Title
Baseline greenhouse gas emissions and removals for forest and rangelands in Arizona

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Publication Date
2009

BASELINE GREENHOUSE GAS EMISSIONS AND REMOVALS FOR FOREST AND AGRICULTURAL LANDS IN ARIZONA

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Winrock International

DOE Contract No.: DE-FC26-05NT42593

Contract Period: October 1, 2005 - May 11, 2011

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Abstract

The project described in *Baseline Greenhouse Gas Emissions and Removals for Forest and Agricultural Lands in Arizona* sought to quantify the baseline of changes in carbon stocks on forest and agricultural lands in Arizona for the 1990s. These baselines provide an estimate of the emissions and removals of greenhouse gases attributable to changes in the use and management of land and are useful for identifying where major opportunities could exist in Arizona for enhancing carbon stocks and/or reducing carbon sources to potentially reduce greenhouse gas emissions.

The analysis revealed that forests were responsible for a net removal of carbon dioxide from the atmosphere of 0.9 million metric tons of carbon dioxide per year ($MMTCO_2$/yr) between 1987 and 1997, and that agricultural lands were responsible for a net emission of 0.04 $MMTCO_2$/yr. On non-federal lands emissions from forests caused by development were estimated at 0.0145–0.0152 $MMTCO_2$/yr, and between 1990 and 1996 154,000 acres of forest and rangeland were burned by fires with an estimated emission of 0.47 $MMTCO_2$eq/yr. Nitrous oxide (N_2O) and methane (CH_4) emissions (in CO_2 eq) from agricultural lands are more than 100 times higher than carbon emission due to land-use change.

Keywords: Carbon sequestration, carbon storage, carbon dioxide, greenhouse gas, emissions, forest fire, agriculture, Arizona, WESTCARB, Regional Carbon Sequestration Partnership

Executive Summary

Introduction

This study is one of a series of carbon sequestration research projects conducted by the West Coast Regional Carbon Sequestration Partnership (WESTCARB), which is managed and co-funded by the California Energy Commission.

Purpose

This WESTCARB project derived a baseline of carbon emissions and removals for Arizona's forest and agricultural lands.

Project Objective

This project sought to establish the baseline carbon stocks and changes in stocks for the forest and agricultural sectors in Arizona during the most recent 10-year period for which data are available (generally the 1990s). Such baselines can assist in identifying opportunities where carbon removals (sequestration) in each sector might be increased, or carbon emissions decreased, through changes in land use and management.

Project Outcomes

Baseline for Forest Lands

The forest baseline is separated into three component parts: a general forests baseline, a baseline effect of development, and a baseline effect from fire. The general forests baseline is presented at the state level for all forestlands, based on U.S. Department of Agriculture's Forest Service data, detailing change in forest area and change in carbon stocks, but with no attribution to the causes for the change. Using additional databases, the specific cases of emissions associated with development and emissions associated with fire are further examined.

General Forestlands Baseline

Between 1987 and 1997 there was an estimated increase in Arizona's forest area of 0.5 million acres (ac), or 0.2 million hectares (ha), a mean of 54,000 ac (22,000 ha) per year. This is equivalent to an increase of 9 million metric tons carbon dioxide (CO_2) equivalent ($MMTCO_2e$), or 0.92 $MMTCO_2e$/yr between 1987 and 1997.

The estimated increase in carbon stocks of 0.92 $MMTCO_2e$/yr is substantially lower than the estimated sequestration in soil and forests reported by the Arizona Climate Change Advisory Group of 6.7 $MMTCO_2e$ in 2000. However, some of this divergence can be accounted for by the inclusion of soil carbon sequestration in the Climate Change Advisory Group analysis. In addition, there is some uncertainty on whether the carbon is artificially inflated due to a U.S. Department of Agriculture Forest Service change in forest definition from 10 percent cover to 5 percent cover in the study period.

Baseline Effect of Development on Forest Lands

The baseline for emissions from development was created using land use data from the National Resources Inventory of the United States Department of Agriculture and carbon data derived from the U.S. Department of Agriculture's Forest Service Forest Inventory and Analysis Database for the period 1987 to 1997. Because of data limitations, the analysis is limited to non-federal lands and to the gross CO_2 emissions from aboveground live-tree biomass on conversion of non-federal forestland to developed land uses. Because the focus is on non-federal lands, the analyses should be used only to explore decisions on private lands.

Between 1987 and 1997 3,499 ac (1,416 ha) of non-federal forest in Arizona were converted to development, which is equal to just 350 ac (140 ha) per year. All of this area was located in the north part of the state. For gross carbon emissions, two scenarios were considered. Under Scenario 1 all tree biomass in the converted area was immediately emitted as carbon dioxide. Under Scenario 2, for developed areas of less than 10 ac (4 ha), it was assumed that 50 percent of the carbon was retained in the form of residual trees.

Under Scenario 1 an estimated 152,000 tons of CO_2 equivalent (t CO_2e) were emitted due to development, or 15,200 t CO_2e/yr. Under Scenario 2, 145,000 t CO_2e were emitted, or 14,500 t CO_2e/yr.

These emissions compare with the estimated gross sequestration from forests in Arizona of 0.92 $MMTCO_2$e/yr between 1987 and 1997 and gross emissions for the state of 99 $MMTCO_2$e/yr (from Arizona Climate Change Advisory Group). Emissions from deforestation therefore represent a fraction of a percentage of the total emissions in the state.

Baseline Effect of Fire on Forest Lands

The emissions from fire were examined through overlaying the wildfire database for Arizona on the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer satellite imagery showing change in normalized differential vegetation index . (The normalized differential vegetation index measures "greenness" of landscapes; greenness decreases immediately after fire). This process determined the location, size, and intensity of fires between 1990 and 1996. Carbon values were applied to these fires using data from the U.S. Forest Service Forest's Forest Inventory and Analysis Database and proportional emissions from the detailed baseline fire analysis for California. The analysis considered all forests and rangelands in Arizona, federal and non-federal.

Across the seven years analyzed, fires with a total area of 1.08 million ac (437,700 ha) were recorded. This is equivalent to 154,000 ac/yr or 62,500 hectares per year (ha/yr). Emissions totaling 904,000 tons of carbon or 3.3 $MMTCO_2$e were estimated to have occurred from fire during the analysis period. This is equivalent to an emission of 0.47 $MMTCO_2$e/yr.

Eighty-five percent of the burned area was on rangelands, but 42 percent of the emissions were from the 15 percent of burned area that was forest. Fire incidence varied by year, with high emissions in 1993 to 1996 (> 168,000 t C) and low emissions between 1991 and 1992 (< 23,000 t C). Fires occurred throughout Arizona during the study period, and there was no apparent geographical relationship between either area burned or carbon emissions from fire and geographic location.

These emissions compare with the estimated gross sequestration from forests in Arizona of 0.92 MMTCO_2e/yr between 1987 and 1997 (see above) and gross emissions for the state of 99 MMTCO_2e/yr (from Arizona Climate Change Advisory Group). During the analysis period, emissions from fire therefore represented only about 0.5 percent of the state's total emissions.

Baseline for Agricultural Lands

Agricultural land area in Arizona amounts to about 1.5 percent of the total land area. The state lost agricultural land area during 1987–1997 through conversion to other land uses, in particular to urban development/transportation and from retiring agricultural land from cultivation. In some counties, the area of woody cropland actually increased, but these increases were more than offset by decreases in non-woody cropland. Accompanying these losses in area were losses in standing carbon stocks on agricultural land, so that conversion of agricultural land to other uses was responsible for a net annual source (emission) of CO_2 to the atmosphere. Losses of agricultural carbon stocks over the 1987–1997 period were estimated at 99,000 tons. The estimated net annual source from Arizona agricultural lands was 0.04 MMTCO_2eq.

Although the primary focus of this report is on emissions of CO_2 from agricultural land conversion, those emissions represent only a portion of the total greenhouse gas emissions attributable to the agricultural sector. The primary non-CO_2 greenhouse gases associated with agricultural activities are nitrous oxide (N_2O) and methane (CH_4). Nitrous oxide (emitted from agricultural soils, especially after fertilizer application) has approximately 296 times the global warming potential of CO_2, and methane (emitted by livestock and through manure management) has approximately 23 times the global warming potential of CO_2. Examination of data from Arizona indicated that GHG emissions from N_2O and CH_4 in the agricultural sector dwarf the annual CO_2 source from agricultural land conversion. In fact, CO_2 emissions from land conversion represented less than 1 percent of the total CO_2 and non-CO_2 greenhouse gas emissions attributable to the agricultural sector.

Conclusions

The authors drew the following general conclusions from this research:

General Forests Baseline

- An estimated 219,000 ha (541,000 ac) of forest on federal and non-federal lands were gained in Arizona between 1987 and 1997 at a rate of 21,935 ha/yr (54,201 ac/yr). These gains are equivalent to 0.28 percent of the forest area per year between 1987 and 1997.
- A gross sequestration of an estimated 9.2 million metric tons CO_2 equivalent (MMTCO_2e) occurred between 1987 and 1997 (0.92 MMTCO_2e/yr) and 42.7 MMTCO_2e (7.1 MMTCO_2e/yr) between 1997 and 2003.

- The sequestration rate estimated in a previous study for the State of Arizona in 2000 exceeds the rate predicted in this study, probably due to methodological and terminological differences.
- Carbon sinks could potentially offset as much as 7 percent of Arizona's emissions.
- For just non-federal forested lands, there was a net loss of 69,000 ha (170,000 ac). Ninety percent of the loss in forested area occurs in the northern counties of the state.

Development Baseline

- An estimated 1,416 ha (3,499 ac) were lost to development in Arizona between 1987 and 1997 at a rate of 142 ha (351 ac) per year. This forest loss is equivalent to a gross emission of between 0.145 and 0.152 million metric tons of CO_2 equivalent, or 0.0145 to 0.0152 $MMTCO_2e$ per year. The emissions were exclusively in the north part of the state.
- Emissions from deforestation represent a fraction of a percent of the state's total emissions.

Fire Baseline

- Across the seven years analyzed, researchers recorded fires with a total area of 437,700 ha (1.08 million ac)—equivalent to 62,500 ha/yr or 154,000 ac/yr. Emissions totaling 904,000 tons of carbon or 3.3 $MMTCO_2e$ were estimated to have occurred from fire during that period—equivalent to an emission of 0.47 $MMTCO_2e$/yr.
- Eighty-five percent of the burnt area was on rangelands, but 42 percent of the emissions were from the 15 percent of burned area that was forest. Fire incidence varied by year with high emissions in 1993 to 1996 (> 168,000 t C) and low emissions between 1991 and 1992 (< 23,000 t C).

Agricultural Baseline

- In 1997, agricultural land represented 1.5 percent of the total land area, and non-woody crops were 93 percent of all agricultural land. Both woody and non-woody cropland are concentrated in the southern counties.
- Statewide, there was a loss of agricultural land of 6.6 percent between 1987 and 1997.
- Total carbon stocks in all agricultural land types in Arizona were estimated at 1 million tons. Between 1987 and 1997, there was a total loss of about 99,000 tons of carbon, or 9.4 percent of the carbon stored in agricultural lands in 1987.
- In CO_2 equivalent terms, total agricultural carbon stocks in Arizona in 1997 were 3.5 $MMTCO_2eq$, and the net loss 1987–1997 disregarding non-CO_2 greenhouse gas emissions was 0.4 $MMTCO_2eq$—equivalent to an annual source of 0.04 $MMTCO_2eq$.
- Non-CO_2 greenhouse gas emissions from N_2O (emitted from agricultural soils after fertilizer application) and CH_4 (from livestock and manure management) dwarf the annual CO_2 source from agricultural land conversion in Arizona.

1.0 Introduction and Background Information

1.1. General Approach

This baseline document's purpose is to examine changes in land use and the associated emissions or sequestration of carbon for forest and agricultural lands in the State of Arizona.

Separate baseline analyses are included here for forestlands and agricultural lands. The agricultural land study follows the same principles as the California baseline study (Brown et al. 2004). For forestlands, the California baseline study was based on California-specific interpreted satellite imagery that detailed the scale of change, vegetation type, and cause of change. Because no comparable data is available for Arizona, the research team instead relied predominantly on two national datasets (see Section 1.2). The consequence of using generalized broad-scale datasets is that the outcome is less certain than that achieved for California.

The forest baseline includes a state-level analysis on the change in area and carbon stocks in all forestland, plus a county-level analysis of changes on non-federal forestland. Also included are specific case studies on emissions due to development and fire.

1.2. Datasets Used in the Analysis

Two datasets are used repeatedly through the baseline analyses: the National Resources Inventory (NRI) database and the U.S. Forest Service Forest Inventory and Analysis (FIA) database.

1.2.1. The National Resources Inventory

The National Resources Inventory is conducted by the U.S. Department of Agriculture - National Resources Conservation Service (NRCS). The NRI is a scientifically designed survey of the nation's soil, water, and other related resources with the purpose of assessing conditions and trends. The NRI contains data only on non-federal lands and water bodies. As noted in the Users' Manual (NRCS 2000), the NRI data are useful in developing estimates of natural resource conditions and in conducting geospatial and temporal analyses of these conditions (however, the location of the survey plots is not given in the database). In these baseline analyses, NRI data were used for estimates of area because NRI data is available across the WESTCARB states, wide in coverage, and available for multiple points in time and multiple classes of land use.

Because NRI data come from sample surveys, it is important to have a sufficient sample size for a reliable estimate. The NRI Users' Manual does not recommend that the data be used for county-level analysis because of sample size issues. To be conservative, here analyses are reported at the state level. County-level results are given for illustrative purposes only.

National Resources Inventory analyses are for the time period 1987 to 1997. More recently the NRI has switched to annual reporting, but these data are not yet publicly available.

1.2.2. The Forest Inventory and Analysis Database

Forest biomass was estimated using the U.S. Forest Service Forest Inventory and Analysis database. Following Acts of Congress in 1928 and 1974, the USFS has been systematically collecting data via the FIA on U.S. forests.

