain salable products) as a basis for calculating carbon in the whole stand. Thus, neither model calculates the existence of biomass before the stands are old enough to have trees at least 5 inches in diameter in them. Consequently, the models show no biomass (or carbon) in stands for the first 5 to 15 years after regeneration (depending on stand type and region). As a result, biomass and carbon are underestimated in the base case and scenarios.

Although this limitation of the model affects the calculation of biomass and carbon in both the base case and scenarios, the impacts are likely to be important only for some scenarios. As forests are managed over time, stands are constantly being harvested and regenerated. In the years following harvest, or in the first few years of new stands, non-merchantable volume may become a more significant portion of the forest condition, and so the carbon models might miss a significant amount of carbon. Such situations can arise in the first few years following a significant increase in harvested acreage, or in the first few years following large amounts of new afforestation or reforestation. Thus, the net carbon accumulation for some scenarios, such as afforestation or increased biomass energy production, may be understated relative to the base case.

3.2 Agriculture Sector Models

Iowa State University's Center for Agricultural and Rural Development (CARD) has constructed the **Basic Linked System (BLS)** of applied general equilibrium models to simulate the world agricultural economy. The BLS consists of 20 national models of the major agricultural producers and 14 regional models, which account for the remainder of global production. At the international level, all countries trade in a world market of 10 commodities, which may be aggregated from more extensive lists at the national and regional level (the U.S. model, for example, contains 23 commodities). For the purposes of this analysis, only the model of the United States was used to model the impacts of alternative agricultural practices and the Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP). Because the BLS was not designed for projections, but rather for determining the effects of different scenarios, model results are more valid for incremental changes of the scenarios from the base case than for the absolute values generated in either individual scenario or base case runs.

The **Resource Adjustment Modeling System (RAMS)**, was developed by Iowa State University's Center for Agricultural and Rural Development (CARD) in order to determine optimal agricultural production levels for regional Producing Areas (PAs). A Producing Area is an aggregation of counties (often across state boundaries) that has been defined by the U.S. Water Resources Council as being a single hydrological area. Each PA is sufficiently small that it can also be assumed that production is homogeneous across the PA. Because each PA acts as an independent decision-making entity, RAMS allows for region-specific targeting of production practices.

RAMS is designed as a short term, static, profit-maximizing, linear programming model of agricultural production. Profit-maximization is subject to a number of constraints including the technology available, the resource base, and government policy. All activities are characterized by four dimensions: crop rotation, tillage, contour management, and irrigation. RAMS is designed to accommodate crop and geophysical process models such as DNDC and CENTURY in order to provide a more comprehensive evaluation of policies designed to sequester carbon in agricultural soils.

The **Denitrification and Decomposition (DNDC)** model, which was developed by the Bruce Company and the University of New Hampshire, is used to examine carbon and nitrogen dynamics in agricultural soils. Nitrous oxide (N_2O), dinitrogen (molecular nitrogen) (N_2), and carbon dioxide (CO_2) production in soils are evaluated as a function of agriculture practices, soil conditions, and climate (both precipitation and temperature). Common agriculture practices that are modeled include: tillage intensity; fertilizer application; seeding and harvest times; and crop rotations. Rainfall events, soil moisture, and temperature (determined from the climatic data and soil properties) drive the fluctuating physical processes. Between rain events, decomposition occurs, which results in CO_2 production and oxidation (including nitrification), while during the rainfall events themselves the denitrification process dominates.

CENTURY was originally developed at Colorado State University, and has been supplemented by more recent collaboration with Michigan State University. CENTURY simulates the dynamics of soil organic matter (SOM) in both grassland and agricultural ecosystems. Specifically, the dynamics of carbon, nitrogen, phosphorous, and sulphur in soils can be modeled in one month intervals for periods as long as 100 to 10,000 years; scenarios can be modeled using monthly time steps. SOM in CENTURY is divided into three categories based on the time scale required for turnover or decomposition: 1.5 years (active), 50 years (slow), and 1000 years (passive). The decomposition rate is a function of chemical composition of the soil, expressed in terms of lignin and nitrogen content, climatic conditions and location of the organic matter.

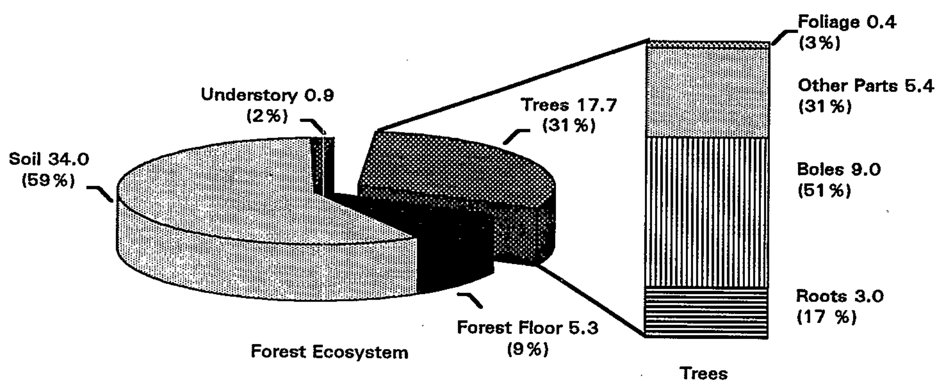
In order to assess both the economic and the physical effects, including changes in carbon levels, associated with different agricultural practices, RAMS, the agricultural economics model, is linked with DNDC and CENTURY, the soil carbon models. As a refinement of the PAs used in RAMS, Production Areas are subdivided into Climate Divisions which allow for a more precise representation of soil and climate conditions. DNDC and CENTURY then use geographic information systems (GIS) data to define land type and area with increased resolution.

ASM, the **Agriculture Sector Model** of the United States, was developed at the Agricultural Economics Department of Texas A&M University to determine changes in U.S. production, consumer and producer surplus, prices, international trade, and food processing based on changes in resource availability. Production is divided into 63 regions and 36 commodities with region-specific data for crop yields and human and natural resource endowments. Each region uses a set of supply and demand budgets, which incorporates prices, quantities, and elasticities. Supply budgets account for transportation costs, while demand includes aggregate demand from foreign markets and domestic demand in the form of food consumption, Commodity Credit Corporation stock, feed grains for livestock, and food processing. ASM has been modified to include a stumpage supply sector (from TAMM), which harvests the trees on both agricultural land and commercial timberland.

4. Tree Planting Scenarios

U.S. forests currently occupy almost 740 million acres, or about 5 percent of the world's forest area, providing an important terrestrial "pool" for carbon (Haynes, et al. 1994; Birdsey and Heath 1993). Trees, which are relatively long-lived structures, sequester CO_2 from the atmosphere as they grow, storing it as carbon in trunks, limbs, foliage, and roots. Soil and vegetative cover also provide a pool for carbon. In 1987, U.S. forest ecosystems stored about 53 billion metric tons of carbon, of which over half was in the soil (Birdsey and Heath 1993). Standing (living and dead) trees store almost one-third of the forest carbon, and the remainder is stored in the understory or on the forest floor (see Figure 4-1). Thus, expanding the carbon pool by increasing the acreage devoted to timberlands and other woodlands has the potential to sequester significant additional amounts of carbon.

Figure 4-1. Carbon Storage in U.S. Forest Ecosystems by Forest Ecosystem Component (in billion metric tons)



Source: Birdsey and Heath 1993

This portion of the report describes the results of the analyses of possible forestation programs. Section 4.1 examines the timber, carbon and economic impacts of large scale tree planting programs that are similar in scale to the originally proposed funding levels for the "America the Beautiful" program. Next, Section 4.2 looks at the implications for both carbon and agricultural production of expanding existing tree planting programs. Last, Section 4.3 links the forest and agriculture sections together, in order to capture the interactions between tree planting on agricultural lands and land prices. Each of the three sections describes the base case and scenarios evaluated, the models used for the analysis, and presents the impacts on carbon and on the forest and agriculture sectors.

4.1 Tree Planting on Marginal Cropland and Pastureland

Two key studies (Moulton and Richards 1990, and Parks and Hardie 1992) have identified land areas in the U.S. that are suitable for establishing forest plantations. These lands are generally marginal crop and pasture land, which are defined based on soil erosion rates, soil type, and U.S. Soil Conservation Service land classifications. The carbon sequestration potential of these lands varies considerably by region and land quality, reflecting different growth rates and wood densities for various tree species and climate conditions (as Table 4-1 illustrates for each region). Planting on these lands can generate benefits other than carbon sequestration, including reduced soil erosion, watershed protection, conservation of biodiversity, and improved recreation and aesthetic opportunities.

Table 4-1
Average Storage of Carbon in Forest Ecosystems by U.S. Region

Region	Carbon Storage (pounds per acre)
South Central	116,748
Southeast	124,146
North Central	162,948
Northeast	165,021
Rocky Mountain	128,040
Pacific Coast	205,225
Total U.S.	**158,225**

Source: Birdsey and Heath 1993

The current analysis examines the carbon, timber, and economic impacts of federally subsidized tree planting programs, using several models (see Section 3). TAMM, an economic model focusing on the forest sector and private timberland, is linked to ATLAS, a forest inventory model, which tracks forest age-class distribution and productivity classes, and to NAPAP, which models the pulp and paper sector. These models are combined with a similar inventory constructed for public lands. For public lands, there are no stand-alone inventory models, and inventory assumptions are embedded in a variety of harvest planning models. Estimated future forest inventories are derived using data from planning efforts at the level of individual National Forests and other public agencies, such as the Forest Planning Model (FORPLAN) used in the National Forests. Carbon data for the forest inventory at any point in time are supplied by two alternative forest carbon models, FCM and FORCARB. HARVCARB analyses of the flow of post-harvest carbon supplement the results of these two forest carbon models. The CGTM, which models global timber markets, provides additional insights into the impacts of tree planting on U.S. timber inventories, harvests, and imports and exports.

This combination of models captures a number of critical impacts and interactions. Together, the models provide projections over the period 1990 to 2040 for carbon stored on forested land, carbon stored in other pools (i.e., in products produced using harvested wood or in landfills), impacts on timber inventory, harvest, and other effects. In the analyses, all trees planted and/or retained from harvest under a tree planting program are available once they reach minimum harvest age.[5] Thus,

[5] Minimum harvest age is approximately 20 years in the South, 45 years in the Pacific Coast states, and 70 years elsewhere.

near-term tree planting, by increasing the standing timber available in the future for harvesting, can significantly affect the prices of both sawtimber and wood-containing products (such as lumber and furniture) and may affect consumer and producer welfare.

These models do not, however, capture several important effects. The impacts of federally subsidized tree planting on stumpage prices will affect not only future decisions about harvesting, but also decisions made by forest landowners to plant or harvest today, made in response to expectations about future prices and profits, an effect not captured by the TAMM/ATLAS models (see Box 4-1). In addition, large-scale tree planting on agricultural lands could potentially increase the prices of crop land. This increase could affect farm income and/or crop prices, as well as alter the cost to the government of planting trees on any given acreage. The analysis using the ASM model, which is reported in Section 4.3, partially captures this interaction. Ongoing work at the U.S. EPA and U.S. Forest Service continues to investigate these effects, and so the results reported here are preliminary. However, they illustrate the significant potential of expanding forested land to sequester carbon.

Box 4-1
Investment Behavior in TAMM/ATLAS

The TAMM/ATLAS models do not include price-sensitive land management decisions and, consequently, do not capture the effects of future prices on current planting decisions. Rather, the models project behavior based on historically observed investment responses. Since there are no historic data on behavior under conditions explored in these scenarios (i.e., large-scale tree planting), the models may not project the most likely responses (Winnett, et al. 1993). These models would have a tendency to project little or no divestment of timber (the observed pattern for private non-industrial forest owners under historically observed conditions) even under conditions of very low prices brought about by large increases in timber supplies. An analogous situation would apply to new timber investment under conditions of very high prices and timber scarcity.

In contrast, a model that included responses to expected prices in management behavior would show very different behavioral responses to a large scale federal tree planting program. In a world of perfect foresight, owners, in anticipation of lower future prices when the trees planted today become available for harvest, may choose to plant less or accelerate current harvest plans, thus mediating the impacts of the program on future prices. Similarly, higher anticipated future prices would lead profit-maximizing owners to delay harvest decisions and undertake additional near-term planting.

The true response is bounded by these two models of behavior, and probably lies somewhere in between. Results, particularly those for prices, could therefore be less extreme than some of those presented here.

SCENARIOS AND BASE CASE

The tree planting analyses examine the impacts of two alternative funding levels and two alternative land base/enrollment schedules. For funding levels, alternative government expenditures of $110 million and $220 million annually for ten years are used. These funding levels correspond to the originally proposed level of funding for rural tree planting under the "America the Beautiful" tree planting program, and to a more aggressive program with double that funding. The funding covers half the cost of planting and establishing trees, and 10 years of land rental costs, or payments made to owners of the land where planting occurs.

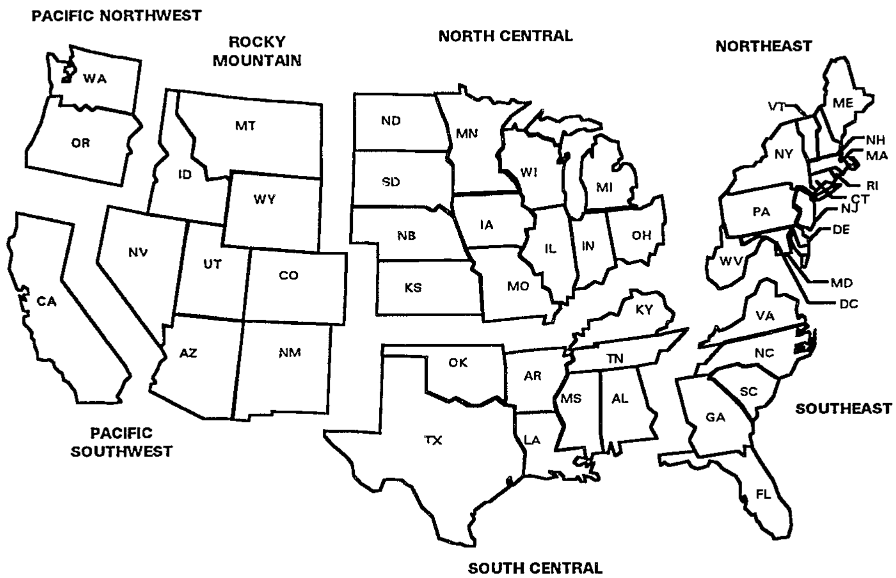
Enrollment schedules are designed to forest land in the most cost-effective manner, i.e., to enroll first those lands on which carbon could be sequestered most cheaply. Because differences in the land base can affect the pattern of cost-effective enrollment, two alternative schedules of land area (described in Table 4-2 and Figure 4-2) are used: a low enrollment schedule and a high enrollment schedule (derived from Moulton and Richards 1990, and Parks and Hardie 1992, respectively). For both enrollment schedules, the majority of acres enrolled are marginal pasture land. These scenarios assume that, at the end of the 10 year contract period, all acres revert gradually to agricultural use (less than one-half percent annually) over the time-frame of the analysis. Table 4-2 also presents the enrollment schedule if $110 million in annual funding (for 10 years) is distributed following the geographic enrollment pattern observed historically in the U.S. over the years 1981-1990.