The FIA data is composed of a hierarchy of the following nine tables: SURVEY, COUNTY, PLOT, SUBPLOT, CONDITION, TREE, SEEDLING, SITETREE, and BOUNDARY. Examples of plot-level records include: State, County, Plot number, Owner, Forest type, Stand age, Site productivity, and Slope. Examples of tree-level records include: State, County, Plot number, Tree number, Diameter at breast height (DBH), Crown class, Volume, Growth, and Expansion Factors (which allow extension from values per plot to per acre). Diameters are included in the database for all trees with DBH > 1 inch. Creating links between the different hierarchies of the database and utilizing the expansion factors allows the user to explore a variety of topics related to biomass stocks in trees.

In this baseline study, data were downloaded from the FIA website on the scale of individual trees within plots within each county within each state. Using the biomass regressions of Jenkins et al. (2003), DBH was converted to biomass for each tree. Area expansion factors (plot to acre), metric conversions, and summation were used to calculate biomass in metric tons per hectare. In the fire baseline, forests are consolidated by forest type which is a plot-level characteristic.

1.3. Geographical Subdivision of the State

In this forest baseline study, the state was subdivided into two regions. These regions were based on FIA "units" but are convenient due to climatic, topographic, and vegetation similarities within units (Table 1-1). Both the forest and agricultural baselines include county-level analyses; counties in Arizona are shown in Figure 1-1.

Table 1-1. Two Arizona regions with the component counties detailed

Region	Counties
Southern	Cochise, Graham, Greenlee, La Paz, Maricopa, Pima, Pinal, Santa Cruz, Yuma
Northern	Apache, Coconino, Gila, Mohave, Navajo, Yavapai

Figure 1-1. Arizona counties
Source: Digital Map Store, http://county-map.digital-topo-maps.com/arizona.shtml

2.0 Baselines for Forestlands in Arizona

2.1. Introduction

This chapter presents a baseline for emissions and sequestration in the forests of Arizona. *Forest* is defined here (as in the FIA and NRI) as land with a greater than 10% stocking of trees.

This chapter is presented in three sections.

Section 2.2 presents a general forest baseline, detailing changes in forest area and in carbon stocks in Arizona's forests with an estimate of annual sequestration/emissions. A state level total is presented for all forests with county level detail only for non-federal lands.

The remaining sections present case studies of individual causes of emissions from forests. These case studies should not be considered as an addition to the general baseline (Section 2.2) but as subsets of it. Emissions from fire or development will have formed part of the total emissions from forests that are presented, or alternatively will have decreased the total estimated sequestration presented from forests.

Section 2.3 presents the case study of emissions caused by development on forestland.

Section 2.4 presents the case study of emissions caused by fire on forestland.

2.2. General Forestlands Baseline

2.2.1. State Level Analysis for all Forestlands

The United States Department of Agriculture (USDA) Forest Service published a baseline for forests in Arizona between 1987 and 1997 (Birdsey and Lewis 2003). Estimates are based on forest inventory data collected by the Forest Service's FIA Unit. Determination of the location of tree measurement plots and changes in land area were assessed using high altitude photography. Where forest inventory was not available, estimates of land use change were derived from the National Resources Inventory.

Between 1987 and 1997, Birdsey and Lewis (2003) estimated a net change in forest area for Arizona from 7.8 million ha in 1987 to 8.1 million hectares in 1997. This is a total gain of 219,345 ha (an increase of 2.8%), which averages out to 21,935 ha/yr (an increase of 0.28%/yr).

Across the state Birdsey and Lewis calculated a mean forest carbon stock density of 42.7 t C/ha in 1987 and 41.9 t C/ha in 1997, or a loss of 0.8 t C/ha over the ten years.

Combining the area data with the carbon density data gives a total stock on forestland in Arizona in 1987 and 1997 and a change in stock between the two dates. The stock in 1987 was estimated as 335 million t C and this grew to 337.6 million t C in 1997. This is equal to a total gain of 2.5 million tons of carbon (a gain of 0.75%), which averages out to 251,700 tons of carbon per year (a gain of 0.075%/yr).

2.2.2. Changes in Forest Area on Private Land

The above section gives the overall picture of changes in area and carbon stocks for the whole state, without any reference to the causes of change. Of particular interest in relation to changes in forest use and management is the potential to conserve significant quantities of carbon in forests under threat for conversion to other uses; particularly development. It is argued that most forest conversion would come from private lands. It is not expected that widespread deforestation is occurring on public lands, though some afforestation may be overlooked. Here is detailed a baseline at the county level for the change in area in privately owned forests in Arizona.

The change in land use associated with forests on Arizona's private lands was analyzed from the NRI. Two dates were used that reported data at the county scale of resolution: the most recent publicly available data for 1997 and for 1987. At the state level all forested land was estimated in 1987 and 1997, as well as the broad destination or origin of land that changed from or to forest in the same time period (Table 2-2-1).

Table 2-2-1. Change in area between 1987 and 1997 for non-federal forestland in Arizona

Area (ha)	Unchanged[1]	Lost to[2]	Gained from[3]
Unchanged	1,644,498		
Development		1,416	
Pasture/Rangeland		102,915	58,803
Farmland/Agriculture			283
Strip mines		23,392	
Other		40	
1987 Total			**1,772,262**
1997 Total			**1,703,585**

[1] *Unchanged* refers to areas remaining forest between 1987 and 1997.
[2] *Lost to* refers to areas lost from forest to other land use categories between 1987 and 1997.
[3] *Gained from* refers to areas becoming forest between 1987 and 1997.

In Arizona, forest area decreased by 68,677 ha in the ten years from 1987 and 1997, or an average of 6,868 ha/yr. Of the total area of forest in 1987, 93.9% remained unchanged as forest ten years later in 1997. There was a loss of 127,764 ha principally to rangeland and to strip mining, and a gain of 59,086 ha back from rangeland. Only 1,416 ha of forest were converted to development (see Section 2.3).

County-Level Changes in Forest Area

National Resources Inventory data is not designed for use at the county level; results are given here for illustrative purposes. Two-thirds of the counties in the State of Arizona contained measured areas of forest. The six most northerly counties (Apache, Coconino, Gila, Mohave, Navajo, and Yavapai), which represent 58% of the area of the state, contained 95% of the forest area. Across the state, 40% of counties experienced a loss in forest area between 1987 and 1997 and 20% gained forest area. Large losses (> 10,000 ha) occurred in Apache, Cochise, Coconino, and Gila counties, while Navajo County gained almost 20,000 ha of forest area (Tables 2-2-2 and 2-2-3).

Table 2-2-2. Area of non-federal forestland in Arizona in 1987 and 1997 and change between the two dates

Area (ha)	County Area (ha)	1987	1997	Change
Apache	2,902,050	706,809	690,782	(16,026)
Cochise	1,597,880	12,384		(12,384)
Coconino	4,821,891	189,238	142,819	(46,419)
Gila	1,234,829	100,608	82,316	(18,292)
Graham	1,198,987	70,782	70,782	-
Greenlee	478,371			-
La Paz	1,165,483	1,052	5,990	4,937
Maricopa	2,383,602			-
Mohave	3,447,699	294,217	293,893	(324)
Navajo	2,577,862	396,363	416,113	19,749
Pima	2,379,232			-
Pinal	1,390,719			-
Santa Cruz	320,546		243	243
Yavapai	2,103,925	809	648	(162)
Yuma	1,428,143			-
TOTAL		**1,772,262**	**1,703,586**	**(68,678)**

Table 2-2-3. Area of non-federal forestland in 1987 and 1997 and change between two dates for two Arizona regions

	Area 1987	(ha) 1997	**Change Area**
Northern	1,688,044	1,626,570	**(61,474)**
Southern	84,218	77,014	**(7,204)**

2.2.3. Conclusions

An estimated 219,000 ha of forest on federal and non-federal lands were gained in Arizona between 1987 and 1997 at a rate of 21,935 ha/yr. These gains are equivalent to 0.28% of the forest area per year between 1987 and 1997.

A gross sequestration of an estimated 9.2 million metric tons CO_2 equivalent ($MMTCO_2e$) occurred between 1987 and 1997 (0.92 $MMTCO_2e$/yr) and 42.7 $MMTCO_2e$ (7.1 $MMTCO_2e$/yr) between 1997 and 2003.

This sequestration compares with the estimated sequestration of 6.7 $MMTCO_2e$ in soil and forest sinks for the State of Arizona in 2000 (Bailie and Lazarus 2005).

The sequestration rate estimated by Bailie and Lazarus (2005) clearly exceeds the rate predicted here. An explanation could be the inclusion of soil organic carbon sequestration and sequestration in the forest floor and in coarse woody debris in the study of Bailie and Lazarus (2005). Alternatively, it is possible that a change in the definition of forest by the USFS from a cover of 10% to a cover of 5% could have artificially inflated the forest area during the study, artificially elevating the estimated sequestration.

The gross emissions for Arizona (excluding sinks) for the year 2000 were estimated as 99 $MMTCO_2e$ (Bailie and Lazarus 2005). Sinks, therefore, potentially can offset as much as 7% of the state's emissions.

For just non-federal forested lands, there was a net loss of 69,000 ha. Ninety percent of the loss in forested area occurs in the northern counties of the state.

2.3. Development Baseline

2.3.1. General Approach

This section provides a baseline for the emissions of carbon attributable to development of forest lands in Arizona. This analysis should be considered a subset of the general forest baseline: the emissions due to development will form part of wider changes in carbon stocks in the state. If this development analysis is added to the analysis of the general forest baseline, then double counting will occur.

Forest land development is examined only for private lands; it is not expected that widespread development is occurring on public land. Changes in stocks are only changes in aboveground tree biomass, because of uncertainties surrounding both the absolute level of carbon in other carbon pools and whether or not development will cause emissions from these pools.

As in the general forest baseline, changes in forest area due to development were based on NRI data for changes in land use. Carbon stocks and changes in those stocks were derived from FIA data. For the purposes of this study, development includes three NRI categories:

- Urban / 10 acres or larger
- Urban / small built-up (< 10 acres). The category *Urban/small built-up* will be referred to as *small-scale development.*
- Transportation (e.g., roads, airports)

Statistical confidence can only be maintained in results given at the state level, because of the design of the NRI database. Results are given here at the county level merely for illustrative purposes.

2.3.2. Changes in Area at the State and County Level

Between 1987 and 1997, 1,416 ha of non-federal forest were lost in Arizona due to development, or 142 ha per year. The loss over ten years is equivalent to 0.08% of the total forest area present in the state in 1987. Of the total area lost to development, 9% could be considered small-scale development (Table 2-3-1).

Table 2-3-1. Non-federal forest area between 1987 and 1997 in Arizona. Area in hectares.

	Unchanged[1]	Lost to[2]	Gained from[3]
Unchanged	1,644,498		
Development		1,416	
% small scale		9%	
Pasture/Rangeland		102,915	58,803
Farmland/Agriculture			283
Strip Mines		23,392	
Other		40	
1987 Total			**1,772,262**
1997 Total			**1,703,585**

[1] *Unchanged* refers to areas remaining forest between 1987 and 1997.
[2] *Lost to* refers to areas lost from forest to other land use categories between 1987 and 1997.
[3] *Gained from* refers to areas becoming forest between 1987 and 1997.

National Resources Inventory data is not designed for use at the county level; results are given here for illustrative purposes. Losses in non-federal forest area between 1987 and 1997 only occurred in three counties in Arizona (Apache, Coconino, Yavapai), all in the state's northern portion (Figure 2-3-1 and Table 2-3-2). These counties, however, account for 33% of the state's area and 49% of the forested area.

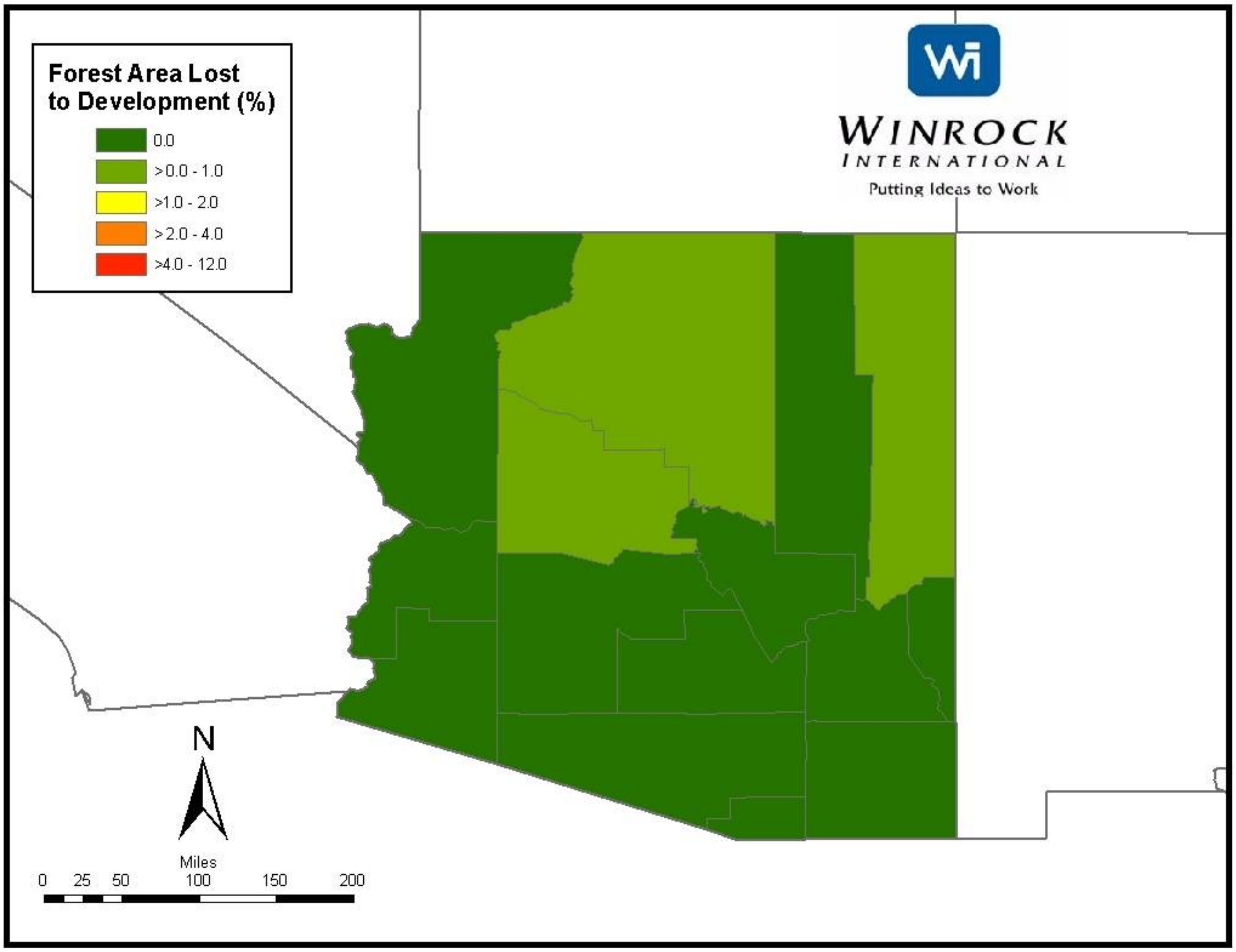

Figure 2-3-1. Loss in non-federal forest area between 1987 and 1997 as a percentage of total non-federal forest area in the county

Table 2-3-2. County-level data on area of non-federal forest in 1997, area of forest lost to development between 1987 and 1997, and % of losses that were small-scale

County	Population	County Area (ha)	Non-Fed Forest area 1997 (ha)	Area Lost to development (ha)	% small scale
Apache	69,423	2,902,050	690,782	121	
Cochise	117,755	1,597,880			
Coconino	116,320	4,821,891	142,819	1,133	11%*
Gila	51,335	1,234,829	82,316	0	
Graham	33,489	1,198,987	70,782	0	
Greenlee	8,547	478,371			
La Paz	19,715	1,165,483	5,990	0	
Maricopa	3,072,149	2,383,602			
Mohave	155,032	3,447,699	293,893	0	
Navajo	97,470	2,577,862	416,113	0	
Pima	843,746	2,379,232			
Pinal	179,727	1,390,719			
Santa Cruz	38,381	320,546	243	0	
Yavapai	167,517	2,103,925	648	162	
Yuma	160,026	1,428,143			
TOTAL			**1,703,586**	**1,416**	9%

*Note: The 11% represents small-scale development for Coconino County; the 9% in the Total represents the percentage of area lost to small-scale development across the state.

2.3.3. Carbon Stocks

Estimates of carbon stocks in live tree biomass were derived from the FIA database. For Arizona, the research team used FIA data from the 2003 inventory because no FIA data exists for dates representing a midpoint of the analysis period 1987–1997, and the previous inventory in 1985 is considered to be rather out of date for this period.

The FIA data were consolidated at the FIA Unit level. Biomass carbon estimates were derived from the measurements of tree DBH for all trees in inventory plots using the allometric equations of Jenkins et al. (2003), scaled up to a per-hectare basis using the plot-area expansion factors (Table 2-3-3).

To be conservative, aboveground tree biomass alone was considered. The rate of emission of carbon stored in roots and soil organic matter is slow and poorly understood, especially when it is considered that some of the developed areas will be capped with concrete. Wood products are also not included, as it is not clear what proportion of the cut trees would be harvested for products, nor what products would be produced (firewood and even paper can be rapidly emitted).

Table 2-3-3. Mean aboveground tree carbon stock (from 2003 FIA data) for each region of Arizona with the number of plots and the confidence interval around the stock estimate

Region	Mean (t C/ha)	95% CI (t C/ha)	# plots	Counties
Southern	18.1	3.31	264	Cochise, Graham, Greenlee, La Paz, Maricopa, Pima, Pinal, Santa Cruz, Yuma
Northern	29.2	2.09	816	Apache, Coconino, Gila, Mohave, Navajo, Yavapai

2.3.4. Carbon Emissions from Development

Two carbon emission scenarios are considered here. In both cases FIA data from federal and non-federal forests are applied to NRI land cover estimates for non-federal forests.

- Scenario 1 assumes that all carbon present on the land in aboveground tree biomass is lost when development occurs.
- Scenario 2 assumes that when small-scale development occurs, a significant proportion of the trees remain during and after the process of development. As examples, these may be trees surrounding residential properties or trees on golf courses. Therefore, in this scenario, the research team assumed that for Transportation and Urban/10 acres or larger, all carbon is lost, but for Urban/small built-up, only 50% of the carbon stocks are emitted.

Emissions discussed here for conversion of forestland to development are gross emissions from aboveground tree biomass only. Total emissions from development over the ten-year period were estimated as 41,300 t C under Scenario 1 and 39,600 t C under Scenario 2. This is equivalent to 4,135 and 3,957 t C per year, respectively. The difference is small because only 9% of the total development change is attributed to small-scale development. Emissions by county are summarized in Figure 2-3-2 and Table 2-3-4.

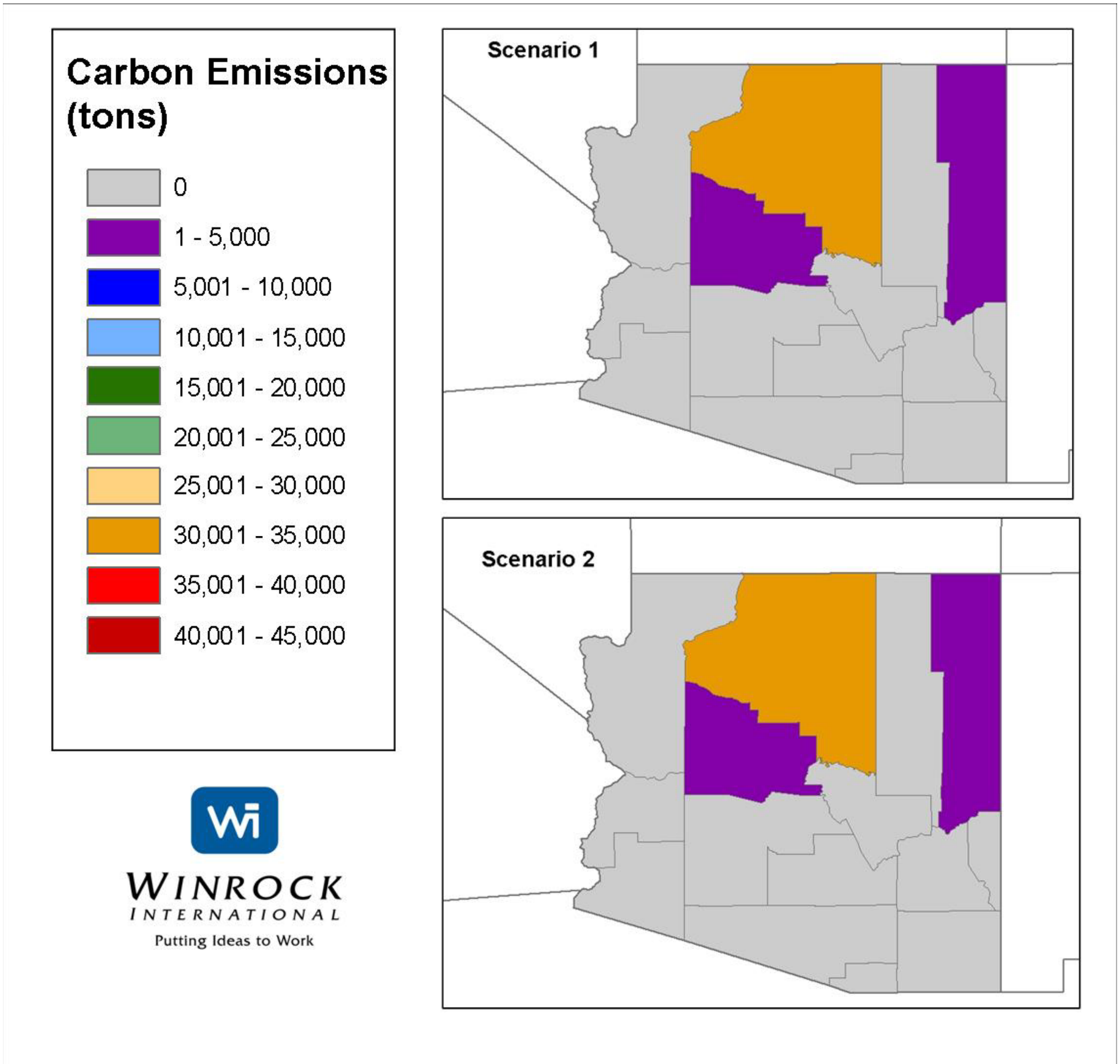

Figure 2-3-2. Carbon emissions under the two scenarios at the county level across Arizona

Table 2-3-4. County-level estimates on the emissions between 1987 and 1997 due to development. Scenario 2 is more conservative, assuming that trees are not clear-cut during small-scale development

County	Population	County Area (ha)	Non-Fed Forest Area 1997 (ha)	Carbon emissions (t C) Scenario 1	Scenario 2
Apache	69,423	2,902,050	690,782	3,544	3544
Cochise	117,755	1,597,880			
Coconino	116,320	4,821,891	142,819	33,077	31,305
Gila	51,335	1,234,829	82,316		
Graham	33,489	1,198,987	70,782		
Greenlee	8,547	478,371			
La Paz	19,715	1,165,483	5,990		
Maricopa	3,072,149	2,383,602			
Mohave	155,032	3,447,699	293,893		
Navajo	97,470	2,577,862	416,113		
Pima	843,746	2,379,232			
Pinal	179,727	1,390,719			
Santa Cruz	38,381	320,546	243		
Yavapai	167,517	2,103,925	648	4,725	4,725
Yuma	160,026	1,428,143			
TOTAL	**5,130,632**	**29,431,219**	**1,703,586**	**41,346**	**39,574**

The carbon emissions as a result of development mirror the loss in forest area. All losses occurred in the northern region of the state (Table 2-3-5). The loss to development over ten years represents less than 0.1% of the total area of forest land in Arizona, and consequently a low level of emissions for a large state.

Table 2-3-5. Region-level summary of loss in area and carbon emissions between 1987 and 1997 due to development. Scenario 2 is more conservative assuming that trees are not clear-cut during small-scale development.

Region	Area lost (ha)	Carbon emissions (t C) Scenario 1	Scenario 2
Southern	0	0	0
Northern	1,416	41,346	39,574

This loss to development is equal to an annual loss in area across the state of just 142 ha with annual CO_2 equivalent emissions of between 14,500 and 15,200 metric tons of CO_2e (Table 2-3-6).

Table 2-3-6. Region-level summary of annual loss in area and carbon dioxide equivalent emissions between 1987 and 1997 due to development. Scenario 2 is more conservative, assuming that trees are not clear-cut during small-scale development.

Region	Annual Area lost (ha/yr)	Annual carbon emissions ($MMTCO_2e/yr$)	
		Scenario 1	Scenario 2
Southern	0	0	0
Northern	142	0.0152	0.0145

2.3.5. Additional Considerations

Emissions discussed here for conversion of forestland to development are gross emissions from aboveground tree biomass only.

Gross versus Net Emissions

The analysis presented above represents gross changes. The only consideration was of emissions from losses of forest to development.

Where gains of forest were made from development (none in Arizona), this was not considered.

The destination of biomass upon development is also not considered. The assumption is made that all carbon is immediately emitted. In reality this is unlikely to be the case. Some of the wood is likely to ultimately become firewood, some will be left to decompose, and some may be used as timber and will have a longer existence as wood products. Regardless, all trees cut for development will ultimately be emitted to the atmosphere as CO_2 or CO_2 equivalents. Instead of including any delay here, it is assumed that the CO_2 is emitted immediately.

Other Carbon Pools

Aboveground tree biomass was the only carbon pool considered in this analysis. The reason behind this decision was the uncertainty involved in other pools generally, and specifically in the case of development.

Soil carbon is particularly uncertain. If the land is capped by concrete it is unlikely that soil carbon will be affected at all. If grasses are planted there is even the possibility that development could lead to an increase in soil carbon.

For similar reasons, roots are also uncertain. The rate at which roots decompose is very poorly known and even less is known about the diminished rate if the roots are buried beneath concrete or tarmac.

Dead wood and litter are likely to be emitted either immediately upon development or through time as decomposition occurs. However, there is no clear relationship between aboveground tree biomass and these pools, and the uncertainty involved with any assumption would be very large.

Non-CO_2 greenhouse gas emissions are also unknown. If site preparation occurs through burning, there will be emissions of methane and nitrous oxide (both potent GHGs). If site preparation involves drainage there will be emissions of methane. Without specific site-by-site information it is not possible to make these estimations.

2.3.6. Conclusions

An estimated 1,416 ha were lost to development in Arizona between 1987 and 1997 at a rate of 142 ha per year. This forest loss is equivalent to a gross emission of between 0.145 and 0.152 million metric tons of CO_2 equivalent, or 0.0145 to 0.0152 $MMTCO_2e$ per year.

The emissions were exclusively in the north part of the state, in the counties of Apache, Coconino, and Yavapai.

These emissions compare with the estimated gross sequestration from forests in Arizona of 0.92 $MMTCO_2e$/yr between 1987 and 1997 (Section 2.2) and gross emissions for the state of 99 $MMTCO_2e$/yr (Bailie and Lazarus 2005). Emissions from deforestation therefore represent a fraction of a percent of the state's total emissions.