Table 4-2
Regional Distribution of New Forest Under Alternative Enrollment Schedules (million acres)

	$110 Million Annually (10 years)			$220 Million Annually (10 years)	
Region	low enrollment	high enrollment	historic enrollment	low enrollment	high enrollment
South Central	5.8	6.4	2.0	8.0	8.5
Southeast	0	0	1.5	0	0.4
North Central	0	0	0.3	0	2.5
Northeast	0	0.1	0.1	0	0.2
Rocky Mountain	0	0	0	1.8	0
Pacific Southwest	0	0	0	0	0.1
Pacific Northwest	0	0.5	0.3	0	0.6
Total U.S.	**5.8**	**7.0**	**4.2**	**9.8**	**12.3**

Source: Birdsey and Heath 1993

Figure 4-2. Geographical Regions Corresponding to Enrollment Scenarios

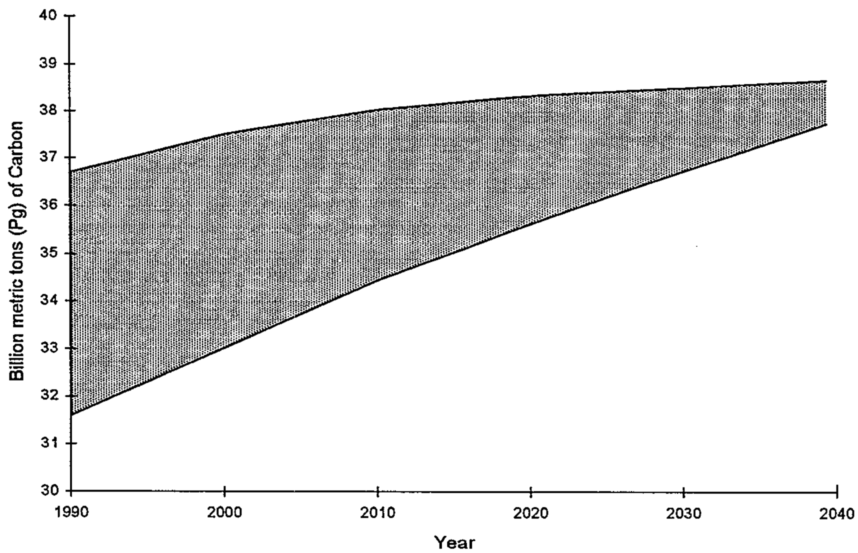


Source: Turner, et al. 1993

The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 requires that the U.S. Forest Service (USFS) of the U.S. Department of Agriculture assess the timber situation and examine possible future trends in cost and availability. USFS performed an assessment in 1989 that examined the period 1989-2040 (USFS 1990). The base case for the forestation analyses in this report is a modified version of the 1989 RPA generated by the TAMM/ATLAS system, and reflects knowledge, as of 1992, about future timber supply, demand, and harvest on private and public lands. The base case projects a growth in GNP of 2 to 3 percent over the 50 year period, increasing energy costs, and an increase in U.S. population to 333 million by 2040. Demand for forest products rises following population projections, but reflects a slowing of per capita demand. The base case for the analysis presented here differs from the 1989 RPA primarily in reducing National Forest timber harvest projections by approximately 0.5 billion cubic feet per year to reflect revised National Forest management plans, additional restrictions on log exports, and harvest set-asides attributable to legal actions under the Endangered Species Act.

Figure 4-3 presents the range of forest carbon projected by FCM and FORCARB for the TAMM/ATLAS base case, against which subsequent scenario analyses are compared. The two carbon models use slightly different assumptions about changes in carbon in the various ecosystem components (especially soils), reflecting uncertainty in the supporting literature. In particular, FORCARB assumes that soil carbon levels undergo significant change in response to forest management activities, with carbon levels decreasing after harvest and increasing during regrowth. In contrast, the FCM model assumes that soil carbon levels are relatively insensitive to management activity and there is little per acre change in carbon due to harvest and regrowth. Consequently, the FCM results show a slow but steady increase in carbon levels, while the FORCARB results show steep increases in carbon inventories, which are then slowed by the harvest of trees as they reach financial maturity.

Figure 4-3. Total Carbon Storage on U.S. Public and Private Timberland: Range of Model Results for Base Case Scenario

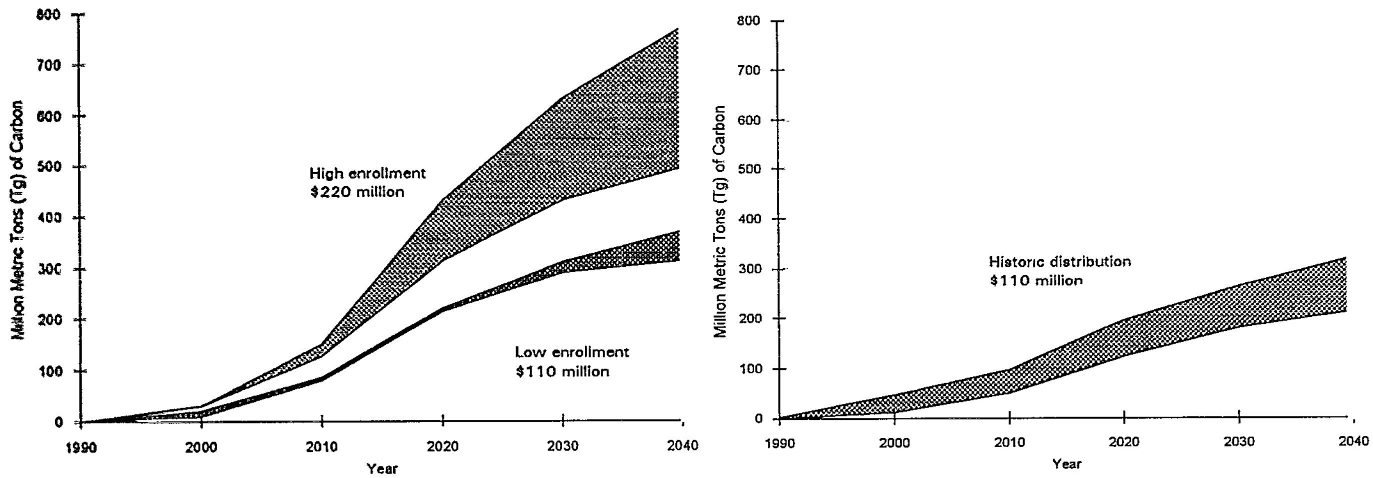


Sources: Lee 1993c; Heath 1993

CARBON IMPACTS

Growth rates change as trees age, so that carbon accumulation rates vary over time. Because trees grow relatively slowly, the bulk of the carbon is accumulated some years after planting occurs. Figure 4-4 illustrates the range of results for two of the scenarios — the lower funding, lower acreage enrollment schedule, and the higher funding, higher acreage enrollment schedule, which together essentially bound the analysis. Results are also presented for the scenario in which $110 million in annual funding (for 10 years) is used to plant trees on lands following the historic distribution of lands planted over the years 1981-1990. The range of carbon accumulation reported for each of these scenarios also results partly from differences between the two forest carbon models used, FCM and FORCARB.

Figure 4-4. Total Carbon Storage on U.S. Public and Private Timberland: Increases Relative to Base Case for Tree Planting Scenarios



Sources: Turner, et al. 1993; Heath 1993

As illustrated in Figure 4-4, large scale tree planting has the potential to increase the size of the forest carbon pool over base case projections by between about 500 million metric tons and 800 million metric tons by the year 2040, with approximately one-fourth of the total achieved by the year 2010. Table 4-3 presents annual carbon accumulation over the base case at decadal intervals. Carbon results in Table 4-3 are the average of the FORCARB and FCM model results.

Harvested timber is an important component of the total forest sector carbon pool, because the carbon can be stored not only in forest ecosystems, but also in products manufactured from harvested trees, and in products discarded into landfills. The model HARVCARB examines the distribution and transfer of harvested wood for the TAMM/ATLAS forestation scenarios. In the base case analysis, HARVCARB allocates 81 percent of each year's harvest during the first decade to storage in products or landfills. The balance of harvested carbon returns to the atmosphere

Table 4-3
Annual Carbon Accumulation on U.S. Public and Private Timberland Relative to Base Case for Three Tree Planting Scenarios, Decadal Intervals (million metric tons)

	2000	2010	2020	2030
$220 million annually for 10 years, high enrollment	6.8	16.7	19.4	13.0
$110 million annually for 10 years, low enrollment	4.1	9.6	10.8	6.2
$110 million annually for 10 years, historic distribution	3.5	6.5	7.5	5.5

Note: Forest carbon estimates are presented as the average of FORCARB and FCM results.
Source: Turner, et al. 1993; Heath 1993

immediately, primarily as a result of energy production.[6] In succeeding years, carbon from current harvests continues to be allocated largely to products, and carbon moves from products to both disposal pools and the atmosphere as older products are retired.

Because a large portion of the carbon contained in harvested timber remains in products for some length of time, these products represent an additional store of carbon, over and above that stored on forested lands. The forestation scenarios show an average annual carbon accumulation (post-harvest) in products of 1.7 to 2.4 million metric tons over the 50 year period. However, the potential climate impact of this carbon accumulation may be offset when it is adjusted to account for the effect of methane emissions from landfilled forest products (Turner, et al. 1993).

Timber Inventory Effects

The scenario analyses suggest that tree planting programs funded at $110 million to $220 million per year for ten years would lead to large increases in U.S. timberland area. Results suggest that the tree planting scenarios would have the largest impact on privately owned U.S. softwood growing stock inventories and harvest. These effects are greatest in the South Central region where a majority of the land enrollment is projected to occur under all scenarios. As Figure 4-5 illustrates, U.S. softwood inventories on privately owned lands in the scenarios increase over the base case by about 2 percent in the year 2010 and by between 6 and 10 percent in the year 2040.[7] Table 4-4 illustrates softwood harvest rates, for selected years and forestation scenarios.

Economic and Trade Effects

Projected increases in timberland are likely to have substantial impacts on U.S. timber markets, particularly in the South Central region where the largest increases occur. The analysis shows that increases in timber supplies drive down stumpage prices relative to the base case, particularly softwood stumpage prices in the South, where prices become low and steady toward the end of the

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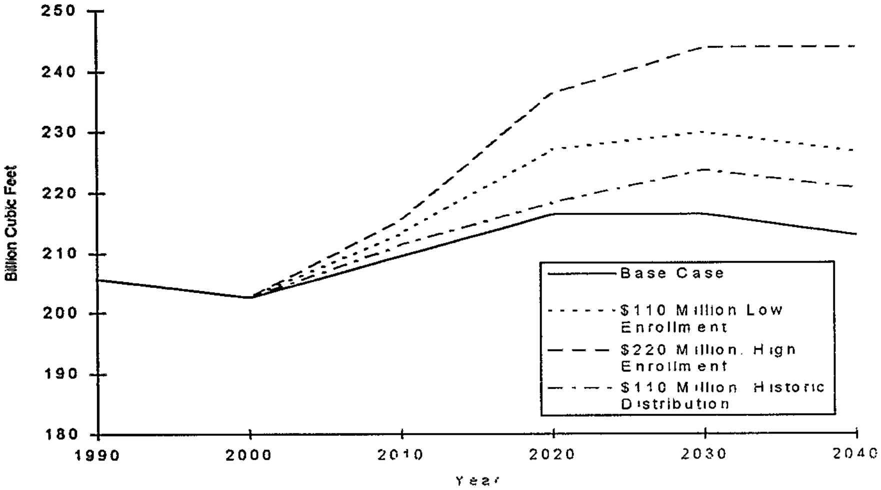
[6] To the extent that it substitutes for energy from fossil fuel use, the use of forest products can be considered to be a permanent carbon sink, or an energy offset.

[7] Timber inventory as used here is the growing stock volume, defined as the cubic volume of all live trees of commercial species, meeting specified standards of quality or vigor, which are at least 5.0 inches in diameter at breast height.

Figure 4-5. U.S. Softwood Inventory Projections For Privately Owned Timberland: Base Case and Tree Planting Scenarios



Source: Haynes, et al. 1994

Table 4-4
U.S. Softwood Harvests for Tree Planting Scenarios: All Owners
(billion cubic feet)

Year	Base Case	$110 Million Annually (10 years)		$220 Million Annually (10 years)
		Historic Distribution	Low Enrollment	High Enrollment
1990	11.0	11.0	11.0	11.0
2000	11.8	11.8	11.8	11.8
2020	14.1	14.1	14.2	14.3
2040	15.3	15.6	15.8	16.0

Source: Haynes, et al. 1994

time-frame examined.[8] If private owners plant at the levels assumed under these scenarios, reductions in stumpage prices are likely to be tempered by actions taken by other landowners to plant less area to trees, an effect which is the subject of ongoing investigation by the U.S. EPA. To the extent that prices decline, consumers would tend to benefit and owners of timber would lose.

[8] Stumpage price is paid for standing timber in the forest, and is typically measured in dollars per thousand board feet.

Although softwood inventory and harvest projections increase under each tree planting scenario, stumpage price projections fall relative to the base case (see Tables 4-5 and 4-6). The price decline is greatest in the South, where the majority of marginal crop and pasture lands are situated, and, hence, where planting occurs. Prices in the South become low and steady soon after the timber inventory begins to increase, i.e., when the wood becomes merchantable (after 2 or 3 decades). Softwood stumpage prices in the Rocky Mountains and Pacific Coast show slight declines, relative to the base case, over the time frame of the analysis, while prices in the North are largely unaffected, as are hardwood sawtimber stumpage prices. The declines are greatest for the largest tree planting program.

Table 4-5
Stumpage Prices in the Base Case
(dollars per thousand board feet)

	2000	2010	2020	2030	2040
Softwood Stumpage Prices					
North	50	66	88	101	111
South	180	260	306	306	297
Rocky Mountains	102	236	287	259	279
Pacific Coast	247	311	365	367	358
Hardwood Sawtimber Stumpage Prices					
United States	463	559	665	784	903

Source: Haynes, et al. 1994

As U.S. stumpage prices decline, U.S. forest products become more competitive, and Canadian lumber imports to northern U.S. markets decline after 2010, falling to between 7 and 9 billion board feet in 2040, as compared to 13 billion board feet in the base case projection (Haynes, et al. 1994). The CGTM analysis finds similar trade impacts. In addition, because there is no or little enrollment of lands in these programs in the Pacific Northwest, exports from this region to Pacific Rim markets are not affected (Perez-Garcia 1994).

4.2 Conservation Reserve and Wetlands Reserve Programs

The analyses of the Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP) provide another view of the impacts of government subsidized tree planting. CRP was established as part of the Food Security Act of 1985 to foster the withdrawal from agricultural production of between 40 and 45 million acres of highly erodible grasslands and wetlands. To be eligible for inclusion in the CRP, land must have an average erosion rate of at least 19.1 tons of soil per acre — nearly three times the national average. By this criterion, an estimated 24 percent of all U.S. cropland — mostly in the Corn Belt, northern and southern plains, and mountain regions — is potentially eligible. Without special dispensation, however, CRP signups are limited to 25 percent of a county's cropland, in an attempt to spare local economies significant damage. This limitation reduces eligible land by almost one-third, to just under 70 million acres (Trexler 1991). To encourage landowners to participate in the CRP, the government shares the cost of converting the land into alternative uses (such as trees and other cover) and provides rental payments throughout the 10-year CRP contracts. Currently, there are approximately 36 million acres enrolled in the program, about 2.4 million of which are planted with trees, and the remainder of which are in grasses.

Table 4-6
Stumpage Prices in the Tree Planting Scenarios
(dollars per thousand board feet)

	2000	2010	2020	2030	2040
$110 million annual funding for 10 years, low enrollment					
Softwood Stumpage Prices					
North	50	66	88	101	111
South	178	237	235	33	*
Rocky Mountains	102	239	265	230	217
Pacific Coast	248	310	342	314	280
Hardwood Sawtimber Stumpage Prices					
United States	463	559	664	782	899
$220 million annual funding for 10 years, high enrollment					
Softwood Stumpage Prices					
North	50	64	82	84	90
South	178	228	199	*	*
Rocky Mountains	102	239	260	210	195
Pacific Coast	248	309	334	293	247
Hardwood Sawtimber Stumpage Prices					
United States	463	558	663	779	896
$110 million annual funding for 10 years, historic distribution					
Softwood Stumpage Prices					
North	50	66	88	100	110
South	179	250	256	203	211
Rocky Mountains	102	243	270	252	253
Pacific Coast	244	316	351	334	313
Hardwood Sawtimber Stumpage Prices					
United States	463	559	664	782	900

Note: "*" indicates prices outside the range of model results.
Source: Haynes, et al. 1994

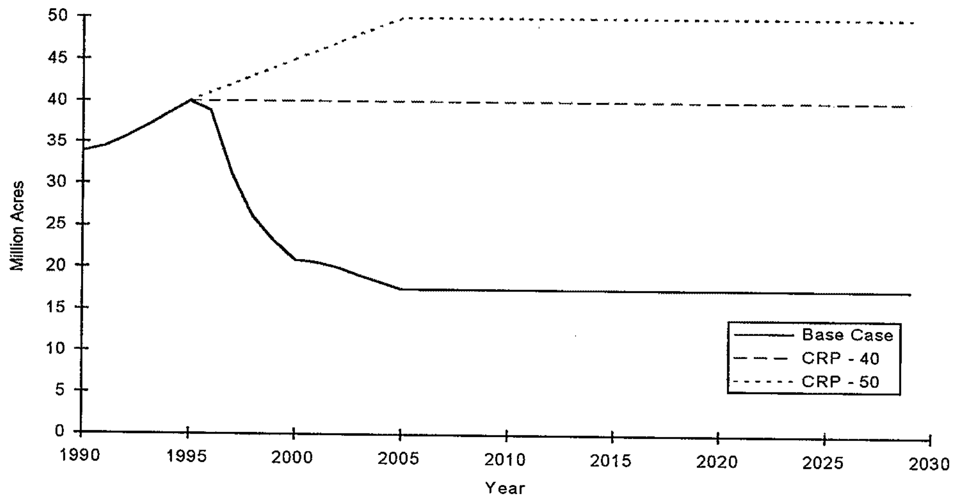
The Wetlands Reserve Program was established as part of the 1990 Farm Bill to restore and protect wetlands that have been partially or fully converted to agricultural use. The WRP places accepted land areas under 30 year or permanent easements that prohibit the draining of wetlands. The WRP encourages land owners to enter the program by paying compensation based on the type of easement and the appraised land value, up to the full value of the land. The program also pays for the cost of any restoration activities. The program goal was to have enrolled slightly less than 1 million acres by 1995, although projected enrollment is a fraction of this amount.