2.4. Fire Baseline

In this fire analysis the emissions caused by fire between 1990 and 1996 are estimated. These emissions are part of the general forest baseline (Section 2.2). Without emissions from fire, the general forest baseline would be raised by an amount equal to these emissions.

This baseline, unlike the general forest baseline and the development emissions baseline contains an analysis of rangelands as well as forests.

There are two components to a fire emissions analysis. It is necessary to know both the area that is burnt and the amount of biomass that is volatilized into GHGs per area. Knowledge of these components permits an estimation of total fire-derived emissions.

The period 1990 to 1996 was chosen for this analysis, because these study dates represent the most recent, consistent complete coverage (although a partial dataset exists for 1997–2003). Complete coverage is essential in order to be able to make state-level conclusions on the fire impact.

2.4.1. Methods for Assessing Biomass Volatilized

Background

The effects of fire on carbon stocks are dependent on the intensity of the fire. An intense fire will destroy biomass and release a great proportion of the carbon to the atmosphere, while a less intense fire will even fail to kill the majority of the trees. Here fires are divided into three potential intensities: high, medium, and low.

As illustrated in Figure 2-4-1, pre-fire carbon has five potential destinations during and after a fire. The first proportion will survive the fire to continue as live vegetation; a second proportion will be volatilized during the fire and immediately released to the atmosphere; and the remainder will be divided between the pools of dead wood, soot, and charcoal. Soot and charcoal are stable forms of carbon and can remain unchanged for hundreds of years; in contrast dead wood decomposes over time.

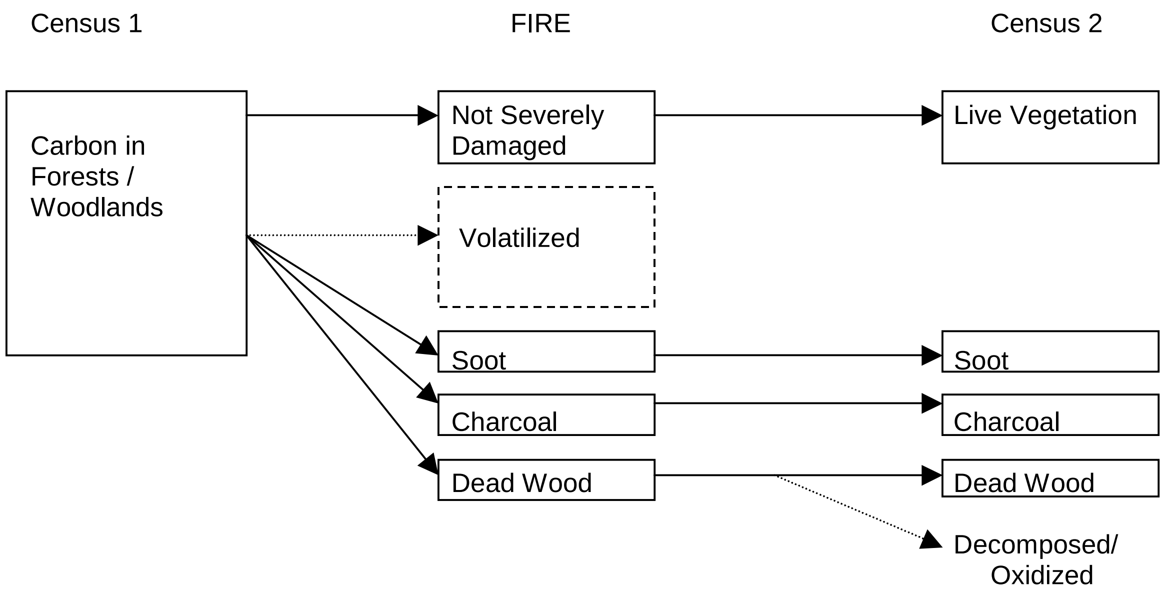

Figure 2-4-1. Flow diagram illustrating the various destinations of pre-burn carbon after a fire

The basis for this baseline analysis was the detailed study conducted for California (Brown et al. 2004). Under the California baseline analysis, changes in canopy coverage (measured from satellite imagery) were recorded through time for forest types and causes (including fire) were assigned. The study assumed (based on expert opinion) that the high, medium, and low intensities are associated with the magnitude of change in crown cover, so that a large decrease in crown cover would be due to a high-intensity fire or a small decrease would be caused by a low-intensity fire.

The midpoint of each decrease in canopy coverage class was assumed to be the proportion of the vegetation killed by the fire. The proportion volatilized is dependent on fire intensity (60% by a high-intensity fire, 40% by a mid-intensity fire, and 20% by a low-intensity fire) (McNaughton et al. 1998; Carvalho et al. 2001). If the volatilized proportion is subtracted from the midpoint of the decrease, then the remaining fraction is the dead wood, soot, and charcoal pool. This fraction was divided using the following proportions: 22% charcoal, 44% soot, and 32% dead wood (Comery 1981; Raison et al. 1985; Fearnside et al. 1993; Neary et al. 1996).

Approach for Calculations

This study' aim was to determine the loss in biomass as a result of fire in Arizona. The California study used data on the area affected by fire in classes of initial and post-fire crown cover and forest type. The degree of reduction in crown cover was used to indicate the intensity of the fire. The research team also had the biomass associated with each crown cover class, so a change between two cover classes could be represented as a loss in carbon. In contrast, in

Arizona available data included only forest type and an indication of fire intensity from fire extent and change in spectral reflectance.

The approach for this study was therefore to use the California data to determine the percentage loss in biomass that occurs as a result of a high-, medium-, or a low-intensity fire in each of the forest types. The percentage loss is then applied to Arizona-specific biomass numbers for comparable forest types.

The source of biomass values is the Arizona 2003 inventory of the forest inventory and analysis database (FIADB). These were split between forest types. In all cases, Arizona FIA data was divided by the five forest/woodland types (Douglas Fir, Fir-Spruce, Other Conifer (typically Ponderosa Pine), Hardwood Forest, and Hardwood Rangeland (typically oak savannah and pinyon-juniper) (Table 2-4-1) at the county level. The division by forest/woodland type was used to align the Arizona analysis with the original California study (Brown et al. 2004).

Table 2-4-1. Forest types for fire baseline analysis cross-walked with FIA forest type

California-analysis forest type	FIA forest type
Douglas Fir	Douglas Fir
Fir Spruce	White fir, Red fir, Noble fir, Pacific silver fir, Engelmann spruce, Engelmann spruce/Subalpine fir, Grand fir, Subalpine fir, Blue spruce, Sitka spruce
Other Conifer	Port-Orford cedar, Ponderosa pine, Western white pine, Jeffrey pine/Coulter pine/big cone Douglas-fir, Mountain hemlock, Lodgepole pine, Western hemlock, Western redcedar, Alaska yellow cedar, Western larch, Misc. western softwoods
Hardwoods - forest	Cottonwood, Willow, Oregon Ash, Aspen, Red alder, Bigleaf maple, Tanoak, Giant chinkapin, Pacific Madrone
Hardwood - rangeland	Western juniper, California black oak, Oregon white oak, Canyon live oak/Interior live oak, California laurel, Misc. western hardwood woodlands, Intermountain maple woodland, Juniper woodland, Pinyon juniper woodland, Rocky mountain juniper, Deciduous oak woodland, Mesquite woodland

The FIA data was further split into regions—Northern and Southern—with the assumption that the climatic variation would lead to variation in biomass that would refine the estimates. The split of counties between regions is listed in Table 1-1.

The mean biomass stocks were calculated from Arizona FIA data by region and forest type (Table 2-4-2).

Table 2-4-2. Mean biomass stock by forest type and region

Forest type	Mean biomass (t biomass/ha)	
	Northern	Southern
Douglas Fir	175.6	153.8
Fir Spruce	244.2	
Other Conifer	118.6	107.7
Hardwood	159.1	
Range Hardwood	43.8	31.8

Biomass Loss through Fire

To calculate the emissions through fire, the research team used results from the California analysis (Brown et al. 2004), taking the estimated stocks for each forest type at each of the four canopy density classes, plus the net emissions for each forest type/canopy density class/fire intensity class. Finally the emissions were calculated as a proportion of the original biomass and the results expressed as a percentage.

Because no canopy cover class data exists for Arizona, a mean emission percentage that excludes canopy cover is required. This was achieved by weighting the emission percentages by the proportion of forest in each canopy class in the most representative region of California (North Sierra).

The proportions by forest type by region by fire intensity were then multiplied by the biomass by forest type by region to give estimated biomass lost through emissions from fire (Tables 2-4-3 and 2-4-4).

Table 2-4-3. Mean emissions (in t CO_2e/ha) from a high-, mid-, and low-intensity fire in the Northern Region of Arizona

Forest type	High	Mid	Low
Douglas Fir	145.0	62.5	25.1
Fir Spruce	263.5	112.9	45.5
Other Conifer	80.7	53.5	26.6
Hardwood	141.2	61.1	24.6
Range Hardwood	27.4	11.8	4.8

Table 2-4-4. Mean emissions (in t CO_2e/ha) from a high-, mid-, and low-intensity fire in the Southern Region of Arizona

Forest type	High	Mid	Low
Douglas Fir	126.9	54.8	22.0
Fir Spruce	0.0	0.0	0.0
Other Conifer	73.2	48.6	24.2
Hardwood	0.0	0.0	0.0
Range Hardwood	31.4	13.5	5.4

Non-Tree Vegetation

Biomass numbers for non-tree vegetation (primarily shrubs and grasses in rangelands) are taken from the literature and Winrock International experience (Table 2-4-5).

Table 2-4-5. Estimates of pre-fire biomass stocks in non-tree vegetation

Vegetation type	Biomass carbon (t C/ha)	Source
Wet Grasslands	5.9	Prichard et al. 2000
Mesic Grasslands	2.4	Brown and Archer 1999
Xeric Grasslands	0.6	Winrock unpublished data
Shrublands	5.1	Martin et al. 1981
Desert scrub	2.6	Winrock unpublished data

Here the conservative assumption is made that 50% of the pre-fire biomass in non-tree vegetation is volatilized to be emitted as carbon dioxide.

2.4.2. Methods for Assessing Area Impacted by Fire and Fire Intensity

Satellite-based analysis is a practical method of quantifying area burned primarily due to the dangerous nature and the wide geographic extent of wildfires. The state reports the location and size of recorded fires but with no measure of fire intensity, nor with the location of the boundaries of the fire. It is necessary to know fire intensity to estimate emissions, and the precise location is necessary for a correlation with a database of vegetation species. The approach for this analysis was to estimate the extent of fires at known fire locations, through delineating areas with a change in reflectance on multiple satellite images—that is, pre-fire and post-fire images.

A common measurement of vegetation from satellite imagery is the Normalized Difference Vegetation Index (NDVI). Very low values of NDVI (0.1 and below) correspond to barren areas of soil without vegetation or of sand, rock, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate forests (0.6 to 0.8).

Databases

The **NDVI** was calculated from 1.1 kilometer (km) pixel resolution NOAA Advanced Very High Resolution Radiometer (AVHRR) 10-day composite images. The temporal frameset covered the month of September and spanned 1990–2003 (except 1994). This encompassed the NOAA 11, 14, and 16 satellites. September was chosen for the analysis time frame because it is toward the end of the fire season and the burned areas are not yet affected by regrowth. Only one September 1994 composite was produced for 1994, due to the failure of the AVHRR sensor aboard NOAA-11. As a result, the imagery for 1994 along with fire data was dropped from the analysis because of data inconsistencies in image values and incomplete temporal coverage from sensor failures.

The **wildfire database for Arizona** encompassed a total of 23,242 occurrences that vary from less than one acre to many thousand acres. Fires for the study period with a final size greater than 2,000 ac were identified for NDVI postfire burn detection analysis to quantify area burned. For state lands, 5,602 fires occurred between 1990 and 1996; for federal lands, 17,636 fires occurred between 1990 and 1996. Each fire record included a unique identification with a global positioning system (GPS) point location, date, and final extent in acres. There was no geographic information system (GIS) polygon representing the extent of the fire in the original database so it was not possible to precisely locate the extent of the fire from these records, so the research team used the approach described below.

Mapping Methods

Fire Identification

This analysis used a postfire burn detection method to quantify area burned by wildfires. The NDVI was calculated from the water vapor-corrected band 10 (visible, 0.58–0.68 micrometer [μm]) and band 11 (near infrared, 0.725–1.10 μm).

$$NDVI = (ch\ 11 - ch\ 10)/(ch\ 11 + ch\ 10)$$

To obtain a single September NDVI for each year of the study period, three (or in some years four) 10-day composites were averaged into a single image ($NDVI_y$). These September images were then averaged into a 13-year historical NDVI reference image ($NDVI_m$).

The NDVI reflectance values are bimodal, ranging from -1.0 to 1.0. Positive values reflect vegetation or "greenness," and negative values indicate soil or non-vegetated areas. Values close to 1 are "greener" than values close to 0, and values close to -1 are more barren than values close to 0. When vegetation is burned, a rise in channel 10 reflectance and a decrease in channel 11 reflectance occurs. The degree of change ($NDVI_d$) was measured by subtracting $NDVI_y$ from $NDVI_m$

$$NDVI_y - NDVI_m = NDVI_d$$

Each individual annual September image was subtracted from the reference image and potential fire locations were identified. In NDVI difference imagery, positive values indicate an increase in "greenness" from $NDVI_m$, and negative values indicate a decrease. For burned area-identification purposes, all positive values were removed, along with negative values greater than -0.05. The result was an image containing areas of concentrated vegetation decrease. The fire location data was then overlaid to confirm the changes as potential fires.

Fire Extent

The extent of fires listed as having over 2,000 ac in final size were mapped by visual interpretation from the changes seen in $NDVI_d$ with assistance from the fire's GPS location and extent information (Figure 2-4-2).

The wildfire mapping process consisted of creating polygons that represent the extent of the burn area. Fires were first divided into big and small, based on final extent. Fires with a final extent of < 2,000 ac or 8 pixels were labeled as small fires. For AVHRR imagery, 1 pixel = 100 ha = 247.5 ac. Areas of vegetation that had a decrease in $NDVI_d$ greater than 8 pixels and a corresponding fire greater than 2,000 ac were digitized using the "heads up method."[1] The area digitized was then compared with the reported fire extent.

All fires with less than 2,000 ac burned were classified as too small to display a change in the AVHRR imagery. For these fires, a buffer was calculated and added to the fire point based on the GPS point (which was considered the center of the fire) and the radius (which was derived from the size reported in the original record).

Additionally, if a fire that was larger than 2,000 ac could not be mapped by visual interpretation, it was mapped by the buffering method.

In the case of the fires that occurred in 1994, they were mapped using the images from 1995.

Fire Severity

For the fires that occurred in forested lands, three classes of burn severity were identified: low, medium, and high (Figure 2-4-2). Again, the intensity was evaluated separately depending on the fire mapping method. For the fires that were identified using the imagery, the value of burn severity corresponded with the value of the difference in NDVI. The rationale is that the more negative the difference between the actual NDVI and the mean NDVI, the more severe is the fire. As a result, one fire can include areas with different burn severities. Small fires (< 2,000 ac) were arbitrarily considered to experience a low burn fire severity, since there was no image data to consistently support the estimation.

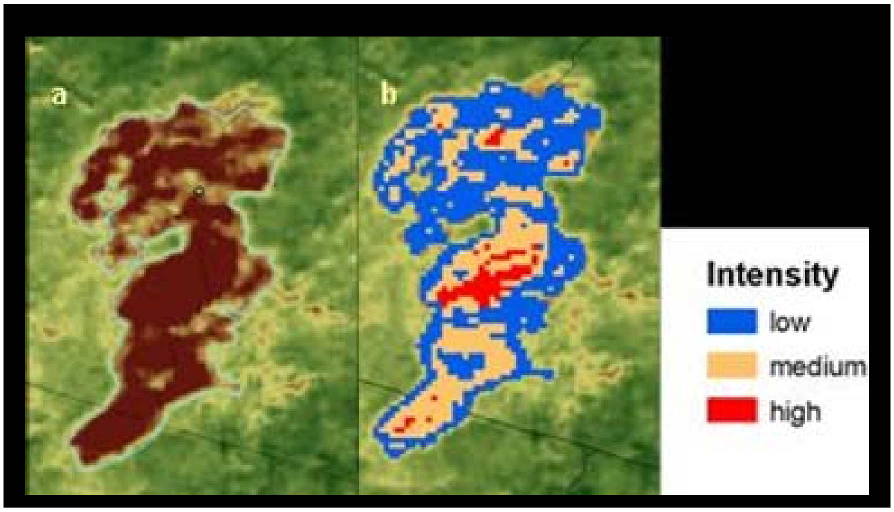

Figure 2-4-2. Illustration of the mapping method. In (a), the point location from the state or federal database is established; a fire boundary is then created and compared to the fire area reported with the point location. In (b), the fire intensity through the burn area is calculated using NDVI values.

[1] "Heads up" digitizing refers to on screen digitizing. It is referred to as "heads up" because the analyst focuses on the screen, as opposed to a digitizing tablet.

Land Cover Affected by Fire

Finally, the fire maps were crossed with the land cover maps, making it possible to estimate the amount of land cover type/forest type that was affected by fires.

2.4.3. Results

Across the seven years analyzed, researchers recorded fires with a total area of 1.08 million ac (437,700 ha), as illustrated in Figure 2-4-3. This is equivalent to 154,000 ac/yr (62,500 ha/yr).

Emissions totaling 904,000 tons of carbon, or 3.3 $MMTCO_2e$, were estimated to have occurred from fire during the analysis period. This is equivalent to an emission of 0.47 $MMTCO_2e$/yr.

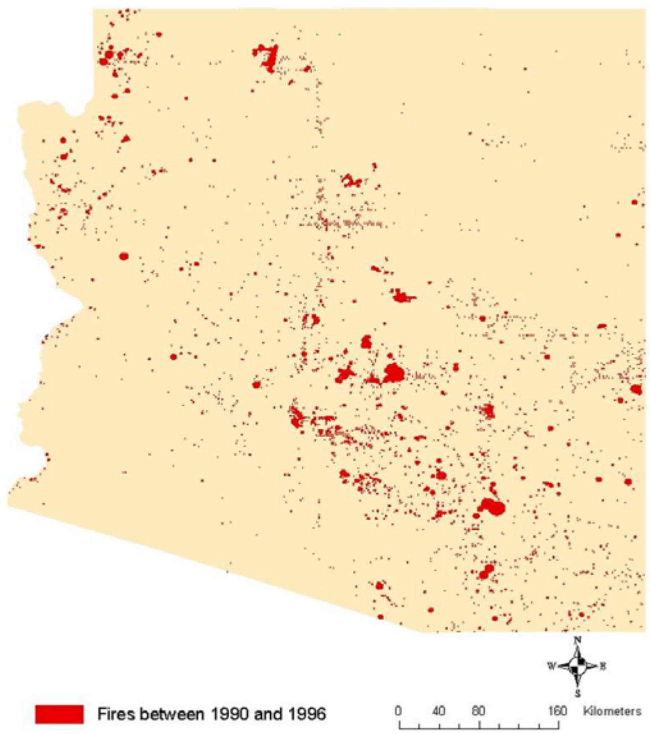

Figure 2-4-3. The location and extent of fires in Arizona between 1990 and 1996

Eighty percent of the fires occurred on rangelands with only 14% in forests (Table 2-4-6).[2] Because of the higher biomass loss from forests during fire, almost 42% of the total emissions from fire originated in the 14% of fire area that was in forest.

[2] The remaining fire area was on developed, agricultural, or barren land.

Table 2-4-6. Area burned and carbon emissions in forests and in rangeland across the analysis period

Area Type	Area burned (ha)	Emissions (t C)
Forest	62,388	375,637
Rangeland	351,891	528,725

The annual emissions ranged between 22,000 tons of carbon and 218,000 tons of carbon (Table 2-4-7 and Figure 2-4-3). The lowest emissions occurred in 1991 and 1992, when just 14,000 and 18,000 ha were burned. The highest emission was in 1996, when 67,000 ha burned; however, the largest area burned in 1993 and 1995, but a greater proportion of these fires occurred in low biomass systems (that is, rangelands with no trees). The largest fires and highest emission came in the later years of the analysis, but more years of data would be needed to consider whether there is a trend to increase in fire coverage and emissions.

Table 2-4-7. Area burned and carbon emissions per year across the analysis period

YEAR	Area burned (ha)	% Forest	Emissions (t C)
1990	34,909	38	111,273
1991	14,215	10	22,352
1992	17,907	5	22,612
1993	109,510	6	168,611
1994	90,476	16	177,601
1995	103,145	7	183,898
1996	67,490	26	218,014
TOTAL	437,652		904,361

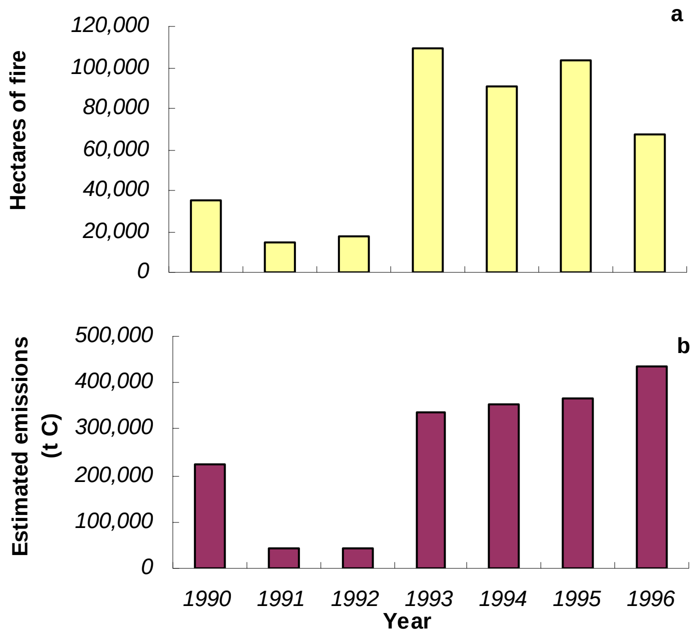

Figure 2-4-4. Area affected by fire and estimated emissions from fire across the study period

Fires occurred throughout Arizona during the study period and there was no apparent geographical relationship between either area burned or carbon emissions from fire and geographic location (Figures 2-4-4 and 2-4-5). As shown in Table 2-4-8, the highest emissions occurred in Coconino and Gila Counties. The largest total areas burned were located in Maricopa and Mohave Counties.

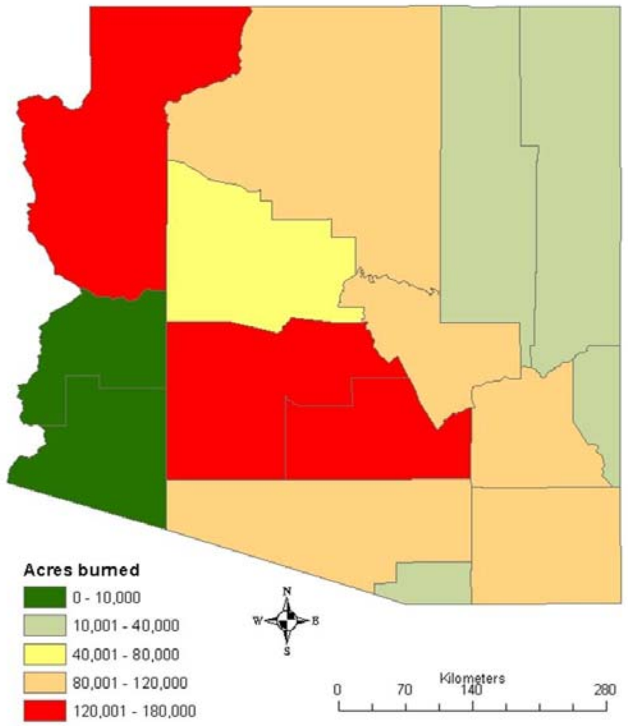

Figure 2-4-5. Area burned (in acres), at the county level, between 1990 and 1996

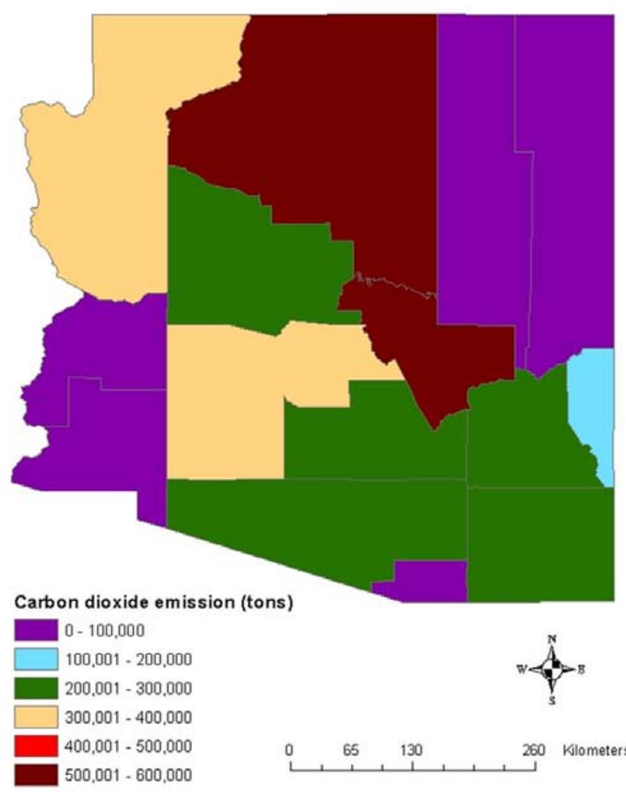

Figure 2-4-6. Metric tons of carbon dioxide emitted, at the county level, between 1990 and 1996

Table 2-4-8. Area burned and carbon emissions per county across the analysis period

County	County Area (ha)	Area burned (ha)	Emissions (t C)
Apache	2,902,050	5,723	14,698
Cochise	1,597,880	36,664	74,279
Coconino	4,821,891	38,221	137,097
Gila	1,234,829	35,485	143,832
Graham	1,198,987	37,391	77,270
Greenlee	478,371	12,396	50,734
La Paz	1,165,483	2,334	2,703
Maricopa	2,383,602	61,479	84,341
Mohave	3,447,699	71,075	94,615
Navajo	2,577,862	5,342	24,481
Pima	2,379,232	48,316	64,908
Pinal	1,390,719	55,492	73,271
Santa Cruz	320,546	4,483	4,549
Yavapai	2,103,925	22,300	56,528
Yuma	1,428,143	950	1,056
TOTAL	29,431,219	437,651	904,362

2.4.4. Uncertainties

The carbon values to which percentage emission factors are applied are averaged values across all FIA plots in a forest type/region combination. Consequently, the same average value is used to represent forests with very high carbon stocks or very low carbon stocks. Fires will occur in forests regardless of starting carbon stock, yet it is possible that the forests with the very lowest carbon stocks (for example in the year immediately after clear-cut logging) may not have enough biomass to sustain a fire. The emissions reported here may therefore be a small *overestimate,* for if the very lowest biomass plots are excluded from the FIA analysis the mean will be raised and consequently, the estimated emissions will be as well.

The calculated emissions presented here are conservatively limited to just aboveground tree biomass and therefore represent an *underestimation* of total emissions. Carbon stored in other pools will combust and be emitted through fire. However, the research team has no detailed source that will link the region and forest type-specific FIA data on aboveground tree biomass with similar data on other carbon pools.