Because the reserve programs operate on agricultural land, the BLS model provides the results for crop, income, and price effects in the agriculture sector. Carbon impacts are calculated from the BLS results using the FCM. Together, these analyses provide results that encompass both carbon and economic impacts. Although the impacts are based on specific policy options, they also illustrate the impacts that other large scale tree planting programs, such as those described in Section 4.1, could have on agriculture.

SCENARIOS AND BASE CASE

The analysis examines the carbon and economic impacts of tree planting for two alternative CRP scenarios and a targeted WRP scenario. For the CRP analyses, the base case assumes that the original CRP target enrollment of 40 million acres is achieved by 1995, then declines over time to 17.5 million acres, an outcome that is considered to be likely after current contracts expire. The CRP scenarios reflect different assumptions about the size of future programs and alternative uses of CRP land. Two alternative proposals — 40 million acres and 50 million acres — are compared to the base case, as illustrated in Figure 4-6. Historical signups under the CRP guide enrollment patterns under the base case and CRP scenarios. For both the base case and the 40 million acre CRP scenario, 3.7 million acres are planted with trees and the remainder is grassland. The incremental 10 million acres in the second CRP scenario is planted with trees.

Figure 4-6. Annual Acreage Under CRP Scenarios

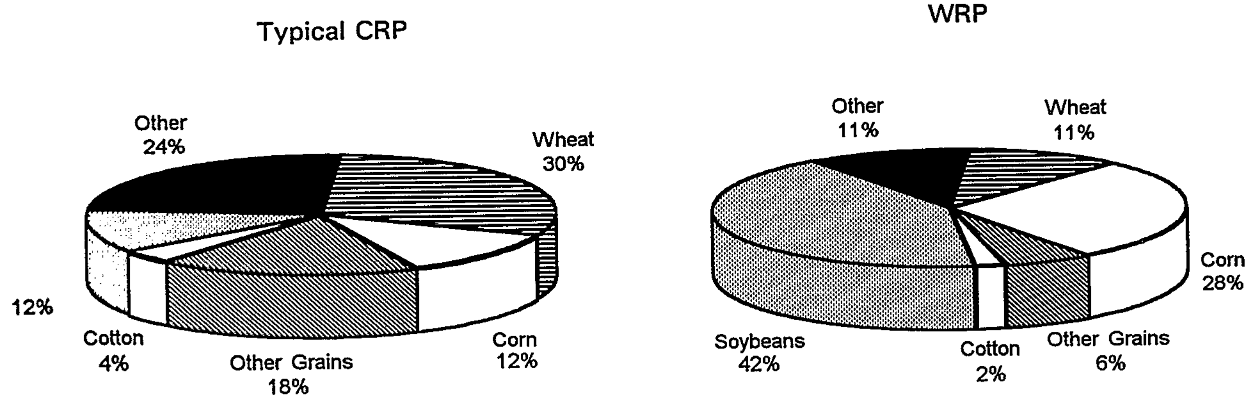


Note: In the base case, the current program reaches 40 million acres in 1995 and then contracts until 17.5 million acres remain in 2005. CRP-40 retains all 40 million acres after 1995. CRP-50 expands the program to cover 50 million acres by 2005.

Source: Reese, et al. 1993

The third scenario, WRP, simulates the introduction of a 5 million acre reserve of wetlands consisting predominantly of drained bottomland previously planted to agricultural crops. These acres are targeted to establish hardwood tree stands for the potential carbon benefits of the trees, and to provide wetlands benefits such as flood control, habitat preservation, and improved water quality. The WRP also involves considerably different crops than the CRP, as displayed in Figure 4-7.

Figure 4-7. Composition of Reserve Scenarios



Source: Reese, et al. 1993

Carbon Impacts

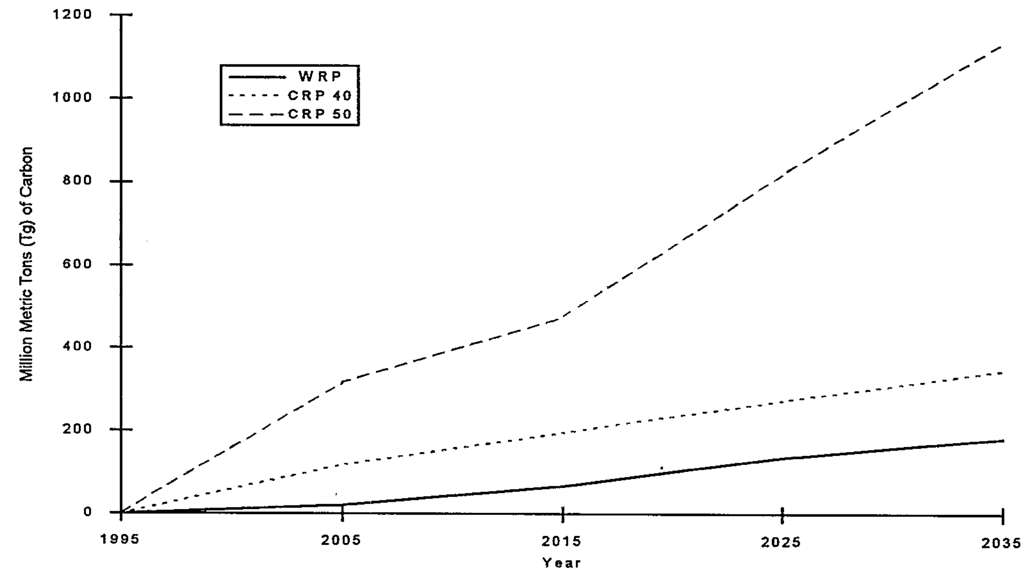
The FCM model suggests that expanding or extending the CRP program and using the WRP to plant hardwood trees can sequester significant additional carbon dioxide. As Figure 4-8 illustrates, maintaining the full 40 million acres results in an additional carbon accumulation of almost 200 million metric tons in 2015 and nearly 350 million metric tons by 2035. This accumulation is relative to the base case; full implementation of the current CRP plans (assuming that land begins to revert to agricultural production after 1995). Carbon storage in the base case is approximately 1,050 million metric tons in 1995, growing to 1,160 million metric tons in 2015 and 1,360 million metric tons in 2035.

Expanding the program to 50 million acres, by planting an incremental 10 million acres with trees, more than doubles the carbon accumulated on CRP lands, relative to the base case. Under full implementation of the 50 million acre CRP program, the total carbon pool on CRP lands, including soil, trees, understory and other forest ecosystem components, is estimated to reach almost 2,500 million metric tons, a gain in excess of 1,100 million metric tons over the base case in the year 2035. The smaller WRP program results in almost 200 additional million metric tons of carbon by the year 2035. For the three scenarios, Table 4-7 presents annual carbon accumulation relative to the base case.

Impacts on Agriculture

Maintaining or expanding the reserve programs can affect agricultural output by removing agricultural land from production and driving up commodity prices. The BLS model is used to estimate the economic impacts of the CRP and WRP scenarios on the agriculture sector of the United States. Crop acreages in both CRP scenarios are consistently lower over time than in the base case (see Table 4-8). In percentage terms, soybean and rice acreages are the least affected of the major crops, and planted acres of the "other grains" are reduced the most, with barley acres falling most dramatically. For most crops the reductions in acreage are slightly offset by increases in yield on planted acres, as producers farm their remaining acres more intensively in response to higher output prices. On balance, production of all major crops is less under the CRP scenario than the base case, and producer prices are concomitantly higher (see Table 4-8).

Figure 4-8. Carbon Storage Under Reserve Program Scenarios: Increases Relative to Base Case



Note: CRP estimates are relative to CRP base case. WRP estimates are relative to carbon storage in 1995 on WRP lands that will be planted with hardwood trees.

Sources: Lee 1993a; Lee 1993b

Table 4-7
Annual Carbon Accumulation for CRP and WRP Scenarios Relative to Base Case, Decadal Intervals (million metric tons)

	2000	2010	2020	2030
CRP-40	11.6	7.9	7.7	7.2
CRP-50	31.5	15.9	34.5	31.6
WRP	2.2	4.4	7.0	4.6

Note: WRP estimates are relative to flux in 1995 on WRP lands that will be planted with hardwood trees. Forest carbon estimates are derived from the FCM model.
Source: Lee 1993a; Lee 1993b

Because the output of feed grains is significantly affected, feed prices are higher under the CRP scenarios, and livestock production is generally lower under the scenarios, reflecting higher feed costs. Beef production increases in both CRP scenarios relative to the base case (by 1 percent to 2 percent) and production of pork, milk, poultry, and eggs falls. Pork shows the largest decline over the time period, on the order of 3 percent to 4 percent, while declines for milk, poultry, and eggs are generally less than one percent (Reese, et al. 1993).

Table 4-8
Impacts of Reserve Program Scenarios on Agricultural Production and Producer Prices: Percent Change Relative to Base Case, Decadal Intervals

CRP - 40 MILLION ACRES PLANTED

Year	Wheat	Rice	Corn	Other Grain	Soybean	Cotton
Acres Harvested						
2000	-7	-2	-4	-13	-1	-6
2010	-8	-2	-4	-15	-2	-7
2020	-8	-2	-4	-17	-2	-7
2030	-7	-2	-5	-18	1	-7
Producer Prices						
2000	4	2	5	--	4	1
2010	4	1	6	--	3	1
2020	4	1	5	--	3	1
2030	6	3	5	--	4	0

CRP - 50 MILLION ACRES PLANTED

Year	Wheat	Rice	Corn	Other Grain	Soybean	Cotton
Acres Harvested						
2000	-8	-2	-5	-12	-3	-7
2010	-10	-2	-6	-20	-5	-9
2020	-10	-2	-6	-25	-5	-9
2030	-9	-2	-7	-28	-1	-10
Producer Prices						
2000	5	2	7	--	6	2
2010	5	1	8	--	6	1
2020	5	1	6	--	5	2
2030	7	3	6	--	8	-0.3

WRP - 5 MILLION ACRES PLANTED

Year	Wheat	Rice	Corn	Other Grain	Soybean	Cotton
Acres Harvested						
2000	0	0	0	0	-2	*
2010	0	0	-2	-1	-4	*
2020	0	0	-1	-1	-4	*
2030	0	0	-2	-1	-3	*
Producer Prices						
2000	1	*	1	-	2	*
2010	1	*	1	-	3	*
2020	1	*	1	-	3	*
2030	1	1	1	-	4	*

Note: "*" indicates an increase or decrease of less than 0.5%.
Source: Reese, et al. 1993

The WRP scenario has similar, but less dramatic, effects. The production of soybeans and corn is most affected, with acreage reductions of about 4 percent and 2 percent, respectively. In contrast, acreage falls by at most 1 percent for other crops. As a result, soybean producer prices increase by about 3 percent and corn prices increase by about 1 percent (see Table 4-8). Correspondingly small impacts occur in livestock; production of pork and of poultry falls by 1 to 2 percent, while production of other livestock products is relatively unaffected (Reese, et al. 1993).

Economic Impacts and Government Costs

Under the CRP scenarios, per capita consumption of most commodities changes only slightly, although consumption of grain products and most meat fall by 1 to 2.5 percent after the programs have been fully implemented. As a result of these changes, producer net returns increase for crop producers, but decline significantly for livestock producers. Government price support payments to crop producers fall by more than the cost of the CRP programs.[9] Combined returns in the agriculture and livestock industries, i.e., the net result of changes in income and in government payments, are about $350 million to $450 million per year lower under the CRP scenarios. By comparison, total net U.S. farm income between 1989 and 1991 averaged $47 billion per year. Consumers are generally worse off with slightly lower consumption and higher retail prices, resulting in about a 2 percent increase in total consumer expenditures (Reese, et al. 1993). The effects of the WRP are similar; results for all three scenarios are reported in Figure 4-9, for selected years.

4.3 The Agriculture Sector: Implications for Federally Funded Tree Planting

Large-scale tree planting affects not only the forest sector but also the agriculture sector. Subsidized tree planting takes marginal land out of agricultural production and may raise crop prices, with consequent welfare impacts for consumers and producers in the agriculture sector, as discussed in Section 4.2. Taking land out of production may also increase land prices, which in turn increases the subsidy that is necessary to induce landowners and others to plant trees. Thus, the cost to the government of funding tree planting on a given number of acres can be higher when agricultural price effects are considered. The cost per ton of carbon sequestered will also be higher. Agricultural price effects may also lead to welfare changes for producers and consumers in both the agriculture and forest sectors.

To assess the carbon and economic implications of land price increases for the agriculture sector, the U.S. EPA initiated an additional series of tree planting analyses. The analyses reported in this section complement the analyses reported in Section 4.1 and Section 4.2. These analyses use the ASM, a U.S. Agriculture Sector Model (Adams, et al. 1993; and Chang and McCarl 1991). In the ASM analyses, land currently enrolled in the CRP is released at the termination of the program and either reverts to cropland or is available for tree planting. For the analyses, TAMM provides regional forest sector supply and demand curves and other information about the demand for wood products. Estimates of the cost of establishing trees are based on estimates in Moulton and Richards (1990), and carbon yield data are taken from Richards (1992).

Scenarios

The ASM analysis evaluates the welfare and carbon impacts of tree planting programs under several alternative assumptions. First, the analysis examines the implications of using alternative land bases for planting trees: cropland, pastureland, and wetlands. These land types differ in carbon sequestration potential, in distribution within the geographic United States, and in current agricultural

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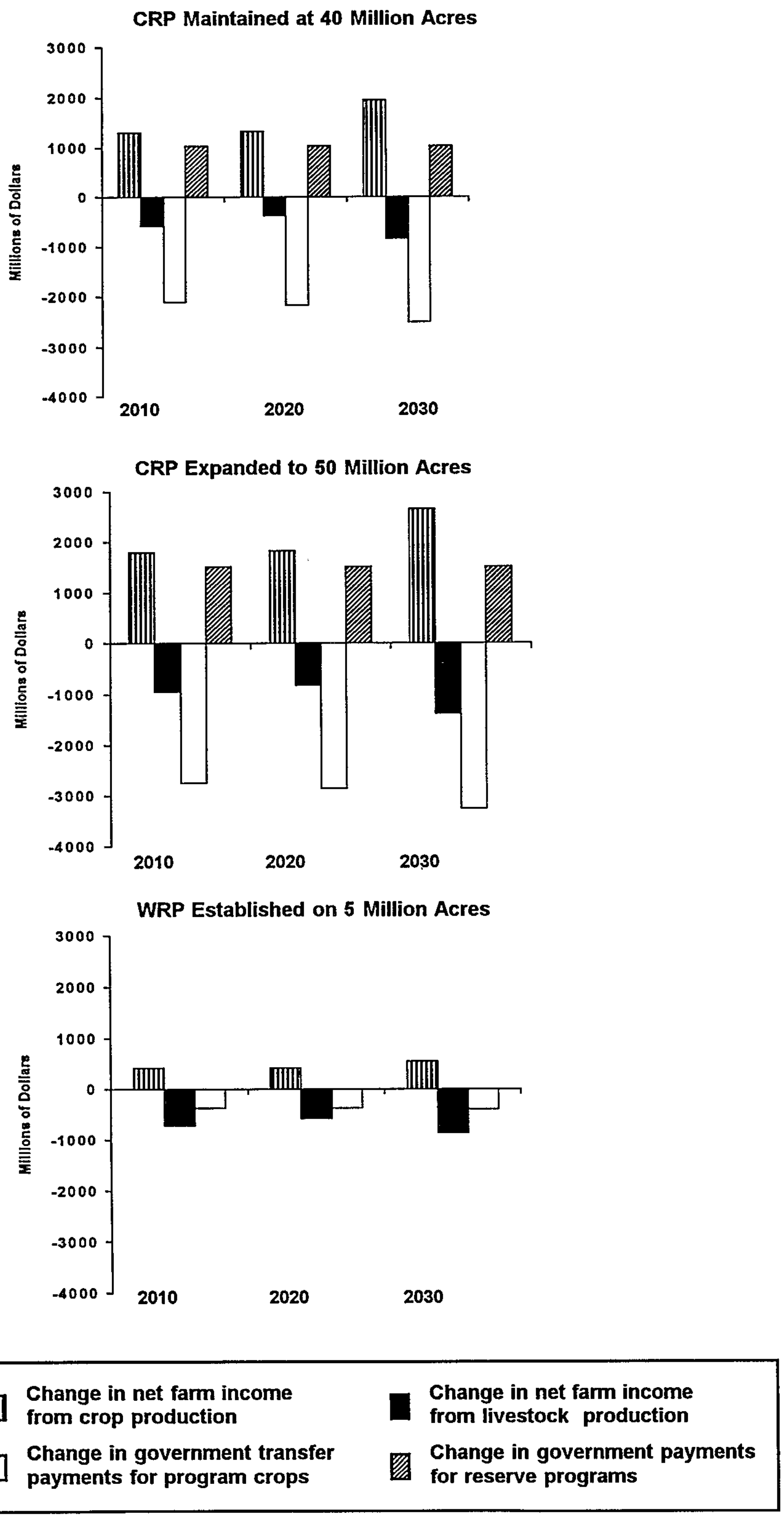
[9] Program costs are not handled endogenously in the models; rather they are based on estimates by analysts familiar with the Conservation Reserve Program. It is estimated that additions to the CRP in the Great Plains states would cost 40 to 50 percent of the current $49 to 50 per acre. Environmentally sensitive acres added to the CRP are expected to cost $70 to 80 per acre.

Figure 4-9. Impacts on Agriculture for CRP and WRP Scenarios, Change from Base Case



Source: Reese, et al. 1993

use. Using alternative land bases, therefore, produces different price impacts for land, crops, and livestock, and different impacts on economic welfare and carbon sequestration. The three specific land scenarios reported here involve planting 6.3 million acres on cropland, 7.5 million acres on pastureland, or 4.6 million acres on wetlands. These programs are roughly similar in magnitude to the smaller tree planting program in Section 4.1 (low enrollment and $110 million in funding) and the wetlands program described in Section 4.2, although the land bases are not directly comparable.

Second, several different enrollment patterns are analyzed. Because land varies in productivity, land price, and the cost of establishing trees, the cost of sequestering a ton of carbon varies within each of the land types.[10] A program that enrolls lands in order of carbon sequestration costs will sequester a given amount of carbon at the lowest cost. For most analyses reported here, land is enrolled on a least-cost basis: for a given land class, acres are planted to minimize the cost per ton of sequestering carbon, so that lands that can sequester carbon most cheaply are enrolled first. For cropland, however, an alternative pattern of enrollment is also analyzed, in which the regional distribution of planted lands follows the pattern of lands enrolled in the current Conservation Reserve Program.

Last, the analysis examines two alternative harvesting assumptions: optional harvests and no harvests. In the optional harvest scenario, the ASM simulates the decision faced by farmers in each region to plant or harvest trees based on economic considerations. While allowing harvesting reduces the amount of carbon stored on planted lands, it provides an additional incentive for landowners to plant trees, an effect that may offset the potential carbon loss from harvesting, as described more fully below.

The ASM has several advantages. Because it is a detailed model of the agriculture sector, it directly models impacts on land prices (previous analyses have assumed no impacts on these prices), captures farm program effects, and reports welfare and other impacts in the farm sector. The ASM analyses are, however, static; all planting essentially takes place in a single time period, and so the model reports average carbon per acre per year, or average cost per ton per year, rather than time paths of carbon, timber, acres, and costs. While this approach captures average carbon accumulation over the rotation of the trees that are planted, it tends to overstate carbon accumulation that would occur during the early years of a multiple year tree planting program and to understate accumulation during later years.

Impacts on Carbon, Costs, and Welfare

Figure 4-10 presents average annual carbon accumulation for three land types, under alternative assumptions about harvesting. In this figure, the highest average annual sequestration rate under the no-harvest assumption occurs for cropland, followed closely by pastureland, and then by wetlands. Although less cropland is enrolled than pastureland, higher annual carbon accumulation on cropland reflects the higher productivity of these lands, at the assumed levels of planting.

The relative productivity of these lands also influences the costs of sequestering carbon, which are reported in Table 4-9. In this table, average cost is calculated as the annual cost (to the government) of the tree planting program divided by the amount of carbon sequestered annually. In turn, government costs represent the subsidy that the government would have to pay landowners to induce them to plant the additional trees. This subsidy, therefore, will be higher if land rents are higher. On a per ton basis, the subsidy will be lower if the enrolled land is more productive. The cost per annual

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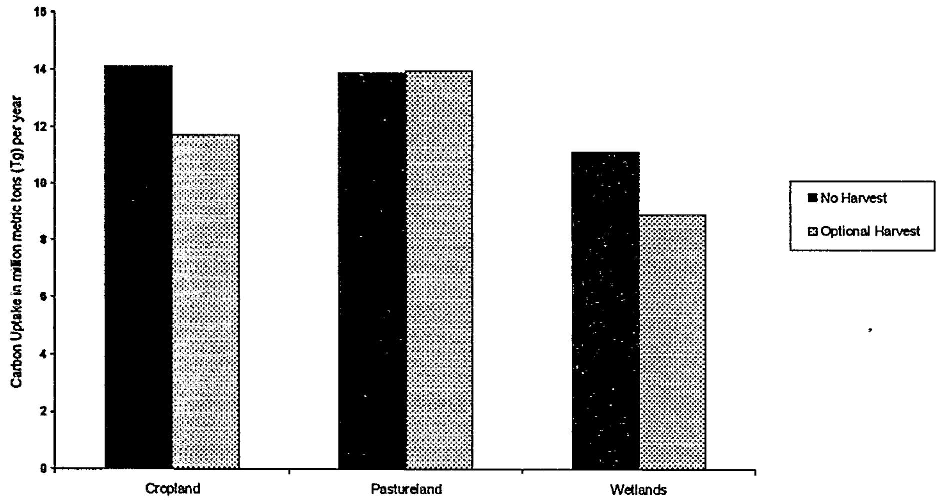
[10] Cost, in this analysis, is calculated as the full "opportunity cost" of planting trees, i.e., the amount farmers must be paid to induce them to plant trees, taking into account land prices and profitability of the land in alternative uses, the cost of establishing trees on the land, and revenues from harvesting mature trees. Cost is not, therefore, fully comparable with costs reported in Section 4.1, where it was assumed that the government fully compensates farmers for foregone land rent, and pays half of the cost of establishing trees, regardless of whether these sum to more or less than the opportunity cost of the land.

Figure 4-10. Average Annual Net Carbon Accumulation: Tree Planting on Three Land Types



Source: Callaway and McCarl 1994

ton of carbon, under the assumption of no harvests, is lowest for wetlands, followed closely by cropland and more distantly by pastureland.

While the results for the restricted harvest scenario illustrate carbon and cost impacts most clearly, a more realistic assumption is that harvesting occurs. Allowing harvesting will have several competing effects. First, harvesting generates some income for those who plant; a lower subsidy, therefore, is required to induce additional planting. In addition, harvesting forested land may lead to more land

Table 4-9
Impacts of Tree Planting on Different Land Bases

	Cropland		Pastureland		Wetlands	
	No Harvest	Optional Harvest	No Harvest	Optional Harvest	No Harvest	Optional Harvest
Annual Government Cost ($ millions)	100	60	220	90	70	40
Annual Carbon (million tons)	14.1	11.7	13.9	14.0	11.1	8.9
Annual Average Cost ($ per ton)	6.90	5.00	15.70	6.60	6.30	4.40

Source: Callaway and McCarl 1994

returning to agricultural use, mitigating the impacts of tree planting on land prices and, thus, reducing the costs to the government of subsidizing forestation. At the same time, harvesting a large amount of timber would tend not only to depress stumpage prices significantly, but partially to reduce carbon sequestration gains.

As displayed in Figure 4-10, allowing harvesting reduces the carbon stored on cropland and wetlands, relative to a situation of no-harvest. Government costs drop substantially, however, as illustrated in Table 4-9. On balance, the cost-per-ton of carbon sequestered drops significantly for all three types of land when harvesting can occur.

Both the amount of carbon sequestered per acre, and the cost of sequestration per ton of carbon, are highly sensitive to the pattern of enrollment. When lands are enrolled on a least-carbon-cost basis, costs of sequestering a given amount of carbon will be lowest. Alternatively, 6.3 million acres of cropland could be enrolled in a pattern reflecting the regional distribution of lands historically enrolled in the CRP. As illustrated in Table 4-10, the two patterns of enrollment produce dramatically different results. Although average annual carbon accumulation is slightly higher under the historic enrollment pattern, costs more than double. When harvests are restricted, the costs of sequestering carbon using the historic distribution are more than triple those using a least-cost enrollment pattern.

Table 4-10
Impacts of Tree Planting on Cropland with Varying Enrollment Strategies

	Least-Cost Enrollment		Historic Enrollment	
	No Harvest	**Optional Harvest**	**No Harvest**	**Optional Harvest**
Annual Government Cost ($ millions)	100	60	340	150
Annual Carbon (million tons)	14.1	11.7	15.7	12.6
Annual Average Cost ($ per ton)	6.90	5.00	21.60	11.61

Source: Callaway and McCarl 1994

Finally, the ASM provides measures of the change in economic welfare and prices in the agriculture and forest sectors. The results for the agriculture sector, displayed in Tables 4-11 and 4-12, are similar to those in Section 4.2. Crop prices (which do not include farm program payments) and livestock prices tend to rise slightly as a result of tree planting on agricultural lands, which results in declines in consumer surplus.[11] These results are particularly pronounced for the historic enrollment pattern, which plants more trees in regions that are important to crop production. Agricultural producers show a decrease in welfare when land is enrolled in order of carbon cost, and an increase in welfare under the historic enrollment scenario. As in the analysis in Section 4.2, impacts under

[11] Table 4-11 reports Fisher price indices for agricultural crops (raw agricultural crop prices not including farm program payments); livestock; and forest consumer prices for logs (which gives an index of prices to all forest producers at the mill dock).

either scenario, while apparently large in dollar terms, are relatively small as a percent of the base case surplus for agricultural producers.[12]

Table 4-11
Economic Welfare Effects of Federal Subsidies for Tree Planting on Cropland
(million dollars, percent change)

	Least-Cost Enrollment				Historic Enrollment			
	No Harvest		Optional Harvest		No Harvest		Optional Harvest	
Forest Sector								
Consumer Surplus	0	(0%)	190	(2%)	0	(0%)	230	(2%)
Producer Surplus	-10	(-1%)	-210	(-13%)	0	(0%)	-240	(-15%)
Agriculture Sector								
Consumer Surplus	140	(*)	-10	(*)	-250	(*)	-610	(*)
Producer Surplus	-100	(*)	-10	(*)	110	(*)	330	(1%)

Notes: Surplus changes estimated relative to surplus in a base case with no planting subsidies.
"*" indicates an increase or decrease of less than 0.5%.
Source: Callaway and McCarl 1994

Table 4-12
Price Effects of Federal Subsidies for Tree Planting on Cropland:
Fisher Price Indices

		Least-Cost Enrollment		Historic Enrollment	
	Baseline	No Harvest	Optional Harvest	No Harvest	Optional Harvest
Crops	100	99.9	100.1	100.7	101.5
Livestock	100	100	100	100.2	100.4
Logs	100	100	88.6	100.0	87.1

Source: Callaway and McCarl 1994

Economic impacts in the forest sector as a result of tree planting are significantly affected by whether or not harvesting occurs. When harvests are restricted, trees that are planted do not ultimately enter timber markets, and so there is no change in the log prices or in the welfare of producers and consumers, as displayed in Tables 4-11 and 4-12. When harvests are allowed to occur, tree planting reduces forest product prices significantly, resulting in benefits to consumers and adverse impacts on producers.

[12] Differences in the magnitude and direction of results between Sections 4.2 and 4.3 may reflect differences in the number of acres enrolled, in enrollment patterns and the assumptions about the rates at which land enrolled in the CRP reverts to alternative uses or become available for tree planting, in how the farm program is modelled, and in interactions between the agriculture sector and the forest sector (which is absent in the CRP analysis) in the ASM.

5. Other Forest Policy Scenarios

Policies that increase the acreage of standing trees by reducing harvest can expand the amount of carbon stored on forest land. Two scenarios, reduced harvest in National Forests and increased rates of utilization of recycled fiber (which decreases the demand for virgin fiber), provide information on the carbon, timber, and economic impacts of such forest policies. A third scenario, increased use of wood fuels, which reduces carbon emissions by displacing fossil fuel generated energy, is also examined. Finally, this part of the report examines the implications of combining policies to take advantage of the potentially offsetting economic impacts.

5.1 Increased Rates of Recycled Paper Utilization

Policies designed to increase the use of recycled paper and fiber in the paper and pulp making process (see Box 5-1) increase the size of the forest carbon pool in three ways. First, manufacturers of pulp and paper products that use greater amounts of recycled fiber use less virgin (freshly harvested) fiber, reducing the harvest of pulpwood-sized trees. By decreasing demand for harvested wood, increased use of recycled fiber can increase forest inventories and enlarge the forest carbon pool. Second, trees left uncut grow larger over time, further increasing forest and carbon inventories. Last, to the extent that the wastepaper in landfills eventually decays and returns greenhouse gases to the atmosphere, increased utilization of recycled fiber can reduce emissions associated with the forest products pool. Pulpwood-sized trees that grow into sawtimber sizes can be cut for long-lived solid wood products, which sequester carbon for longer periods of time than do paper products.

Although increased recycling has the potential to expand forest carbon, timber market effects may mitigate the beneficial impacts of recycling on forest carbon. If decreased demand for harvested timber for paper production reduces long-term prices in the forest sector, then less near-term planting may occur, in anticipation of lower returns in the long term. At current rates of recycling, however, projections for the U.S. suggest that serious supply shortages will exist for sawtimber in the future, resulting in rapidly rising stumpage prices. Increased recycling, therefore, can extend fiber supply and partially mitigate potential increases in stumpage prices over time; the scenario results presented below suggest that, with increased recycling, real prices of softwood remain relatively stable (rather than rise) through the time period.

Box 5-1
Paper Recycling in the U.S.

The U.S. currently recycles several types of paper, including newspaper, and the rate at which recyclable paper is being utilized has risen from around 25 percent in the late 1980s to almost 30 percent in 1992. Continuing growth in recycling rates is technically feasible, particularly for newspaper, and a variety of policies are being considered at both the federal and State levels to increase the rate at which wastepaper is used.

Reducing the pressure on landfills provides much of the impetus for recycling programs; in 1990, paper and paperboard comprised approximately 37.5 percent, by weight, of the material deposited in landfills. Policies that have been proposed to improve waste paper recycling include minimum recycled content standards for newspaper, per-unit disposal fees for trash removal, mandatory recycling rules, and financial incentives to use or recycle wastepaper. Increased recycling may also have added benefits for carbon storage.

Source: Ince 1994

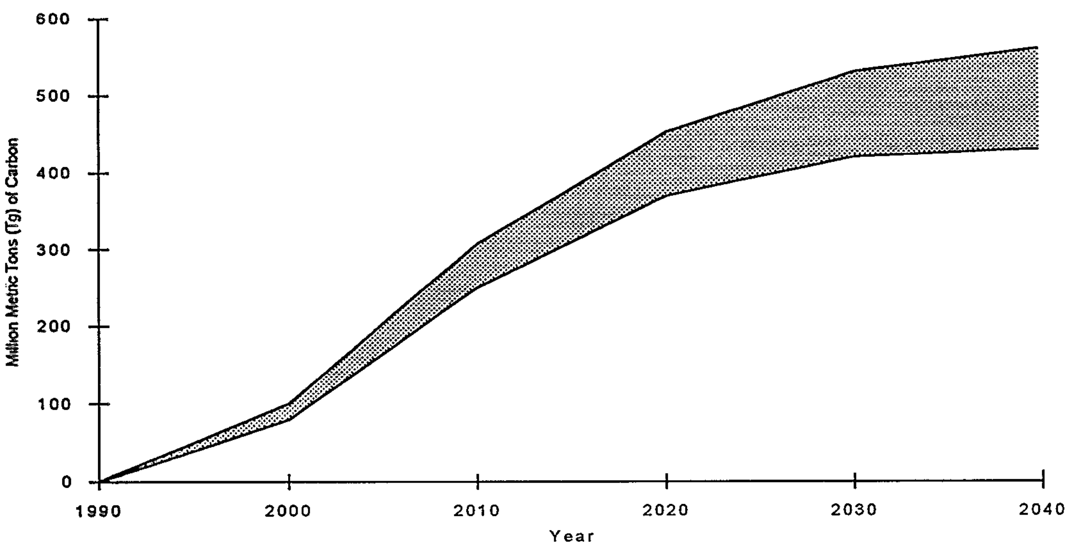
This analysis employs the same models used for the analyses of large scale tree planting presented in Section 4.1. The NAPAP model provides the framework necessary to analyze the impacts of policies designed to increase recycling rates. This model (described in Section 3) simulates the evolution of process technology (for using recycled fiber and virgin wood fiber) for all primary paper and paperboard products (such as newsprint, printing and writing paper, and linerboard). The model combines regional information on supply and demand, manufacturing processes, and transportation costs to project future technological changes, production, capacity, imports and exports, and related market equilibria for the United States and

Canadian pulp and paper sector. Combining this model with TAMM/ATLAS provides the necessary link for analyzing the implications of increased paper recycling on forest product markets and on carbon storage. The CGTM model provides additional insight into the regional distribution of impacts on pulpwood and sawtimber markets within the U.S., and the associated effects on international trade in the forest products sector.