Fire will directly impact dead wood, litter, shrubs, and herbs (though even these pools may not be completely volatilized in low-severity fires [e.g., Skinner 2002]). The influence of fire on soil carbon or the carbon stored in roots is less clear. When a tree is killed, the roots will not be burned but will become dead material that will decompose at a rate that is not well understood. A very intense fire will affect soil carbon, though it is not fully understood what proportion of soil carbon is volatilized, nor to what depth the impact penetrates.

The research team consulted the literature to get an indication of the scale of potential additional emissions for pools not included here. Smithwick et al. (2002) took measurements of all carbon pools across 43 stands at seven sites in Washington and Oregon. The authors divided their measurements into three regions: Coastal, Cascades, and Eastern. The results from the dry pine forests of Eastern Oregon are presented here to represent the forests in Arizona. Values for roots were not taken from Smithwick et al. (2002); roots were estimated more directly by using the temperate forest allometric equation of Cairns et al. (1997), which calculates belowground biomass from aboveground biomass. The amount of additional biomass carbon as a percentage of aboveground live tree biomass carbon stocks is given in Table 2-4-9.

Table 2-4-9. Relative increase in stocks that would result from adding each of the additional carbon pools to live aboveground trees

	Litter	Dead Wood	Shrubs	Herbs	Roots	Soil Carbon
Arizona	22%	23%	0.38%	0.09%	25%–31%	43%

The measurements of Smithwick et al (2002) were in old-growth forests. In younger forests lower absolute amounts of dead wood might be expected together with similar quantities of litter, shrubs, and herbs. Therefore a lower proportion of dead wood and a higher proportion of litter, shrubs, and herbs might be expected in younger forests.

Here, as an indication of potential additions, the values of Smithwick et al. (2002) are used. An addition of litter, dead wood, shrubs, and herbs (assuming that these pools are volatilized at the same proportion as live aboveground trees) results in an additional emission over the study period equal to 206,936 tons of carbon, or an additional 23%.

2.4.5. Conclusions

Across the seven years analyzed, fires with a total area of 437,700 ha (1.08 million ac) were recorded. This is equivalent to 62,500 ha/yr or 154,000 ac/yr. Emissions totaling 904,000 tons of carbon or 3.3 $MMTCO_2e$ were estimated to have occurred from fire during the analysis period. This is equivalent to an emission of 0.47 $MMTCO_2e$/yr.

Eighty-five percent of the burnt area was on rangelands but 42% of the emissions were from the 15% of burned area that was forest. Fire incidence varied by year with high emissions in 1993 to 1996 (> 168,000 t C) and low emissions between 1991 and 1992 (< 23,000 t C). Fires occurred throughout Arizona during the study period, and there was no apparent geographical relationship between either area burned or carbon emissions from fire and geographic location.

3.0 Baseline for Agricultural Lands in Arizona

3.1. General Approach

The goal of this part of the research was to quantify the baseline of changes in carbon stocks in the Arizona agricultural sector for the decade of the 1990s. Baselines provide an estimate of the emissions and removals of GHGs caused by changes in the use and management of land. The focus of this report is on emissions and removals of carbon dioxide and not on non-CO_2 greenhouse gases. Baselines are useful for identifying where, within the landscape of a state, opportunities exist for enhancing carbon stocks and/or reducing carbon sources to mitigate GHG emissions.

The baseline for the agricultural sector depends on two types of data: (1) the total area of agricultural land, and area of each of the major agricultural land-use types, through time, and (2) the carbon stocks in each land-use type. Areas and changes in area of agricultural lands are based primarily on the NRI database for the period 1987–1997. Carbon stock estimates for various agricultural land-use types were derived from consultation with experts in local universities and from the literature in combination with standard methods. The analysis is conducted for the entire state of Arizona at the county scale of resolution.

3.1.1. Classification of Agricultural Land

In this study, NRI data were used for estimates of area because of the NRI's relative strength in agricultural surveys compared with other sources of data. The coverage of NRI data is wider and is available across the states for multiple points in time and for multiple classes of agriculture.

In this analysis, agricultural land is equated to cropland as defined in the NRI (NRCS 2000). The NRI recognizes two categories of cropland: cultivated and non-cultivated. Cultivated cropland includes small grains and row crops, hay and pasture with cropping history, and horticulture with double cropping (meaning horticulture with crops planted under the trees). Non-cultivated cropland includes horticulture without double cropping and hay without cropping history. Grazing lands are included under the analyses of rangelands in Chapter 2.

The distinction between cultivated and non-cultivated crops is not useful for the purpose of (aboveground) carbon analysis, which depends instead on biomass models based on the growth form of the vegetation. Therefore, the specific land-use categories from NRI were regrouped for this analysis into categories related to the growth form of the crop. All horticulture lands, with or without double cropping, were reclassified as woody cropland. The rest of the croplands, including hay, row crops, and small grains, were considered to be non-woody crops (Table 3-1).

Table 3-1. NRI categories and subcategories in Arizona

Broad classification	Detailed classification	NRI classification
INCLUDED AS AGRICULTURE IN THIS CHAPTER		
Perennial woody crops	Fruit orchards	Fruit orchards
	Nut orchards	Nut orchards
	Vineyards	Vineyards
	Bush crops	Bush crops
	Berry crops	Berry crops
	Other horticulture	Other horticulture
Annual non-woody crops	Row / close crops	Row/Corn
		Row/Sorghum
		Row/Soybeans
		Row/Cotton
		Row/Peanuts
		Row/Tobacco
		Row/Sugar beets
		Row/Potatoes
		Row/Other veg/truck crops
		Row/All other row crops
		Row/Sunflower
		Close/Wheat
		Close/Oats
		Close/Rice
		Close/Barley
		Close/All other close grown
		Hay/Grass
		Hay/Legume
		Hay/Legume-grass
		Other crop/Summer fallow
		Other crop/Aquaculture
		Other crop/Other-set-aside, etc.
FOCUS OF CHAPTER 2		
Pasture / rangeland	Pasture / rangeland	Pasture/Grass
		Pasture/Legume
		Pasture/Grass-forbs-legumes
		Rangeland
Forest	Forest	Forestland/Grazed
		Forestland/Not grazed

Table 3-1. (cont'd)

Broad classification	Detailed classification	NRI classification
OTHER CATEGORIES		
Urban / transportation	Urban / transportation	Urban/10 acres or larger Urban/Small built-up Transportation
Other	Other	Other farmland/Farmsteads Other farmland/Other land Other farmland/CRP land Barren/Salt flats Barren/Bare exposed rock Barren/Strip mines Barren/Beaches Barren/Sand dunes Barren/Mixed barren lands Barren/Mud flats Barren/River wash Barren/Oil wasteland Barren/Other barren land Other rural/Permanent snow-ice Other rural/Marshland All other land Water/Body 2–40 acres Water/Body less than 2 acres Water/Streams < 66 ft. wide Water/Streams 66–660 ft. wide Water/Large

CRP = Conservation Reserve Program

3.1.2. Limitations of the NRI Database

Despite the general acceptance of NRI for agricultural resource analysis, it is important to note its limitations. First, the samples were taken from non-federal lands only, while in the West Coast states, federal lands occupy half or more of the total land area. Second, the data are not from a complete census, but rather from a statistically sound sampling design. Finally, the NRI's classification of land cover/land-use types may not be consistent with other classification schemes commonly used in land cover/land use analysis; for example, the classification in USGS National Land Cover Classification system.

For this chapter's purpose, however, these limitations have virtually no effect on the analysis, because the data are only being used for the agricultural sector, where lands are privately owned, easy to classify, and statistically well reported.

The NRI reports a margin of error for the 1997 reporting (equivalent to a 95% confidence interval) of ±9% for its sampling of areas of cultivated cropland.

3.1.3. Area and Change in Area of Agricultural Land

The research team reclassified the NRI data for each state into the broad classes shown in Table 3-1 and then calculated the areas for each class for 1987 and 1997. Although 1992 data were available, a similar analysis for California, where the change over two five-year periods (1987–1992 and 1992–1997) was included, indicated that using two periods did not appear to add any further insights into the dynamics of land-use and carbon stock change (Brown et al. 2004). Thus this study only examined the change over the 10-year period 1987 to 1997.

3.1.4. Carbon Density of Agricultural Land

The baseline analysis for the agricultural sector focuses on carbon in vegetation only, including above- and belowground (roots) components. Carbon in vegetation is estimated as 50% of the biomass of the vegetation.

Carbon Stocks for Non-Woody and Woody Crops

A difficulty in estimating the biomass of non-woody annual crops is caused by the seasonal change of the vegetation. During the non-growing season, there is little biomass in annual crops, while at the peak of the growing season just before harvest, biomass can be high. Considering that litter production is usually low in these crops, peak biomass is assumed to be equivalent to the annual primary production of the crops on the land. In many cases the majority of the biomass (or production) is removed from the field at harvest. An approximate temporal average of the biomass was used to derive the carbon stock. The biomass in cultivated non-woody crops was estimated based on three data sources: (1) crop biomass from the U.S. Department of Agriculture – National Agriculture Statistics Service (USDA NASS, see www.usda.gov/nass/sso-rpts.htm), (2) length and timing of harvest cycles, and (3) the relative abundance of each crop type.

Carbon stocks of horticultural crops have less seasonal variation, but data on carbon stocks for these crops are scarce. Yield data from the USDA NASS represents only the biomass of the harvest—a useful estimate of peak biomass for non-woody crops, but only a small portion of the standing biomass for woody crops. Thus estimates were instead derived from consultation with extension agents, university researchers, and government officials in combination with literature searches, principally to determine typical stocking densities (number of trees per unit area), tree diameters, and tree heights. Biomass could then be estimated from tree diameter and height using a regression equation (Winrock unpublished). The stocking densities were combined with estimates of biomass per plant to arrive at an estimate of biomass carbon density in metric t C/ha. For fruit orchards and bush fruits, multiple crop types were included, and the relative abundance of each crop type in the state, derived from USDA NASS, determined the area-weighted mean carbon stock that was used in this analysis (Table 3-2).

Table 3-2. Estimates of the average carbon stock (t C/ha) for each of the crop types in Arizona

Crop type	Average C stock (t C/ha)
Fruit orchards	17.3
Nut orchards	10.8
Vineyards	4.3
Bush fruits	-
Berry fruits	-
Other horticulture	4.5
Non-woody crops	1.5

Soil carbon stocks are not included in this report because the research team assumed that most agricultural land has been under cultivation long enough that changes in soil carbon would be minimal to non-existent under current practices. The stability of soil carbon on cultivated land was confirmed by the study of DeClerck and Singer (2003), who showed that the percent change in soil carbon under row crops in California remained constant over an approximate period of 50 years. Interestingly, DeClerck and Singer also found the same trend for tree crops, but an increase in soil carbon over the past 50 years for soils under viticulture (about a 1.7-fold increase) and pasture (about a 1.6-fold increase). These results are difficult to apply in baseline determination because the results were reported as an increase in percent carbon with no indication of changes in soil bulk density; calculating changes in carbon stocks requires not only the change in percent carbon but also the change in soil bulk density.

Estimates of the carbon stocks in non-agricultural lands (such as urban/transportation, and all of the "other" class) are assumed to be zero. This assumption is probably reasonable for "other," because this contains mostly barren lands, but for urban/transportation there is likely to be more carbon than in non-woody croplands. Urban development often contains significantly more (but unknown) amount of biomass in trees and shrubs that homeowners and local municipalities plant than in the agricultural lands that they replace. This is an area of further research—estimating the amount of carbon in biomass of urban areas as a function of density and other factors.

Change in Stocks

When a change in agricultural land use occurred, it was assumed in this analysis that the entire carbon stocks in vegetation present before the change would be emitted into the atmosphere as carbon dioxide. This is a reasonable assumption given the necessity to clear the land to plant alternative crops or initiate urban development.

Regarding changes in land use to agricultural crops, it is assumed that the change occurred at the midpoint of the period under analysis (in 1992), five years before 1997, and five years after

1987. For non-woody crops such as vineyards, bush and berry crops, and other horticulture crops, it is reasonable to assume that in five years these crop types will have reached their predicted steady-state biomass. The same assumption cannot be applied to orchards, which will take longer than five years to attain their maximal biomass. Instead, the biomass accumulation that might have occurred in five years of growth for fruit and nut orchards was estimated based on conservative estimations of stocking density, tree heights, and diameters at five years age (Table 3-3).

Table 3-3. The estimated average biomass carbon accumulation after five years of growth for fruit and nut orchards in Arizona (t C/ha)

Location	Average biomass carbon accumulation
Fruit orchards	1.6
Nut orchards	0.4

In addition, it can be expected that fruit orchards and nut orchards will continue to accumulate biomass for many years. The research team therefore applied an average biomass accumulation to areas of orchards that remained constant over the ten years of the analysis. The rate of biomass accumulation was determined by estimating the stocks at years 40 and 60 and dividing the difference by 20 to get an annual accumulation. The annual accumulation was multiplied by 10 to give an accumulation for the ten years 1987 to 1997 (Table 3-4).

Table 3-4. The estimated average biomass carbon accumulation over 10 years of growth for fruit and nut orchards in Arizona (t C/ha). This growth rate is for existing orchards; that is, for areas unaffected by land-use change.

Location	Average biomass carbon accumulation
Fruit orchards	3.4
Nut orchards	2.1

3.1.5. Uncertainty

Uncertainty in NRI Data

The estimated margin of error (95% confidence interval) for the area of cultivated cropland in 1997 is 12.6% for Arizona (NRCS 2000). For areas presented at finer scales (that is, at the county level or for a specific crop) or for changes in area, the margin of error will be significantly higher.

Uncertainty in Carbon Stock Data

To evaluate the confidence in the estimated carbon stocks, ranges were determined (Table 3-5) based on the ranges in diameter, height, biomass, and planting density provided by the data sources consulted, as described in Section 3.1.4.