Scenarios and Base Case

Increasing the use of recycled fiber in the manufacture of paper and board replaces a percentage of the newly harvested (virgin) fiber in the production process. Using less virgin fiber reduces the harvest of trees and leaves more of the forest, intact to grow longer and to sequester more carbon. The increased recycling scenario differs from the base case both in how quickly higher levels of recycled fiber use are attained, and in the magnitude of the final level of recycled fiber use. The increased recycling scenario achieves 45 percent utilization by 2000 and maintains that level through 2040. This scenario, which was derived from suggestions by the American Paper Institute, assumes that policies and programs are aimed at reducing volumes of waste (through more efficient product use, public education, disposal fees, and other means).

Figure 5-1. Total Carbon Storage on U.S. Public and Private Timberland: Increases Relative to Base Case for the Increased Recycling Scenario



Sources: Turner, et al. 1993; Birdsey and Heath 1993

Carbon Impacts

Increasing the use of recycled fiber increases the supply of standing timber and the associated carbon storage, as Figure 5-1 illustrates. Carbon storage above base case levels rises to between 400 and 600 million metric tons by the year 2040, a level that is comparable to that achieved by the large scale tree planting programs discussed in Section 4.1 (the range reflects estimates from FORCARB and from FCM). Because the gains in carbon storage under the increased recycling scenario depend less on new growth than on conserving existing standing stock, increases in carbon occur more rapidly than in the tree planting scenarios; more than half of the carbon accumulates by the year

2010. Table 5-1 presents annual carbon accumulation at decadal intervals. The HARVCARB analysis suggests additional average annual carbon accumulation in post-harvest pools of 1.9 million metric tons of carbon per year, over the 50 years of the analysis. However, the potential climate impact benefit of post-harvest carbon accumulation may be offset when the relative climate impact of methane is taken into account (Turner, et al. 1993).

Table 5-1
Annual Carbon Accumulation on U.S. Public and Private Timberland Relative to Base Case for Increased Recycling Scenario, Decadal Intervals (million metric tons)

	2000	2010	2020	2030
Increased Recycling	13.5	15.6	10.0	4.4

Note: Forest carbon estimates are presented as an average of FORCARB and FCM results.
Source: Turner, et al. 1993; Heath 1993

TIMBER INVENTORY EFFECTS

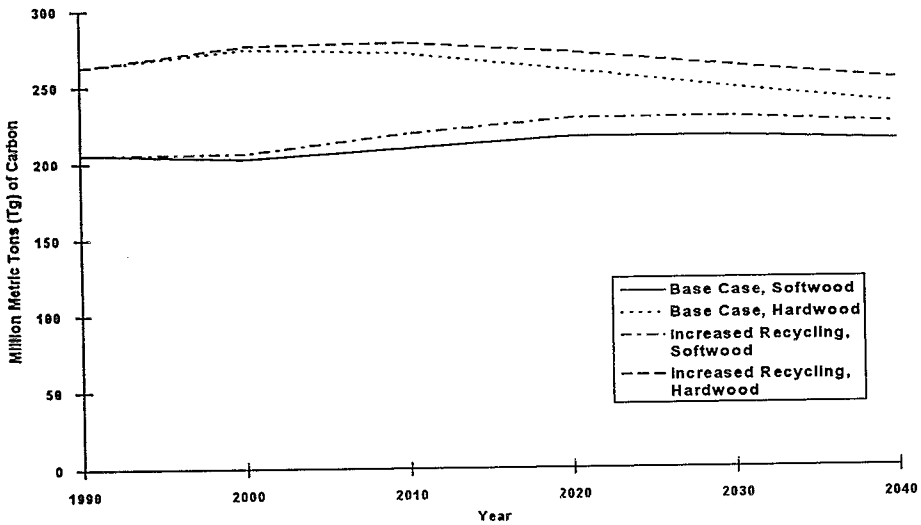
As the demand for virgin fiber declines, fewer acres are harvested and timber inventories rise (see Figure 5-2). Relative to the base case, softwood inventories in 2040 rise by about 5 percent, and hardwood inventories rise by 7 percent. Overall harvest levels decline, as illustrated in Table 5-2. The magnitude, as well as the pattern, of changes in harvests reflects the fact that some of the "savings" in wood that would have been used as pulp for manufacturing paper and paperboard are being used for the manufacture of other products, especially lumber, after the time lag needed for pulpwood-sized trees to grow to sawtimber size.

Table 5-2
Changes in Harvest Levels for the Increased Recycling Scenario, Relative to the Base Case (million cubic feet)

	Hardwood			Softwood		
Region	**2000**	**2020**	**2040**	**2000**	**2020**	**2040**
North	-154	-171	-123	-60	-60	-40
South	-304	-285	-172	-580	11	300
Rockies	0	0	0	-5	-48	-17
Pacific Coast	-14	-14	-8	-160	-187	-128
Total U.S.	**-473**	**-470**	**-304**	**-805**	**-284**	**117**

Note: Sum of regions may not equal totals because of rounding.
Source: Haynes, et al. 1994

Figure 5-2. U.S. Softwood and Hardwood Inventory Projections for Privately Owned Timberland: Base Case and Increased Recycling Scenario



Source: Haynes, et al. 1994

Economic and Trade Effects

Because additional recycling reduces the demand for pulpwood, stumpage prices and revenues to forest land owners decline over time under the increased recycling scenario relative to the base case. Reduced harvest for pulpwood increases the future supply of sawtimber, thereby increasing harvests of sawtimber and decreasing prices (see Table 5-3). Increases in the supply of sawtimber do not happen immediately, but may lag more than 10 years behind the initial impacts of recycling on pulpwood markets. Results are felt most strongly in the softwood and hardwood markets in the South, which produces the bulk of the paper pulp consumed in markets that switch to recycled fiber.

Similarly to the tree planting scenarios, reduced sawtimber prices in the U.S result in decreased imports from Canada. Softwood lumber imports from Canada drop significantly throughout the time period and by over 4,600 million board feet in 2040, or 36 percent of base case imports in that year (Haynes, et al. 1994).

5.2 Reduced National Forest Harvests

The analysis of changing National Forest harvest levels examines the effects of harvest reductions. These reductions result from elimination of harvest of old growth in the Pacific Northwest, protection of spotted owl habitat in Washington, Oregon and California, protection of the red cockaded woodpecker in the South, elimination of below cost timber sales, and elimination of harvesting in existing roadless areas. As illustrated in Table 5-4, the overall level of National Forest harvest for the scenario is about 1.36 billion cubic feet in 2000 and 1.59 billion cubic feet in 2040, about 21 percent below harvest levels in the base case. Harvest levels projected under the base case, for all public and private lands, are presented by region in Table 5-5. Most of this analysis relies on the base case and models used for the analyses of large scale tree planting presented in Section 4.1, and the CGTM provides additional results.

Table 5-3
Stumpage Prices in the Increased Recycling Scenario
(dollars per thousand board feet)

	2000	2010	2020	2030	2040
Softwood Stumpage Prices					
North	48	50	63	67	75
South	125	6	29	70	165
Rocky Mountains	99	197	190	191	202
Pacific Coast	241	274	274	252	236
Hardwood Sawtimber Stumpage Prices					
United States	461	551	651	764	879

Source: Haynes, et al. 1994

Table 5-4
National Forest Harvest Under Base Case and
Reduced National Forest Harvest Scenario
(billion cubic feet)

Year	Base Case	Reduced Harvest Scenario
1986	2.07	2.07
2000	1.54	1.05
2010	1.64	1.08
2020	1.70	1.09
2030	1.74	1.11
2040	1.78	1.11

Source: Haynes, et al. 1994

RESULTS: CARBON, TIMBER INVENTORY, ECONOMIC EFFECTS, AND TRADE

Timber inventory and carbon impacts for this scenario are modeled using the TAMM/ATLAS system and the forest carbon models, FCM and FORCARB. The CGTM model provides additional analysis of the impact of international trade linkages. Under this scenario, declines in timber inventories result in intensified competition for the available timber and upward pressure on softwood stumpage prices. In regions where there are sufficient private timber supplies, however, decreases in National Forest harvest are offset by increased timber harvests from private timberlands.

Overall, there is little change in the total timber inventory and, hence, in the total carbon stored on U.S. timberland. Because of offsetting private harvests, total public and private harvest remain relatively unchanged under this scenario, as does the carbon stored in the product and landfill pools. It is important to note (as described in Box 4-1) that this analysis does not account for changes in management behavior in response to price signals, and likely overestimates the economic impacts of these policies.

Table 5-5
Base Case Harvest Projections by Region: Public and Private Timberland Owners (billion cubic feet)

	Hardwood Harvest			Softwood Harvest		
Region/Owner	**2000**	**2020**	**2040**	**2000**	**2020**	**2040**
North						
Public	.2	.3	.4	.1	.2	.2
Private	1.8	3.8	4.9	.6	1.0	1.6
South						
Public	.1	.2	.3	.4	.4	.5
Private	2.8	5.3	5.3	5.3	5.6	7.5
Rockies						
Public	--	--	--	.5	.6	.7
Private	--	--	--	.3	.5	.6
Pacific Coast						
Public	.1	--	--	1.8	1.3	1.3
Private	.1	.3	.4	2.1	2.3	2.9
Total U.S.	**5.1**	**9.9**	**11.3**	**11.2**	**11.8**	**15.4**

Note: Hardwood harvest is reported for the West, i.e., Rockies and Pacific Coast combined.
Source: Haynes, et al. 1994

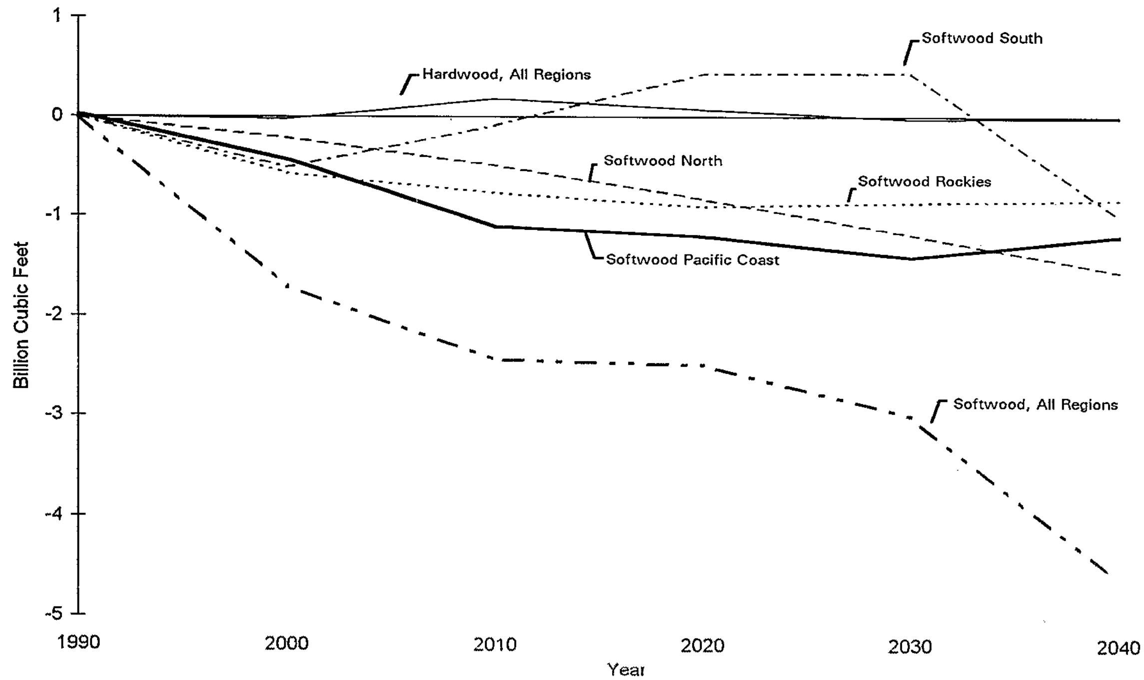
Private softwood inventory (which is illustrated in Figure 5-3) declines by about 1 to 2 percent over the time period relative to the base case. This change in available timber supply affects the prices of sawtimber and timber products. Softwood stumpage prices in all regions are significantly affected through 2040, as a comparison of Tables 5-6 and 4-5 illustrates. Softwood stumpage prices on the Pacific Coast, for example, are about 12 percent above the base case by the year 2040. Softwood lumber prices, overall, are about 7 percent higher in 2040 than in the base case (Haynes, et al. 1994). There are no significant impacts on hardwood timber inventories or hardwood saw timber stumpage prices, illustrating the small role of National Forests in the hardwood sector.

Because of the lumber price increases, softwood lumber consumption declines slightly, by about 16 percent, and lumber imports from Canada rise by 10 percent by 2040 (Haynes, et al. 1994). The increase in lumber imports comes progressively after 2010 because domestic production is reduced as a consequence of the lower timber inventories and the associated higher prices.

The CGTM analysis provides slightly different results; higher Pacific Northwest log prices prompt higher-cost producers to increase their production levels both internationally and domestically. Thus, reduced harvests on U.S. public lands are replaced not only by large increases in supply from the U.S. South, but also by increased production from Europe and possibly from mature softwood stands in Siberia. In addition, CGTM projects non-wood product substitution to meet as much as one-third of the supply reduction (Perez-Garcia 1993).

The CGTM results have several implications for the carbon and economic impacts of reducing harvest levels in National Forests. The analysis using TAMM/ATLAS and FCM/FORCARB finds that increased harvests on U.S. private timberland replace decreased harvests on public lands, resulting in little net effect on total U.S. inventories or carbon flux from all U.S. timberland. The CGTM analysis

Figure 5-3. U.S. Private Timber Inventory: Changes Relative to Base Case for National Forest Harvest Scenario



Source: Haynes, et al. 1994

finds, however, that a significant portion of the offsetting harvests occurs in countries other than the U.S. (see Figure 5-4). Thus, carbon storage in U.S. forests could be higher in the reduced harvest scenario than under the base case.[13] The impacts on global carbon, however, are unclear and depend on the relative productivity of the lands harvested in the U.S. and internationally, and on the carbon impacts of substituting more energy-intensive products for forest products.

The CGTM analysis also shows economic surplus gains of $1.4 billion to timber producers worldwide. U.S. producers experience a net welfare loss of almost $100 million. Economic losses to lumber mills in the U.S. West are about $270 million, which are only partially offset by gains to mills in the South and North of $56 million. Consumer surplus losses in the U.S., which total $971 million, are evenly distributed among all regions (Perez-Garcia 1993).

5.3 Increased Use of Biomass Energy

This analysis examines the implications of using existing forest resources in the U.S. to increase the use of bioenergy for electricity generation. This analysis derives the wood energy (biofuel)

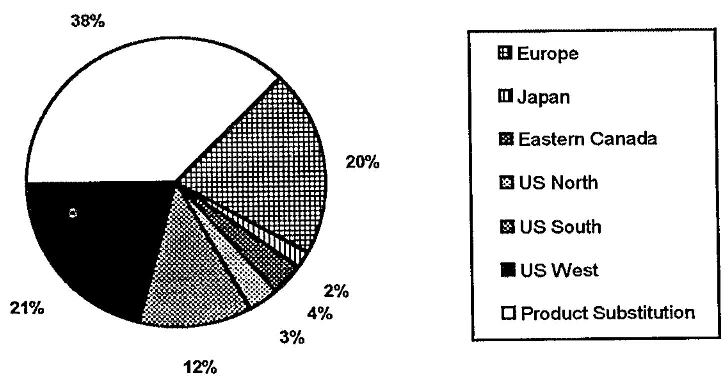
[13] The CGTM analysis assumes that public harvests decline significantly in Western Canada, thereby reducing potential timber supplies to the U.S.

Table 5-6
Stumpage Prices in the Reduced National Forest Harvest Scenario
(dollars per thousand board feet)

	2000	2010	2020	2030	2040
Softwood Stumpage Prices					
North	53	72	98	114	129
South	208	322	370	331	342
Rocky Mountains	159	276	315	305	329
Pacific Coast	288	357	405	409	401
Hardwood Sawtimber Stumpage Prices					
United States	463	559	665	784	903

Source: Haynes, et al. 1994

Figure 5-4. Projected Global Production Increases in Response to Habitat Preservation, by Region: 1995



Note: Distribution reported as a percent of total production increase of 33.3 million cubic meters.

Source: Perez-Garcia 1993

scenario from the National Energy Strategy (NES) (USDOE 1991). The scenario assumes that wood energy supply increases from 3.1 Quads in 2000 to 5.4 Quads in 2030, compared to the base case in which wood energy supply increases from 1.8 Quads to 2.0 Quads over the same period (Colin and Skog 1990). The scenario accounts for changes both in fuelwood consumption and in the proportion of fuelwood that comes from the growing stock part of timber inventories (USDOE 1991). Harvest projections for the base case and scenario are shown in Table 5-7.

Table 5-7
Biomass Fuelwood Consumption: Assumptions for Base Case and Biofuel Scenario, Decadal Intervals

	Base Case		Biofuel Scenarios	
Year	Softwood	Hardwood	Softwood	Hardwood
Biomass Fuelwood Consumption (million cubic feet)				
2000	883	3,377	1,030	3,940
2010	1,207	4,395	1,650	6,020
2020	1,312	4,420	2,160	7,200
2030	1,271	4,113	3,040	9,890
2040	1,219	3,875	3,200	10,070
Fuel from Non-growing Stock Sources (percent)				
2000	85	75	73	73
2010	85	76	82	82
2020	86	77	70	70
2030	85	77	61	61
2040	86	77	67	67

Source: USDOE 1991, reported in Haynes, et al. 1994

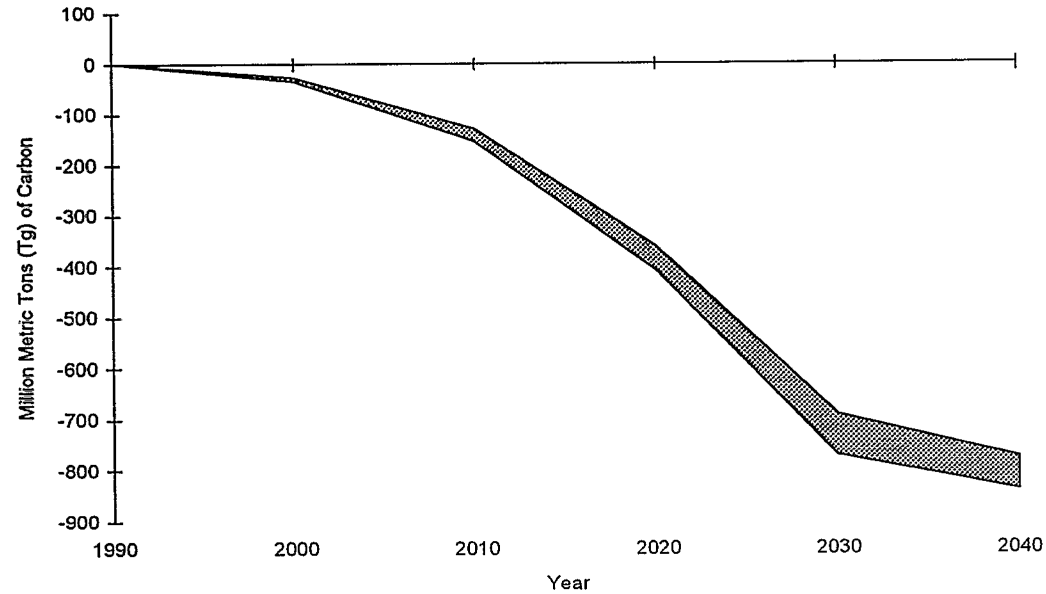
The growing stock fraction is especially important in dealing with fuelwood demand on forest resources. Of the approximately 737 million acres of forest land in the U.S., 47 million acres are reserved from harvest, and 200 million acres are urban or low productivity forest land, leaving 490 million acres to support harvests for various products (Haynes, et al. 1994). Harvests for fuelwood primarily come from urban forest land, low productivity forest land, or from residues left after logging. There has, thus, been little actual harvest for fuelwood in some regions and, overall, the majority of both hardwood and softwood fuelwood comes from non-growing stock, both currently and under the base case and scenario projections. The percentage of fuelwood derived from growing stock (wood of merchantable quality) is projected to increase in the NES scenario for both softwoods and hardwoods. That increase, combined with the higher overall harvest level has dramatic effects on forest resources, especially hardwoods.

Timber Inventory Effects and Carbon Impacts

Increasing the production of energy from biomass has three distinct effects on CO_2 emissions: *(1)* CO_2 is released when the wood is combusted to produce energy; *(2)* carbon is sequestered during the growth or regrowth of forests harvested for biofuels; and *(3)* carbon emissions are "avoided" when fossil fuel combustion is displaced by bioenergy. Removing wood for biofuels initially has the effect of reducing the carbon inventory on the forest base.[14] Over time, however, regrowth on harvested lands replaces the biomass carbon. The real benefit to the atmosphere occurs as wood displaces fossil fuels, and the CO_2 emissions from burning wood are absorbed by regrowing forest.

[14] Strategies that plant dedicated energy crops will initially increase the carbon inventory prior to harvesting, unlike strategies that harvest existing forests.

Figure 5-5. Total Carbon Storage on U.S. Public and Private Timberland: Changes Relative to Base Case for Increasing Biomass Energy Scenario



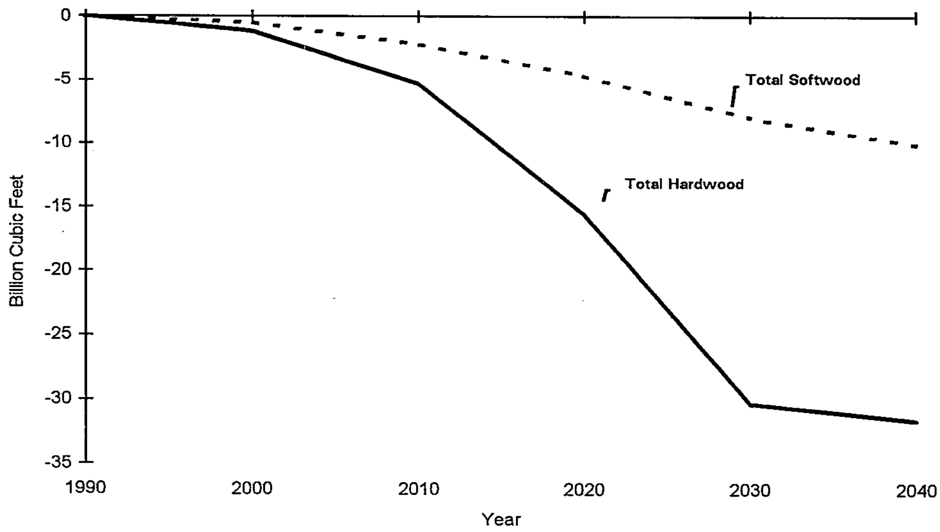
Sources: Lee 1993c; Heath 1993

The considerably greater harvest levels associated with increased biofuels utilization result (by 2040) in a large reduction in the U.S. timber inventory and, thus, the total carbon pool, relative to the base case. Estimates of the changes in carbon storage and inventory are shown in Figures 5-5 and 5-6, respectively. The large declines in timber inventory and carbon displayed in these figures result from several factors. First, the additional biofuel harvest levels under this scenario are large; in 2010, additional biofuel harvest over the base case is about 37 percent over the base case, and as large as the total harvest from National Forest lands in 1990. These increases in harvest leave gaps in the inventory that cannot be filled until the forest regenerates. Because hardwoods, which in general regenerate more slowly than softwoods, supply much of the harvested timber, regrowth lags significantly behind harvest, and the inventory shows large declines throughout the time period.

Second, the volume of harvest rises almost uniformly throughout the time period of the scenario analysis, relative to the base case. As more volume (and more acreage) is being harvested in each succeeding decade than is being regenerated, the regeneration cannot keep pace with the size of the harvest. This result is mirrored in the increasingly steeper downward trajectory of carbon storage losses in the first four decades of Figure 5-5. As the size of the increase abates towards the end of the simulation period, regeneration begins to catch up with the harvest, and carbon losses from inventory level out in Figure 5-5. The depletion of inventory and the carbon pool could be mitigated to some degree, but not prevented, by taking more of the harvest volumes from southern softwoods, which grow and regenerate faster than hardwoods.

Last, as discussed in Section 3, the analysis does not take into account the carbon contained in timber stands before they reach merchantable size (see Box 3-2). Accounting for biomass in stands in the first few years after harvest might therefore reduce the size of the depletion in inventory. A rough calculation of carbon in young stands suggests that the results of this scenario analysis are not changed significantly by such inclusion (Birdsey 1995).

Figure 5-6. U.S. Private Timber Inventory: Changes Relative to Base Case for Increasing Biomass Energy Scenario



Source: Haynes, et al. 1994

On balance, the results suggest that large increases in the rate of removal of standing inventory immediately deplete forest inventories and carbon pools, and that depletion effect is maintained or magnified when the size of the harvest increases over time. The carbon pool is likely to return to a point of no net loss, compared with the baseline, when harvest volumes reach a steady state, although the analysis was not carried out far enough to confirm this.

Avoided Fossil Fuel Emission: Net Carbon Impacts

Although the combined forest inventory and carbon models do not produce estimates of the impact on CO_2 emissions of displacing fossil fuels in the bioenergy scenario, projected harvest levels can be used to estimate these carbon benefits. The magnitude of avoided emissions depends on a number of factors, including the energy content of the biomass, the heat rate of the biomass-fired energy technology, and the carbon intensity of the displaced fossil fuel. Cumulative emissions avoided by the year 2040 could, however, under a reasonable set of assumptions, range between 470 and 840 million metric tons of carbon with a mean of about 650 million metric tons (ICF 1995).

Including avoided emissions does not completely offset the reduced carbon storage due to increased harvest until the final decade reported here. Table 5-8 presents annual carbon accumulation in forest ecosystems at decadal intervals, avoided carbon emissions from displaced fossil fuel use, as well as total net accumulation under this scenario. Savings of fossil fuel emissions do not completely offset forest carbon losses because fossil fuels (especially coal) are more efficient, or have a higher energy content per ton of carbon, than wood. Consequently, more tons of wood must be burned to create the same amount of energy produced by a given tonnage of fossil fuel.

This result makes an important point. Even when considering the contribution of an offset in the use of fossil fuels, harvesting an additional portion of existing forest resources for bioenergy depletes forest carbon pools, and will not fulfill greenhouse gas mitigation objectives in the short term, and

Table 5-8
Annual Carbon Accumulation on U.S. Public and Private Timberland Relative to Base Case for Increased Use of Biomass Energy, Decadal Intervals (million metric tons)

	2000	2010	2020	2030
Forest Carbon	-7.3	-17.8	-29.6	-21.1
Avoided Fossil Fuel Emissions	2.6	7.5	13.2	27.5
Net Carbon Flux	-4.7	-10.3	-16.4	6.4

Note: Forest carbon estimates are derived as an average of FORCARB and FCM results. Avoided fossil fuel emissions are an average of results assuming the displacement of coal and gas-fired generation.
Sources: Birdsey and Heath, 1993; Lee 1993; ICF 1995

possibly in the medium term. Once the forest returns to a steady state where removals and regeneration balance, the fossil fuel offset would probably be a net contribution to greenhouse gas abatement. The results suggest that a forest bioenergy strategy that uses wood from plantations established in advance for growing biofuel stocks would mitigate the adverse impacts on forest inventories and carbon pools of a significant biomass harvest. Combination scenario 3, below, addresses that situation. Additional planting and regrowth would further mitigate the impacts of harvest on carbon storage. Forestation can also mitigate increases in stumpage prices that occur in the biomass energy scenario, presented in Table 5-9.

Table 5-9
Stumpage Prices in the Increased Biomass Energy Scenario (dollars per thousand board feet)

	2000	2010	2020	2030	2040
Softwood Stumpage Prices					
North	52	76	103	125	150
South	183	278	345	341	358
Rocky Mountains	106	233	291	342	339
Pacific Coast	254	332	392	420	425
Hardwood Sawtimber Stumpage Prices					
United States	465	565	685	827	947

Source: Haynes, et al. 1994

5.4 Effectiveness of Combined Scenarios

In reality, climate change mitigation activities are unlikely to be implemented singly or in a policy vacuum. The U.S. Climate Change Action Plan, for example, identifies some 44 climate change mitigation activities for simultaneous implementation (White House 1993). The analyses considered thus far in this report — as well as most analyses of climate change mitigation options — examine the carbon, timber, and economic impacts of isolated policies. The impacts of policies implemented jointly, however, may differ from those suggested by inspecting the results for individual policies, because of complementary, synergistic, or competing effects across the policies. To investigate the impacts of broader forest sector strategies, this report analyzes several additional scenarios that combine policies reported earlier in Sections 4 and 5.

Analyzing combined scenarios allows an evaluation of the relative success or failure of jointly executed programs in achieving the competing goals of maximum carbon sequestration and minimum economic disturbance. There are, thus, two key reasons to analyze the impacts of simultaneous implementation of forest sector policies. First, combining policies can increase the aggregate carbon sequestration that is achieved. Because most of the forest sector policies considered in this report act to expand the forest carbon sink, combining policies is likely to have additive impacts on aggregate net carbon sequestration. Whether these impacts are, indeed, additive (or less or more than additive), can be a consideration in appropriately devising, and analyzing the cost-effectiveness of, policy strategies to sequester carbon in the forest sector.

Second, many of the policies, taken in isolation, potentially have adverse economic impacts on at least some groups in the forest sector, because of price and other market effects (such as changes in trade flows). Combining policies that have opposite impacts, e.g., those that create upward pressure on prices by reducing timber supply and those that create downward pressure on prices by reducing timber demand, can result in less economic disruption than occurs under the individual policy scenarios. Again, confirming this result and understanding the net impacts of these offsetting effects solidifies the analytical underpinnings of the analysis of the economic impacts of forest sector carbon sequestration actions.

Table 5-10
Combination Scenarios

Scenario	Reduced National Forest Harvest	Increased Recycling	Biofuels	Low Enrollment $220 million funding
Combination 1	✓	✓		
Combination 2	✓	✓	✓	
Combination 3	✓	✓	✓	✓

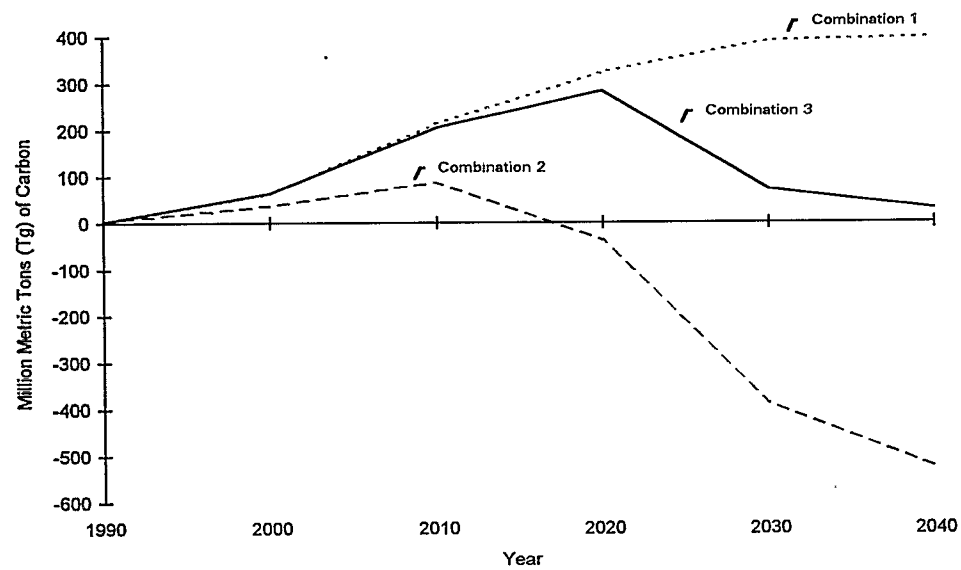
Combining scenarios, thus, presents an opportunity to evaluate the carbon, timber, and economic consequences of a coordinated forest sector strategy to sequester carbon. The three combination scenarios analyzed are described in Table 5-10. Strategy 1 combines reduced National Forest harvest with increased paper recycling. These two policies have positive or no (and, hence, complementary) impacts on carbon accumulation and opposite (and, hence, offsetting) impacts on prices and economic welfare. Strategy 2 combines the first strategy with the increased production of biomass energy; this addition would tend to reduce the carbon stored on timberland (relative to Strategy 1) and to aggravate the upward pressure on prices created by reduced harvest of National Forests. The third strategy adds large-scale tree planting to the second strategy.[15] The addition of this scenario would tend to offset the declines in timber inventory and carbon storage associated with the biomass energy scenario, and provide offsetting downward pressure on softwood stumpage prices.