Table 3-5. Estimated ranges in average carbon stock for each crop type in Arizona (t C/ha)

Crop type	Range in C stocks (t C/ha)
Fruit orchards	12.9–26.1
Nut orchards	4.4–23.5
Vineyards	2.4–6.7
Bush fruits	–
Berry fruits	–
Other horticulture	3.4–5.7
Non-woody crops	1.0–2.0

Weighting the deviations from the mean by area and carbon stock gave a mean deviation value for carbon stocks of 42%.

3.2. Results

3.2.1. Statewide Land Use and Land Use Change 1987–1997

The total area of Arizona is 29.53 million ha, of which 57% is covered by the NRI and the remainder is federal land falling outside the scope of the NRI.

In 1997 agricultural land in Arizona, including both perennial woody and annual non-woody lands, was estimated at 438,289 ha, or 1.5% of the land area of the state (Figure 3-1). The area of woody cropland was 6.9% of the total area under agricultural cultivation.

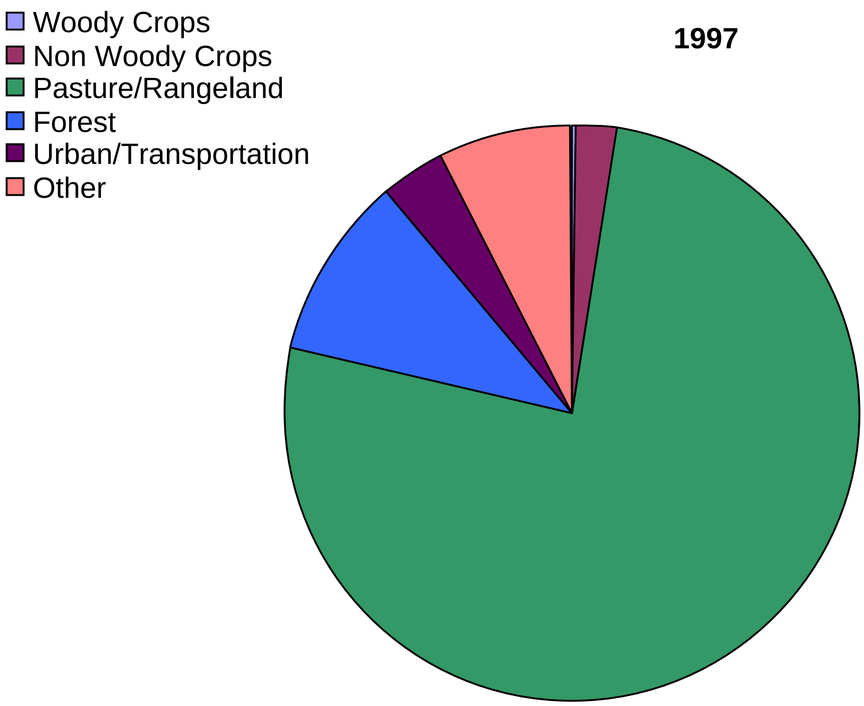

Figure 3-1. Proportional area for land uses in Arizona in 1997, based on NRI data (non-federal lands only)

Table 3-6. Areas (ha) and changes in areas (ha) for lands in Arizona from the NRI dataset

	1987	1997	Change	% Change
Woody crops				
Fruit orchards	16,229	17,766	1,537	+9.5
Nut orchards	8,660	7,648	-1,012	-11.7
Vineyards	4,492	4,654	162	+3.6
Bush crops	-	-	-	-
Berry crops	-	-	-	-
Other horticulture	-	-	-	-
Total woody crops	29,381	30,068	687	+2.3
Non-woody crops				
Row/Close crops	439,667	408,221	-31,446	-7.2
Other land uses				
Pasture/Rangeland	12,991,477	12,906,045	-85,432	-0.7
Forest	1,772,262	1,703,585	-68,677	-3.9
Urban/Transportation	514,536	603,570	89,034	+17.3
Other	1,198,357	1,294,190	95,833	+8.0
TOTAL	16,945,680	16,945,680		

Overall, agricultural land in Arizona experienced a 6.6% (30,759 ha) loss in area during the 10-year period from 1987–1997. However, this loss included a 7.2% loss in area of non-woody crops and a 2.3% increase in area of woody crops (Table 3-6 and Figure 3-2). In the same time period there were small decreases in the area of pasture/rangeland (0.7%) and non-federal forest (3.9%), and increases in the area of urban/transportation (17.3%) and the Other category (8.0%).

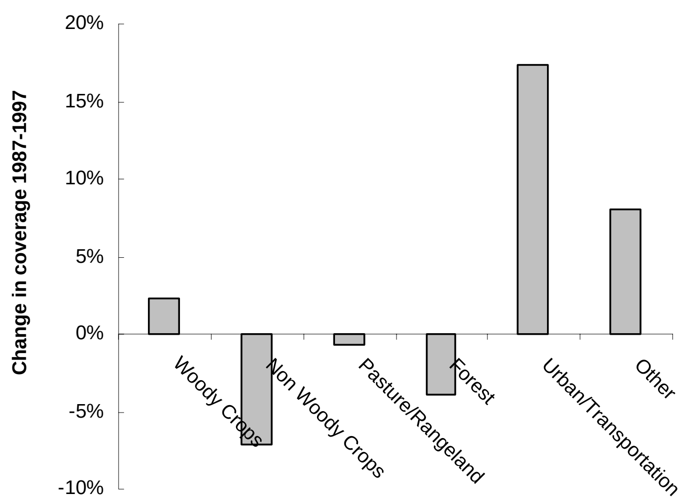

Figure 3-2. Proportional change in area between 1987 and 1997 for broad land uses in Arizona

3.2.2. Changes in Specific Land-Use Type

As shown in Figure 3-3, agricultural land in Arizona is dominated by non-woody crop types (93%). Among the woody crops, fruit orchards make up 59%, nut orchards 25%, and vineyards 15%.

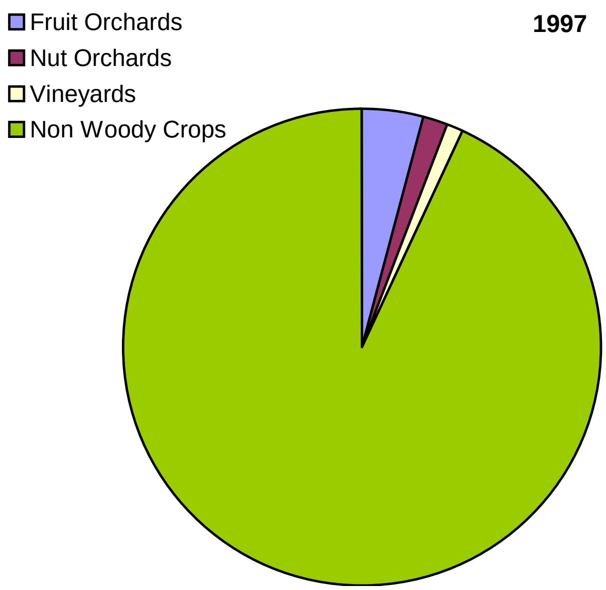

Figure 3-3. Proportional coverage of each agricultural land-use in Arizona in 1997

The 2.3% increase in area of woody crops between 1987 and 1997 was composed of a 9.5% increase in fruit orchards (1,537 ha) and a 3.6% increase in vineyards (162 ha), balanced by a 11.7% decrease in nut orchards (1,012 ha) (Table 3-6 and Figure 3-4).

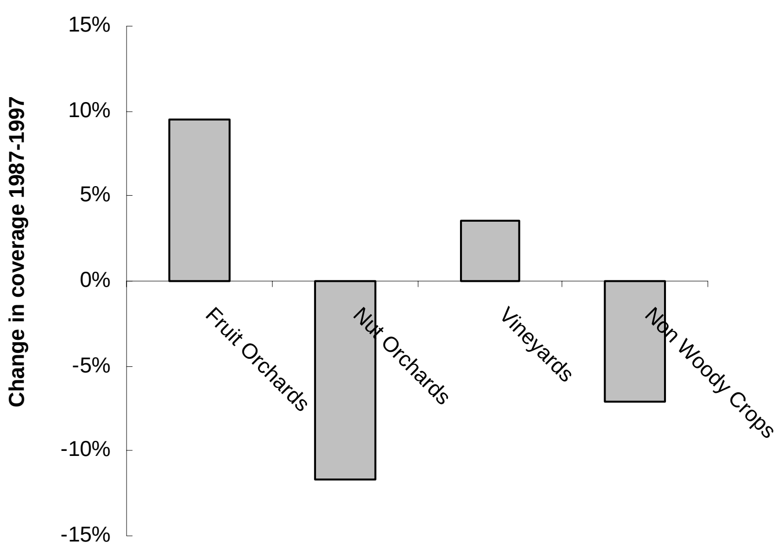

Figure 3-4. Proportional change in area between 1987 and 1997 for agricultural land uses in Arizona

There was a net loss in area in each of the land uses to development—the Urban/Transportation NRI land class (Table 3-7). The greatest loss was from pasture/rangeland to development (65,805 ha), although this was balanced by a loss in forest to pasture/rangeland (44,112 ha). The loss in forest to pasture runs contrary to the sentiment among ranchers that mesquite and juniper are encroaching on grasslands (pers. comm. Melanie Lenart, University of Arizona). However, it should be remembered that NRI classifies oak and juniper woodlands (and any areas with less than 10% crown cover) as rangeland.

The decrease in area of nut orchards resulted in an increase in non-woody crops (202 ha), forest (283 ha), and development (526 ha). Non-woody crops gained area from fruit orchards (81 ha), nut orchards (202 ha), and rangeland (3602 ha) but lost area to development (14,488 ha) and the Other category (20,842 ha).

3.2.3. County-Level Estimate of Agricultural Land Area

The NRI data is not designed for use at the county level; results are given here for illustrative purposes. Woody cropland is concentrated in the south of the state, but even in this region it is never a dominant component of the landscape (< 0.5% by area) (Figure 3-5a). Non-woody crops are also concentrated to the south but are more dominant than woody crops, occupying up to almost 9% of some counties (Figure 3-5b). The counties with the greatest coverage of non-woody crops include Maricopa and Pinal, with 115,900 ha and 124,200 ha, respectively, in 1997 (Table 3-8).

Only six counties recorded net changes in area of woody crops (Figure 3-6a). Losses in area occurred in Cochise, Graham, Yuma, and Pima and gains occurred in Maricopa and Pinal. Losses in area of non-woody crops were recorded in all but two counties: Mohave and Pinal (Figure 3-6b and Table 3-8).

3.2.4. Carbon Stocks of Agricultural Land During 1987–1997

The total estimated carbon stock in the vegetation of all Arizona agricultural crops is approximately 1 million tons. In the ten-year period between 1987 and 1997, the carbon stock decreased by 98,900 tons, caused by the conversion of agricultural land to alternative uses. Of this total, just over 47,000 tons were lost from non-woody crops and 51,700 tons were lost from woody crops (Table 2-4). This represents a loss of 7.2% of the carbon in non-woody crops and of 13.1% in carbon in woody crops, for a total loss from agriculture in Arizona proportional to 9.4% of the carbon stored in 1987. The main source of the loss was from fruit orchards (a loss of 57,500 t C), which far exceeded small gains in carbon stored in nut orchards and vineyards (Table 3-9 and Figure 3-7).

Table 3-7. Land-use change transition matrix, showing the source and direction of changes in Arizona 1987–1997. A negative sign indicates a net loss of area from the land use in the row to the land use in the column.

Land-Use Type	Unchanged	Fruit Orchards	Nut Orchards	Vineyards	Non-Woody Crops	Rangeland	Forest	Urban / Transportation	Other	TOTAL CHANGE
Fruit Orchards	10,198				-81	6,435		-3,238	-1,578	1,538
Nut Orchards	7,649				-202		-283	-526		-1,011
Vineyards	4,492								162	162
Non-Woody Crops	381,834	81	202			3,602		-14,488	-20,842	-31,445
Rangeland	12,768,771	-6,435			-3,602		44,112	-65,805	-53,704	-85,434
Forest	1,644,498					-44,112		-1,416	-23,149	-68,677

Table 3-8. The county level coverage (ha) for specific agricultural land uses and the change in coverage in Arizona, 1987 to 1997

County	High-carbon Crops						Low-carbon Crops		TOTALS	
	Fruit Orchards		Nut Orchards		Vineyards		Non-Woody crops			
	1987	1997	1987	1997	1987	1997	1987	1997	1987	1997
Apache							2,469	2,266	2,469	2,266
Cochise	1,052	1,012	445	445			47,876	40,227	49,373	41,684
Coconino							283	243	283	243
Gila							1,214	243	1,214	243
Graham	486	243					18,454	16,350	18,940	16,593
Greenlee							1,497	931	1,497	931
La Paz							28,693	23,756	28,693	23,756
Maricopa	7,285	10,805			728	728	121,653	115,866	129,666	127,399
Mohave							971	1,174	971	1,174
Navajo							1,255	364	1,255	364
Pima			5,787	4,775			12,101	11,251	17,888	16,026
Pinal	2,307	2,307	1,052	1,052	3,764	3,926	123,353	124,162	130,476	131,447
Santa Cruz							1,821	809	1,821	809
Yavapai							2,550	2,104	2,550	2,104
Yuma	5,099	3,399	1,376	1,376			75,477	68,475	81,952	73,250
TOTAL	16,229	17,766	8,660	7,648	4,492	4,654	439,667	408,221	469,048	438,289

Table 3-9. Carbon stocks (t C) and changes in carbon stocks (t C) for land-use types in Arizona

	1987	1997	Change
Woody crops			
Fruit orchards	280,753	223,216	-57,537
Nut orchards	93,534	98,670	5,136
Vineyards	19,316	20,012	697
Bush crops	-	-	-
Berry crops	-	-	-
Other horticulture	-	-	-
Total woody crops	393,603	341,898	-51,705
Non-woody crops			
Row / Close crops	659,501	612,332	-47,169
TOTAL	1,053,104	954,230	-98,874