[15] The afforestation program added to the Combination 3 analysis is the low enrollment distribution (Moulton and Richards 1990) with an annual funding level of $220 million for 10 years.

Impacts on Timber Inventory and Carbon Accumulation

Figure 5-7 displays the impacts of the combined scenarios on total carbon storage, using the results from the FCM carbon model. Figures 5-8 and 5-9 display the underlying changes in U.S. private softwood and hardwood timber inventories over the period of the analysis. Because there is little change in net carbon accumulated over the base case in the reduced harvest scenario, the carbon impacts of the increased paper recycling scenario, reported earlier in Section 5, are similar to those of combination 1 (illustrated in Figure 5-7). As would be expected, the incremental carbon stored, relative to the base case, is lower for combination 2 than for combination 1, because of the addition of the increased biomass energy scenario, which reduces the timber inventory substantially. Adding an aggressive tree planting program (the third combination) further increases the carbon benefits of forest sector policies.[16] Table 5-11, which presents net annual carbon accumulation in the forests at decadal intervals for the FCM model, displays analogous results.

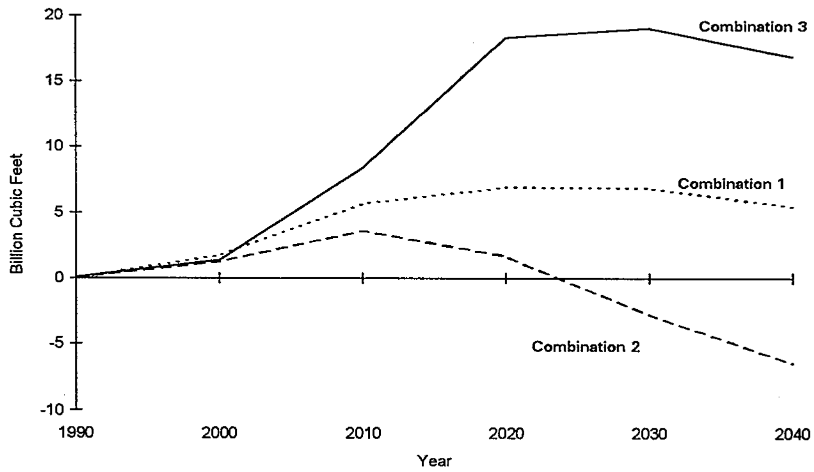
Figure 5-7. Total Carbon Storage on U.S. Public and Private Timberland: Changes Relative to Base Case for Combined Scenarios



Source: Lee 1993c

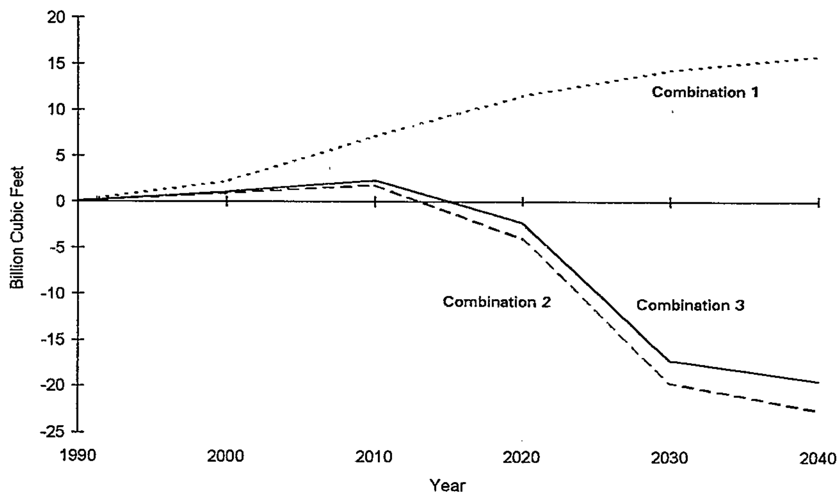
[16] Using the high, rather than the low, enrollment assumptions for the $220 million afforestation program in combination 3 would not change the overall results dramatically, although the net accumulation of carbon would exceed that in Figure 5-7.

Figure 5-8. U.S. Private Softwood Timber Inventory: Changes Relative to Base Case for Combined Scenarios



Source: Haynes, et al. 1994

Figure 5-9. U.S. Private Hardwood Timber Inventory: Changes Relative to Base Case for Combined Scenarios



Source: Haynes, et al. 1994

Table 5-11
Annual Carbon Accumulation on U.S. Public and Private Timberland Relative to Base Case for Combined Scenarios, Decadal Intervals (million metric tons)

	2000	2010	2020	2030
Combination 1	10.6	13.0	8.8	3.7
Combination 2				
Forest Carbon	*4.2*	*-3.8*	*-23.8*	*-24.2*
Avoided Fossil Fuel Emissions	*2.6*	*7.5*	*13.2*	*27.5*
Net Carbon Flux	6.8	3.7	-10.6	3.3
Combination 3				
Forest Carbon	*10.1*	*11.0*	*-6.6*	*-12.7*
Avoided Fossil Fuel Emissions	*2.6*	*7.5*	*13.2*	*27.5*
Net Carbon Flux	12.7	18.5	6.6	14.8

Note: Forest carbon estimates are derived from the FCM model. Avoided fossil fuel emissions are an average of results assuming the displacement of coal and gas-fired generation.
Sources: Lee 1993c; ICF 1995

Economic Impacts

In Table 5-12, stumpage prices over the time frame of the analysis are provided for each of the combined scenarios. In combination 1, stumpage prices for softwood, are higher than for the recycled fiber scenario and lower than the harvest reduction scenario. Prices do not, however, return back to base case levels, demonstrating (in this case, at these levels of activity) that increased use of recycled fiber utilization has more of an effect on prices than do the public harvest reductions. Similar trends are evident for these scenarios in consumer and producer surplus, and stumpage producer (landowner) surplus (Haynes, et al. 1994).

Adding a large biomass energy program based on existing wood resources from the forest sector increases prices over the first combination, as the large draw on the forest resource for biofuel feed stocks depletes timber supplies. The magnitude of the price change varies by region, with those regions supplying the most additional biomass for energy experiencing the largest price increases. Stumpage suppliers gain somewhat in economic welfare, but other economic players (consumers and product producers) show almost no change in welfare compared to the base case (Haynes, et al. 1994).

Finally, the third combination scenario adds an aggressive tree planting program. Economic impacts vary, with the most severe effects experienced in South for the latter decades of the analysis, when the large increase in timber inventories from federally subsidized tree planting undermines the stumpage market and drives prices down. This analysis suggests that a bioenergy program that draws extensively on Southern timber markets could raise demand enough to partially offset the negative impacts of a large tree planting program. The addition of a tree planting program mitigates the price increases stimulated by the bioenergy program in the second combination, and prices in some regions and years falls below those in the base case. Here again, the presence of other activities in the combination reduces the adverse economic impacts of a tree planting program implemented by itself.

Table 5-12
Stumpage Prices in the Combination Scenarios
(dollars per thousand board feet)

	2000	2010	2020	2030	2040
Combination 1					
Softwood Stumpage Prices					
North	52	56	73	80	94
South	161	67	111	168	253
Rocky Mountains	155	224	238	264	232
Pacific Coast	280	314	317	305	287
Hardwood Sawtimber Stumpage Prices					
United States	461	551	651	764	879
Combination 2					
Softwood Stumpage Prices					
North	53	71	100	125	157
South	161	102	134	202	261
Rocky Mountains	150	241	261	329	333
Pacific Coast	282	326	339	341	337
Hardwood Sawtimber Stumpage Prices					
United States	462	557	671	813	935
Combination 3					
Softwood Stumpage Prices					
North	53	71	100	125	157
South	161	78	30	*	*
Rocky Mountains	161	220	245	273	232
Pacific Coast	286	327	324	299	280
Hardwood Sawtimber Stumpage Prices					
United States	462	557	668	810	931

Note: "*" indicates prices outside the range of model results.
Source: Haynes, et al. 1994

6. Modified Agricultural Practices

Agricultural soils store an estimated 1.5 trillion metric tons of carbon, which is about twice the amount held in the atmosphere (Post, et al. 1990). Modifying current agricultural practices to increase or maintain this carbon sink may have a significant effect on the flux of carbon between agricultural soils and the atmosphere. Possible alternative management strategies include modifying tillage practices, using winter cover crops, changing crop rotations, and altering the extent or composition of fertilizer use. Specifically, this section analyzes two types of scenarios: *(1)* increased use of conservation tillage practices; and *(2)* increased planting of winter cover crops. Conservation tillage can reduce the loss of soil organic carbon by decreasing the soil disturbance of conventional tillage; using winter cover crops can increase the stored carbon in agricultural soils by expanding biomass production on existing farm lands.

These practices can also affect the release of soil N_2O. Although the magnitude of N_2O emissions is much smaller than that of CO_2, because the global warming potential of N_2O is 270 times that of CO_2 the potential impacts on global warming may be significant. While preliminary results indicate that these policies may also reduce N_2O emissions (Cialella and Li 1993), because of the complex interactions between carbon and nitrogen emissions from agricultural soils no quantitative results are presented.

The analysis of agricultural management practices was conducted by integrating the RAMS economic model with the CENTURY soil carbon model, with the use of GIS analysis to combine results and incorporate meteorologic and soils databases. As described in Section 3, the RAMS model is a short-term, profit maximizing model, which is used in this analysis to determine detailed production activities (e.g., crop rotations, tillage, and irrigation) under the constraints of the scenarios chosen for this report. The production activities determined in the RAMS analysis for each area of the study region are used by the CENTURY model to estimate the associated soil carbon impacts with a high level of regional detail. The DNDC (Denitrification and Decomposition) model was used to validate the results of the CENTURY model, and to assess potential impacts on N_2O emissions.

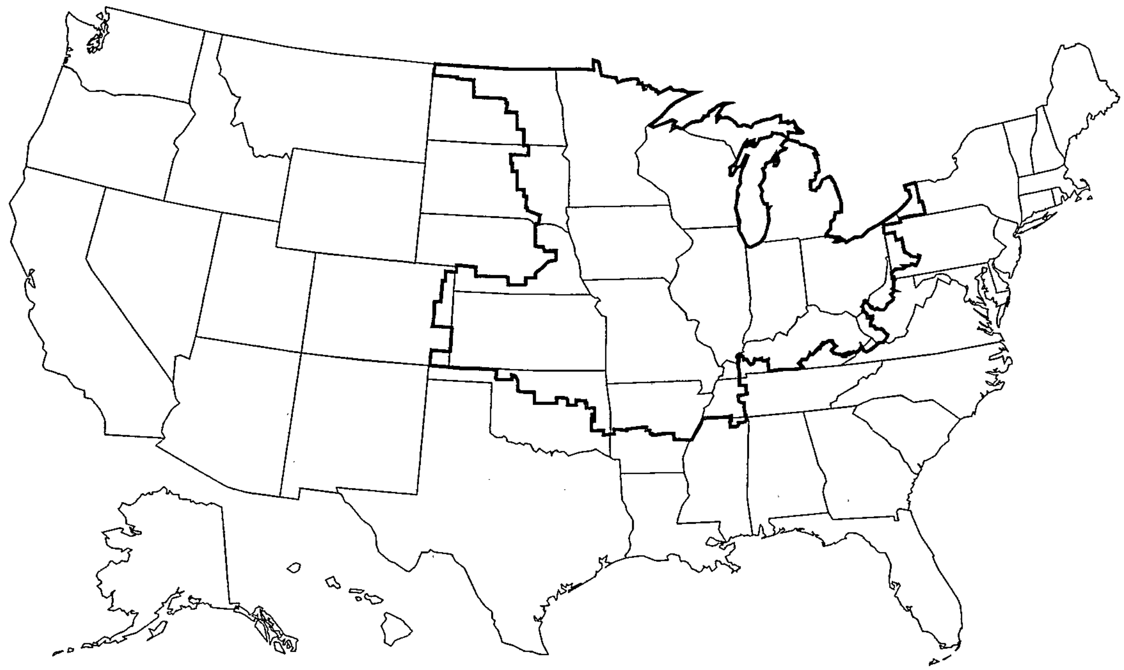
The RAMS model focuses on the Midwestern and Central U.S. (see Figure 6-1), which comprises about 216 million acres, or 60 to 70 percent of the agricultural cropland in the contiguous U.S. (Donigian, et al. 1994). Because factors that influence soil carbon and economic impacts, such as soil type, season length, and management practices (e.g., crop rotations), vary significantly from region to region, the results presented below cannot be directly generalized to all regions in the U.S. Nevertheless, given the magnitude of the RAMS study region, they indicate that modifying agricultural management practices can significantly increase the accumulation of soil carbon.

6.1 Modified Tillage Practices

Modifying tillage practices can have significant impacts on the sequestration of carbon in agricultural soils, soil erosion, and economic welfare. In this analysis, four types of tillage practices are modelled: conventional spring and fall tillage, reduced tillage, and no-tillage. These four practices differ in important physical aspects, such as the frequency and depth of plowing, as well as other tillage operations, resulting in different transfers of carbon and nitrogen between various above and below ground pools. Depending on a range of regional factors captured in the models, such as crop rotation, soil type, climate, and management practices, the reduced disturbance of the soil using conservation tillage practices (i.e., reduced tillage and no-tillage) may increase the retention of soil organic carbon relative to conventional tillage.

The impacts of these tillage practices are assessed using four scenarios that represent progressively greater acreages of farmland managed with conservation tillage practices. Figure 6-2 shows the degree to which each tillage practice is used in each scenario. These scenarios were developed by targeting the application of conservation tillage practices on agricultural lands with the highest erodibility indexes (EI). By including land with progressively lower EI ratings (i.e., implementing conservation tillage on progressively less erodible land), more land is managed with these practices. The low, medium, and high conservation scenarios shown in Figure 6-2 have minimum EI limits of 8, 5, and 2, resulting in the inclusion of 18, 27, and 53 percent of U.S. agricultural land, respectively. The targeting of highly erodible lands in these policy scenarios has the additional benefit of reducing soil erosion on agricultural lands.

Figure 6-1. RAMS Study Region



Source: Donigian, et al. 1994

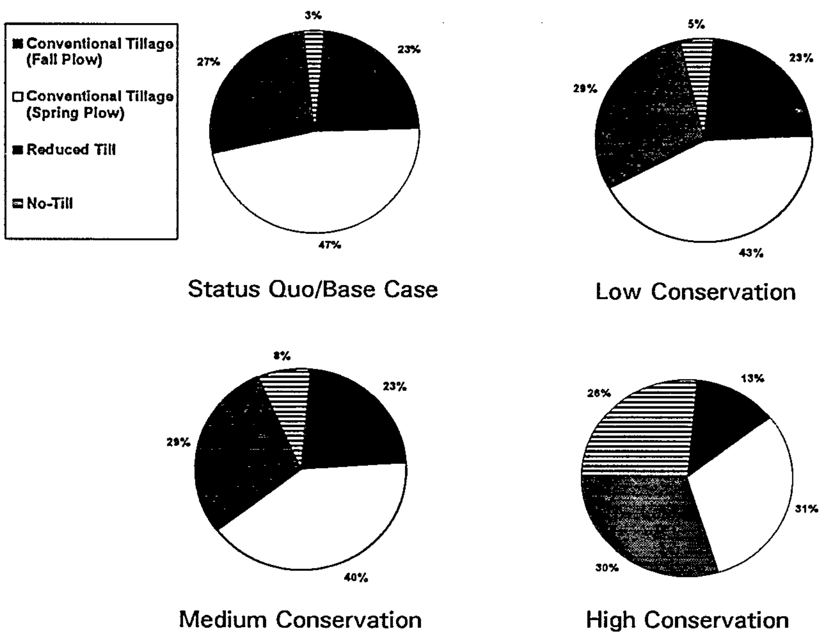
The base case (status quo) scenario, as defined by the RAMS model, is based on data for the 1990 growing season. The use of conservation tillage may, however, already exceed levels comparable to the medium conservation scenario. If the actual "no-policy" base case has a higher use of conservation tillage than the base case used in the current analysis, then aggressive policies (i.e., high conservation) will in fact be easier and less costly to implement, although carbon sequestration benefits will also be reduced. Nevertheless, the results presented in the next section indicate the potential importance of promoting conservation tillage.

Carbon Impacts: Soil Organic Carbon[17]

In general, the models show a net accumulation of carbon in agricultural soils within the RAMS study region, resulting in an increase in soil organic carbon of 26 to 52 percent by 2030, depending on tillage practices, crop yield increases, and other assumptions. The low conservation scenario results in roughly a 1 percent increase in soil carbon levels relative to the base case by 2030, while the medium and high scenarios result in 2 and 6 percent increases, respectively. These increases correspond to average annual carbon accumulations above base case levels of 0.25, 0.5, and 2.5 million metric tons for the low, medium, and high conservation scenarios, respectively (see Table 6-1).

[17] Soil organic carbon refers to carbon in the first 20 centimeters of the soil profile, including roots and surface residues.

Figure 6-2. Tillage Distributions for Alternative Scenarios



Source: Donigian, et al. 1994

Table 6-1
Soil Organic Carbon Accumulation for the Conservation Tillage Scenarios in the RAMS Study Region (million metric tons)

Scenarios	Carbon Accumulation 1990-2030	Percent Increase from 1990 Value	Percent Increase above Base Case	Average Annual Carbon Accumulation Above Base Case
Base Case	1,800	49%	--	--
Low Conservation	1,810	49%	1%	0.25
Medium Conservation	1,820	50%	2%	0.50
High Conservation	1,900	52%	6%	2.50

Note: These results assume an annual crop yield increase of 1.5%.
Source: Donigian, et al. 1994

The potential of conservation tillage practices to increase carbon sequestration is greatly affected by factors such as crop yield, crop rotation, and regional variations in soil type, geography, and season length. As a result of these variations, the aggregate results presented here cannot be generalized to specific land areas. The impacts of any policies to encourage conservation tillage will depend greatly on which agricultural lands, and associated production activities, are targeted. Box 6-1 provides an illustration of the regional variation of crop rotations and tillage practices, and their importance for soil carbon results. The remainder of this section discusses how the analysis addressed each of these factors, and their impact on soil carbon results.

Box 6-1
The Effects of Crop Rotation, Tillage Practice, and Climate on Soil Carbon for Two Neighboring Climate Divisions

As an example of how soil carbon varies with crop rotation, tillage practice, and Climate Division, consider the example of two neighboring Climate Divisions. CD 312 is in the eastern-most part of the study region on the border of Ohio and West Virginia. This CD attains its highest levels of soil carbon for a rotation of Corn Silage-Corn Silage-Soybean, for which, by the year 2030, soil carbon levels reach 10,095 gC/m^2 for Reduced Till and 10,400 gC/m^2 for No-Till. When this rotation is replaced by Corn-Corn-Soybean, however, soil carbon is only 6,925 gC/m^2 under Reduced Till and 7,221 gC/m^2 under No-Till.

Considering the exact same two crop rotations and tillage practices in the neighboring Climate Division 313 (same Production Area, different climates, on the West Virginia-Kentucky border) produces a significantly different story. For the Corn Silage-Corn Silage-Soybean rotation, by the year 2030, soil carbon levels reach 8,413 gC/m^2 for Reduced Till and 8,526 gC/m^2 for No-Till. When this rotation is replaced by Corn-Corn-Soybean, however, soil carbon is only 5,415 gC/m^2 under Reduced Till and 5,758 gC/m^2 under No-Till.

It should be noted, however, that even the initial soil carbon levels were somewhat different for the two CDs. In 1980, soil carbon was estimated at 3,543 gC/m^2 in CD 312, while in CD 313, SOC was only 3,105 gC/m^2. Thus, although soil carbon increases in CD 312 were indeed higher in percentage terms than in CD 312, they were not quite as high as the absolute projections would otherwise indicate.

Source: Donigian, et al. 1994

Crop Yield. Crop yield can have several important effects on the soil carbon impacts of conservation tillage policies. First, potential short term crop yield decreases following the introduction of conservation tillage may deter individual producers from changing tillage practices, and also may influence the choice of crop rotations. Second, assumptions about long term annual crop yield increases have a large impact on total carbon accumulation.

Although implementing conservation tillage practices may not have a significant long term impact on crop yield, lower yield may be expected during the initial adoption period as producers learn to use the new tillage systems (Cruse 1992). The magnitude of such losses will affect the degree to which conservation tillage practices are adopted. With small or negligible economic losses, gains realized from reduced soil erosion may be sufficient to make conservation policies widely appealing, while large initial losses may hinder implementation.

Two alternative assumptions are evaluated in order to assess the impact of short term crop yield decreases. The first assumption keeps crop yields roughly the same for both conventional and conservation tillage practices; the second assumes 5 and 10 percent yield reductions for reduced till and no-till practices, respectively. As shown in Table 6-2, these assumptions affect the acreage of farmland on which conservation tillage practices are employed, and thus reduce carbon accumulation within the study region. Crop yield decreases also affect the type of crop rotations used, which, as described below, have a large impact on carbon accumulation. Table 6-3 illustrates the variation in major crop rotations under different conservation targets and short term yield assumptions.

Table 6-2
Impact of Short Term Yield Assumptions on the Introduction of Conservation Tillage
(percent change in acreage of each tillage practice)

	Conservation Tillage Targets			
	Low Conservation		High Conservation	
Tillage Practice	Reduced Yield	No Yield Change	Reduced Yield	No Yield Change
Conventional Tillage/ Fall Plow	-7%	-2%	-46%	-44%
Conventional Tillage/Spring Plow	-4%	-7%	-32%	-33%
Reduced Tillage	9%	7%	56%	8%
No-Tillage	48%	69%	401%	905%

Source: Bouzaher, et al. 1993

Table 6-3
Impact of Short Term Yield Assumptions on Major Crop Rotations
(percent change in acreage of each crop rotation)

		Conservation Tillage Targets			
Crop Rotation	Base Case	Low Conservation		High Conservation	
		Reduced Yield	No Yield Change	Reduced Yield	No Yield Change
Continuous CRN	8.36	8.37	8.42	7.96	8.71
CRN CRN SOY	7.11	7.22	6.03	7.13	6.39
CRN SOY WWT	23.87	23.92	25.03	24.23	24.82
Continuous HLH	8.43	8.43	8.34	7.63	8.45
Continuous NLH	8.34	8.39	7.94	6.96	6.65

Key: CRN = Corn for grain
HLH = Legume hay
NLH = Non-Legume hay
SOY = Soybeans
WWT = Winter wheat
Source: Bouzaher, et al. 1993

The second analysis examines the significance of annual increases in crop yield during the simulation period. Higher crop yields will increase soil carbon accumulation because, for a given set of production activities and conditions, more biomass is produced and subsequently returned to the soil. A 1.5 percent annual increase in crop yield, based on historic data and projected future yields, was used for the results presented in this section. For comparison, analyses were also conducted assuming percentage increases of 1.0 and 0.5. Although total carbon accumulated on agricultural land rises with the assumed yield level, the absolute amount of carbon accumulated in the scenario over the base case is relatively insensitive to the yield level (Donigian, et al. 1994).

Crop Rotation. Carbon sequestration depends on the specific crop rotation that is in production, in large part because crop rotations return different quantities of biomass to the soil. For example, crop rotations involving spring wheat sequestered 30 to 60 percent less carbon than continuous corn planting, and crop rotations involving hay sequestered 60 percent less carbon than spring wheat (Donigian, et al. 1994; Cialella and Li 1993). Thus, the targeting of specific production regimes, and effects that alter crop rotations (i.e., short term yield decreases), can influence the soil carbon impacts of conservation tillage policies.

Regional Variation. Variation in regional characteristics, such as soil type, geography, and season length, also affects carbon accumulation in agricultural soils. To analyze this effect, the study region was divided into 80 climate divisions (CDs). Table 6-4 provides an illustration of the regional differences in soil organic carbon impacts by showing results for five different CDs with the same crop rotation (corn - soybeans). Even for the two neighboring CDs (CD272 and CD321), percent increases in soil carbon levels differ by 10 to 20 percent.

Table 6-4
Regional Variation in Soil Carbon Accumulation
(percent increase in soil carbon, 1990-2030)

Tillage Practice	CD272 (NW Ohio)	CD321 (W Ohio)	CD392 (S Minnesota)	CD413 (Iowa)	CD603 (W Missouri)
Conventional Till/ Spring Plow	45%	53%	37%	20%	64%
Reduced Till	50%	58%	40%	23%	69%
No-Till	61%	68%	52%	36%	78%

Note: Most CDs cross one or more state boundaries. The primary state is listed for each CD.
Source: Donigian, et al. 1994

AGRICULTURAL IMPACTS: SOIL EROSION AND NET RETURN PER ACRE

Soil erosion rates decrease under the more aggressive conservation tillage scenarios. For the low conservation case, soil erosion rates are reduced by approximately 3 percent from base case levels. In the high conservation case, erosion drops by 23 to 34 percent from erosion rates in the base case, depending on the short term crop yield decreases and other assumptions (Bouzaher, et al. 1993).

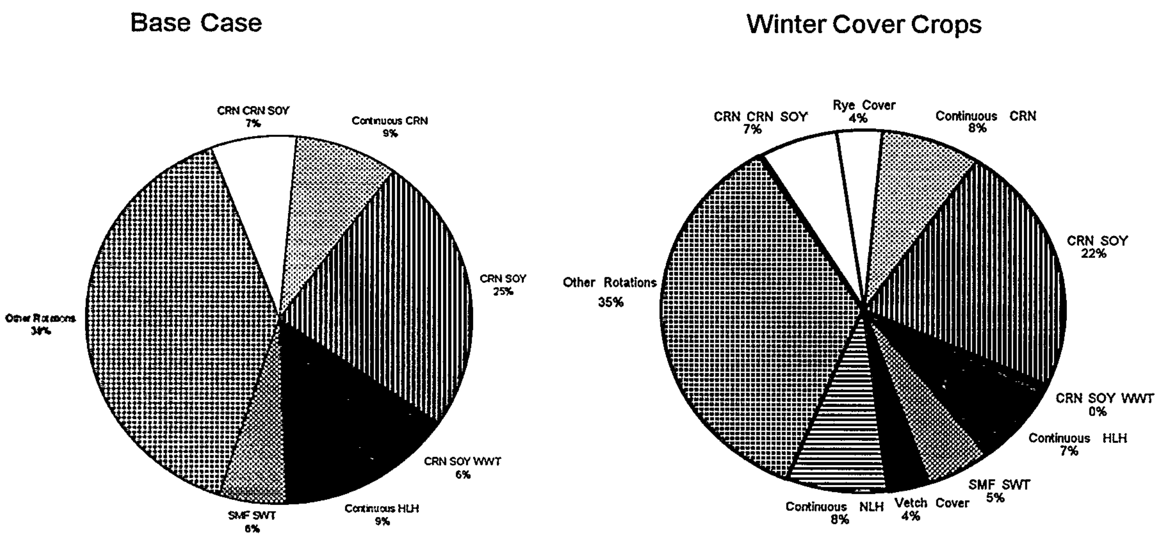
Economic impacts in the agricultural sector depend primarily on assumptions about crop yield changes. Without yield decreases, net returns increase relative to the base case by $0.67 per acre (0.8 percent) under the low conservation scenario, and by $4.73 per acre (5.4 percent) under the high conservation scenario. If lower yields are assumed with conservation tillage practices, then net returns decrease by $3.07 per acre (3.4 percent) under the low conservation scenario, and by $2.93 per acre (3.3 percent) under the high conservation scenario. These results reflect the change in both crop revenues (which decline if yields fall) and production costs (which are lower with conservation tillage). If yields are assumed to remain constant, then revenues also remain constant and the reduced machinery costs associated with using conservation tillage practices result in increased net returns. If yields are assumed to decrease, then the lower revenues associated with decreased yields are not fully offset by reduced machinery costs. In either case (i.e., with or without yield adjustments), net returns per acre are greater under the high conservation scenario than under the low conservation scenario (Bouzaher et al. 1993).

6.2 Winter Cover Crops

Winter cover crops can increase soil carbon, but are only appropriate for use on a fraction of U.S. agricultural land due to restrictive crop rotations, growing season lengths, and climates. Based on these factors, approximately 5 to 10 percent of the land in the RAMs model was targeted as being suitable to establish winter cover crops. The desired sequence of crop rotation for winter cover crops was small grains or silage followed by crops not seeded in the fall. Crops seeded in the fall (e.g., winter wheat and leguminous and non-leguminous hay) already provide for winter cover, while the growing period for winter cover crops was greater following crops with early harvest dates.

Figure 6-3 provides a breakdown of how crop rotations would change if winter cover crops were introduced on suitable land. In addition to timing issues (crop rotation, and harvest and planting dates), the availability of water is a limiting factor. For example, some planting areas in the West do not have enough water to support a winter cover crop, whereas the longer growing seasons in the South allow substantial growth.

Figure 6-3. Major Rotations: Base Case and Targeted Levels of Winter Cover Crops (percentage of total acres)



Source: Bouzaher, et al. 1993

Of the cover crops planted, 55 percent by acreage were rye and 45 percent were hairy vetch, which is often used to fix nitrogen. In the scenarios evaluated, rye cover was used with corn-soy-winter wheat, corn silage-soy-legume hay, and sorghum-winter wheat rotations. Hairy vetch cover was planted with the corn-soybean-winter wheat rotation.

Results: Carbon, Economic, and Agricultural Impacts

Where appropriate, policies to promote cover crops have the potential to increase soil carbon levels significantly. Although only a small fraction of the agricultural land would be included in such a scenario, there is a net soil carbon accumulation above the base case of roughly 140 million metric tons of carbon into soil by 2030, or an average annual carbon accumulation of 3.5 million metric tons (see Table 6-5).

Table 6-5
Soil Organic Carbon Accumulation for the Winter Cover Crop Scenario
(million metric tons)

Scenarios	Carbon Accumulation	Percent Increase from 1990 Value	Percent Increase above Base Case	Average Annual Carbon Accumulation above Base Case
Status Quo	1,800	49%	--	--
Winter Cover Crops	1,940	53%	8%	3.5

Note: These results assume an annual crop yield increase of 1.5%.
Source: Donigian, et al. 1994

Because carbon sequestration is sensitive to the rate at which crop yield is assumed to increase over time, alternative assumptions of annual increases in crop yield of 0.5, 1.0, and 1.5 percent were examined. As with the conservation tillage analysis, lower crop yield increases result in similar soil carbon accumulation relative to the base case, despite lower absolute soil carbon levels by the end of the study period (Donigian, et al. 1994).

Average net returns are reduced by 1.2 percent, or $1.05 per acre.[18] Soil erosion is also reduced by using winter cover crops in the model, with average soil erosion rates decreasing from 4.51 tons per acre to 4.39 tons per acre, a decline of almost 3 percent (Bouzaher, et al. 1993).

7. Conclusions: Directions for Future Research

The results of the preceding sections suggest that a variety of strategies, in both the forest and the agriculture sectors, could reduce emissions of greenhouse gases or increase the carbon stored in biomass and soil. Such policies could also have significant impacts (in some regions or nationally) on product prices, forest and agricultural production, consumer and producer welfare, and trade. Thus, research at the U.S. EPA and its collaborators in the U.S. Forest Service, at universities, and at private research organizations, continues to address outstanding questions.

For the tree planting and other forest policy scenarios, which (with the exception of biofuels) sequester carbon primarily by enlarging the acreage devoted to trees over time, both economic and carbon impacts depend critically on how private forest land owners respond to changing inventories and prices over time. Economic impacts also depend on interactions between the forest and agriculture sectors, which influence both the cost of land available for tree planting (and, hence, the cost of government-subsidized planting) and also affect consumer and producer welfare in agricultural and forest markets. Research continues to address these questions, and to investigate issues related to other aspects of the forest-climate change link, such as the impacts of alternative management strategies on public and private lands, improving the data on all portions of the forest sector carbon budget, and continuing to evaluate the effects of climate change on forests.

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[18] This decrease includes the fact that cost is partially offset by using hairy vetch as a winter crop, since it fixes nitrogen, thus resulting in nitrogen savings.

The analyses of policy scenarios that change agricultural practices have focused on a few of the agricultural areas located in the central United States. Estimating the implications for national GHG emissions of changing agricultural practices requires understanding how these results can be generalized to all regions, which may require additional data on selected crops (such as soybeans), regions, and tillage practices. Other areas requiring further investigation include: improved estimates of impacts of policies on crop yields; impacts of climate change on carbon sequestration; physical impacts on the carbon and nitrogen balances of animal waste applications; a more thorough investigation of the impact of No-Till practices on soil carbon levels; and better tracking of erosional soil organic carbon losses.

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