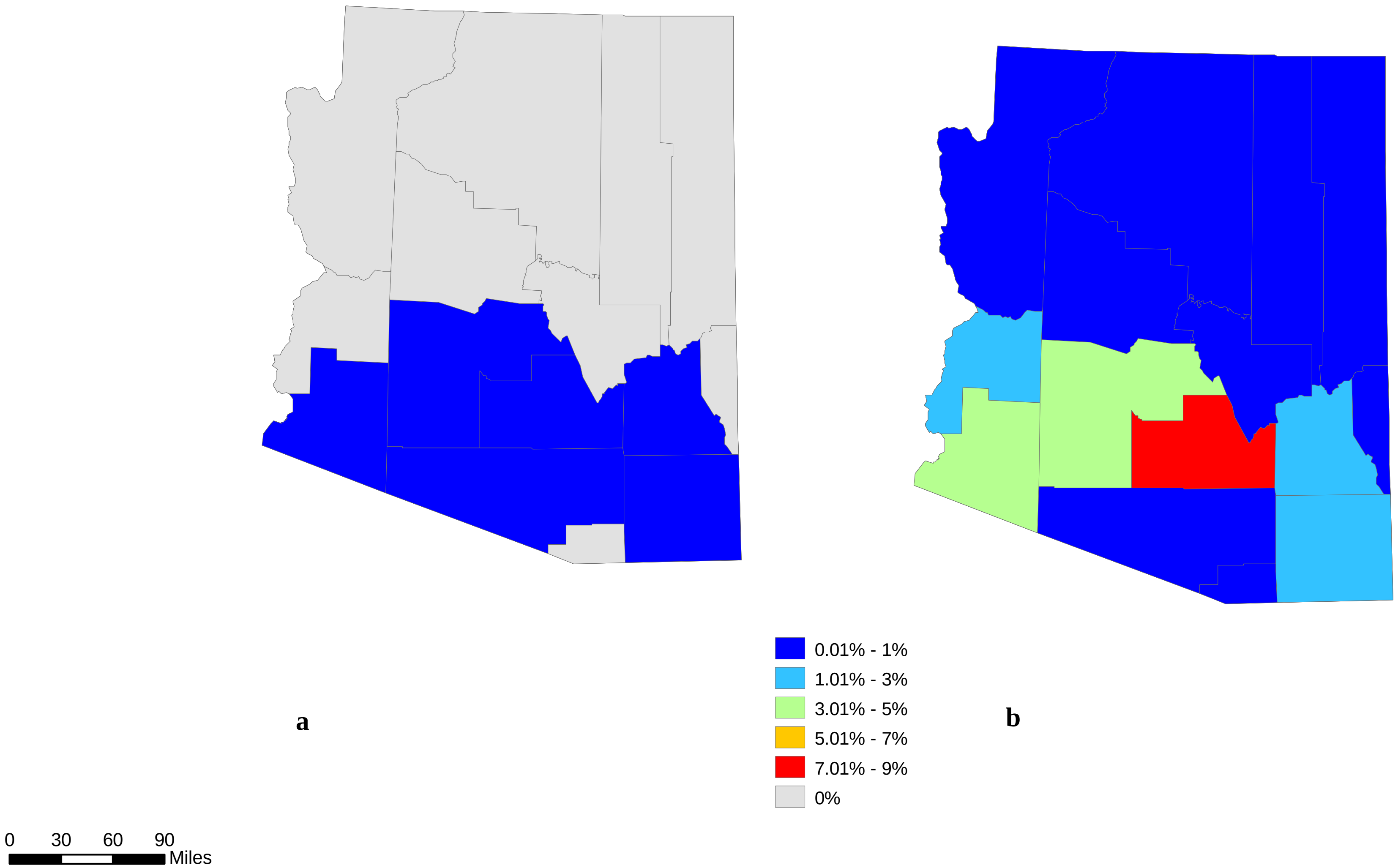

Figure 3-5. Land use by county in Arizona, 1997, showing distribution of (a) woody and (b) non-woody cropland. Values indicate the percentage of total land area in each county occupied by each class of agricultural land

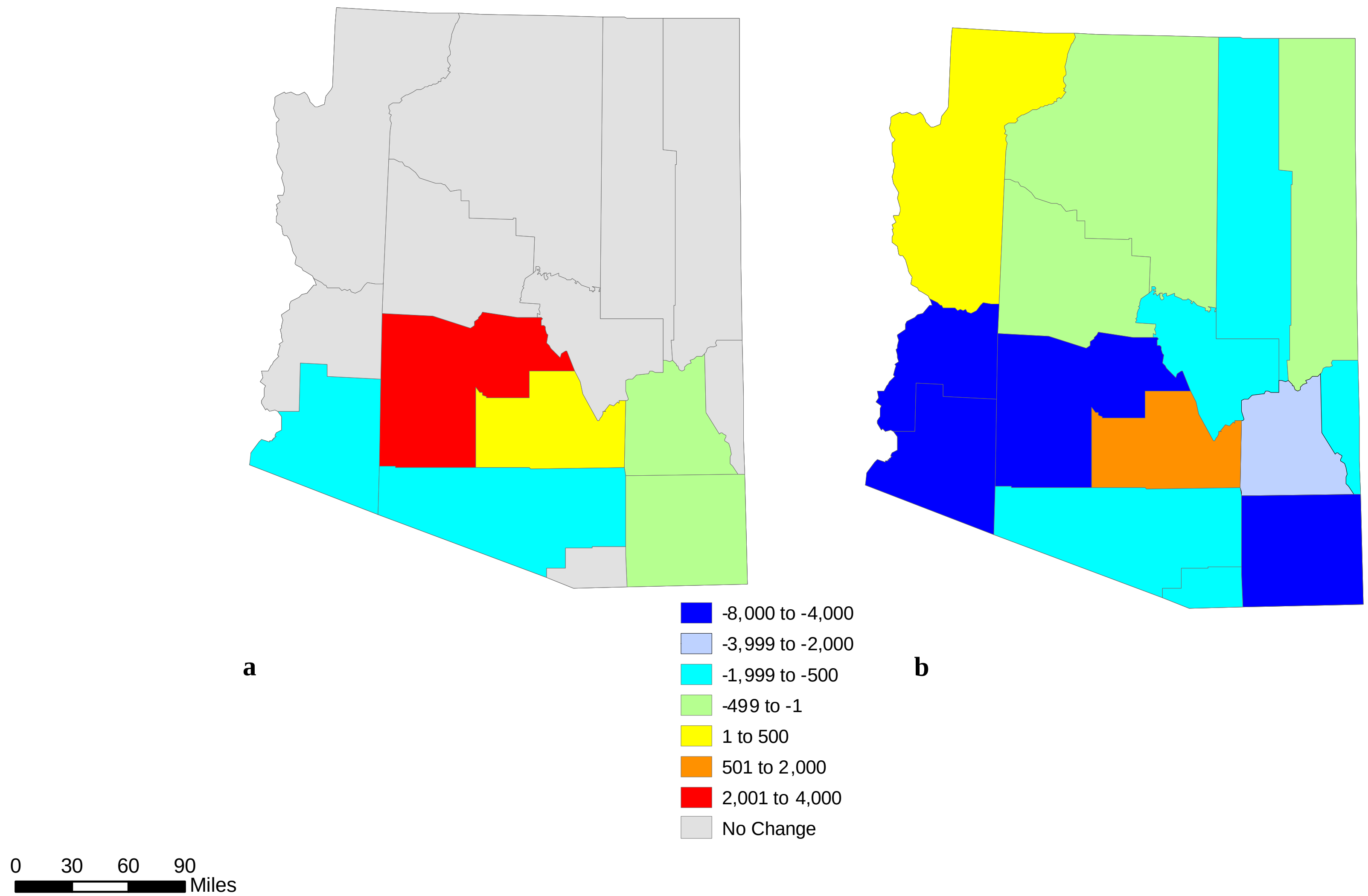

Figure 3-6. Land use change by county in Arizona, 1987 to 1997, showing distribution of change in area in (a) woody and (b) non-woody cropland. Values indicate change in hectares; a minus sign indicates a loss in area from 1987 to 1997; a plus sign indicates a gain in area in the same period.

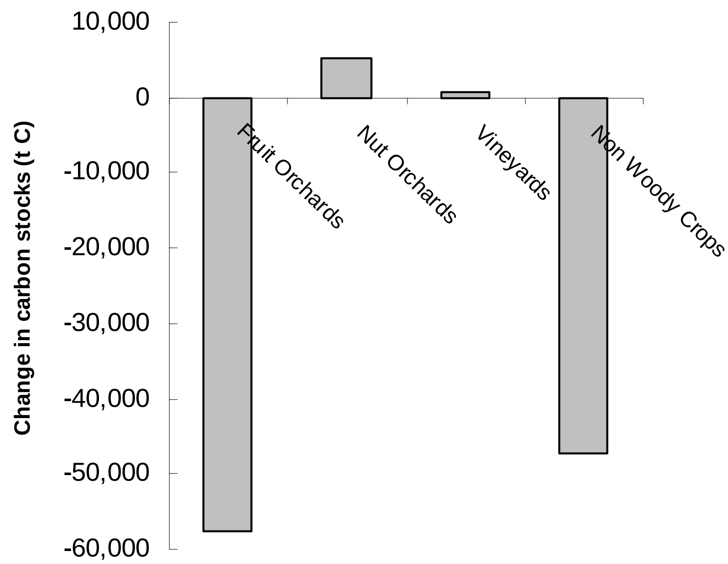

Figure 3-7. Changes in carbon stock (t C) across crop types in Arizona between 1987 and 1997

Large losses in carbon resulted from conversion of cropland to development (83,400 t C) and other land changes (60,900 t C). No changes were recorded from cropland to forestland or vice versa. Gains in carbon in cropland between 1987 and 1997 resulted from the conversion of rangeland to fruit orchards and non-woody crops (11,900 t C). Of the gross gains in carbon in fruit orchards, 74% was from growth of existing orchards and 26% was from growth in new plantings. There was no expansion in the area of nut orchards and consequently 100% of the gains in carbon were from growth in existing orchards (Table 3-9).

When converted to CO_2 equivalents, the total stocks in 1997 on agricultural land in Arizona are estimated at 3.5 $MMtCO_2eq$ (Table 3-10). There was a net loss of 0.4 $MMtCO_2eq$ between 1987 and 1997. This is equal to an annual source of 0.04 $MMtCO_2eq$. Thirty-six percent of the stocks are estimated to be in woody vegetation. Both woody and non-woody vegetation represented an annual source of 0.02 $MMtCO_2eq$.

Table 3-10. Carbon stocks on agricultural land and their change (million tons of CO_2 equivalent, $MMTCO_2e$)

Date	Agricultural Land	Woody	Non-woody
1987	3.9	1.4	2.4
1997	3.5	1.3	2.2
1987–1997	-0.4	-0.2	-0.2

Table 3-11. The land use origins and destinations of changes in carbon stocks in agriculture in Arizona between 1987 and 1997. A negative sign indicates a net loss of carbon stocks from the land use in the row to the land use in the column

Land-Use Type	Growth of existing stands	Fruit Orchards	Nut Orchards	Vineyards	Non-Woody Crops	Rangeland	Forest	Urban / Transportation	Other	TOTAL CHANGE
Fruit Orchards	34,675				-15,379	6,483		-56,010	-27,305	-57,536
Nut Orchards	16,063				-2,185			-5,682	-3,060	5,136
Vineyards									697	697
Non-Woody Crops		122	303			5,403		-21,732	-31,263	-47,168

3.2.5. Carbon Stocks of Agricultural Land by County

The losses of carbon stocks from non-woody crops were spread through all but two counties in the state (Mohave and Pinal counties). In contrast, the net losses from woody crops were limited to four counties (Graham, Maricopa, Pima, and Yuma), with the losses of 29,900 and 34,900 tons of carbon from fruit orchards coming from single counties (Maricopa and Yuma, respectively) (Table 3-12 and Figure 3-8).

Table 3-12. Change in carbon stocks (t C) between 1987 and 1997 by crop types for counties in Arizona

County	Woody Crops			Non-woody Crops	
	Fruit Orchards	Nut Orchards	Vineyards	Row / Close crops	TOTAL
Apache	0	0	0	-305	-305
Cochise	2,740	935	0	-11,474	-7,799
Coconino	0	0	0	-60	-60
Gila	0	0	0	-1,457	-1,457
Graham	-3,376	0	0	-3,156	-6,532
Greenlee	0	0	0	-849	-849
La Paz	0	0	0	-7,406	-7,406
Maricopa	-29,892	0	0	-8,681	-38,573
Mohave	0	0	0	305	305
Navajo	0	0	0	-1,337	-1,337
Pima	0	-899	0	-1,275	-2,174
Pinal	7,844	2,210	697	1,214	11,965
Santa Cruz	0	0	0	-1,518	-1,518
Yavapai	0	0	0	-669	-669
Yuma	-34,853	2,889	0	-10,503	-42,467
TOTAL	-57,537	5,135	697	-47,171	-98,876

3.3. Non-CO_2 Greenhouse Gas Emissions

The primary non-CO_2 greenhouse gas emitted from croplands is nitrous oxide (N_2O), with approximately 296 times the global warming potential of CO_2. Nitrous oxide is emitted from agricultural soils especially after fertilizer application. A second important non-CO_2 gas is methane (CH_4), with approximately 23 times the global warming potential of CO_2. Methane is emitted during manure management and through livestock enteric fermentation.

The Arizona Climate Change Advisory Group (Bailie and Lazarus 2005) report an annual emission from agricultural sources (manure management, fertilizer use, and livestock [enteric fermentation]) of 4.2 $MMTCO_2e$ for the year 2000. This is more than 100 times the total estimated here for CO_2 emissions attributable to agricultural land conversion (0.036 $MMTCO_2e$/yr). The CO_2 equivalents from nitrous oxide and methane thus make up more than 99% of the total summed annual sources estimated for Arizona's agricultural sector.

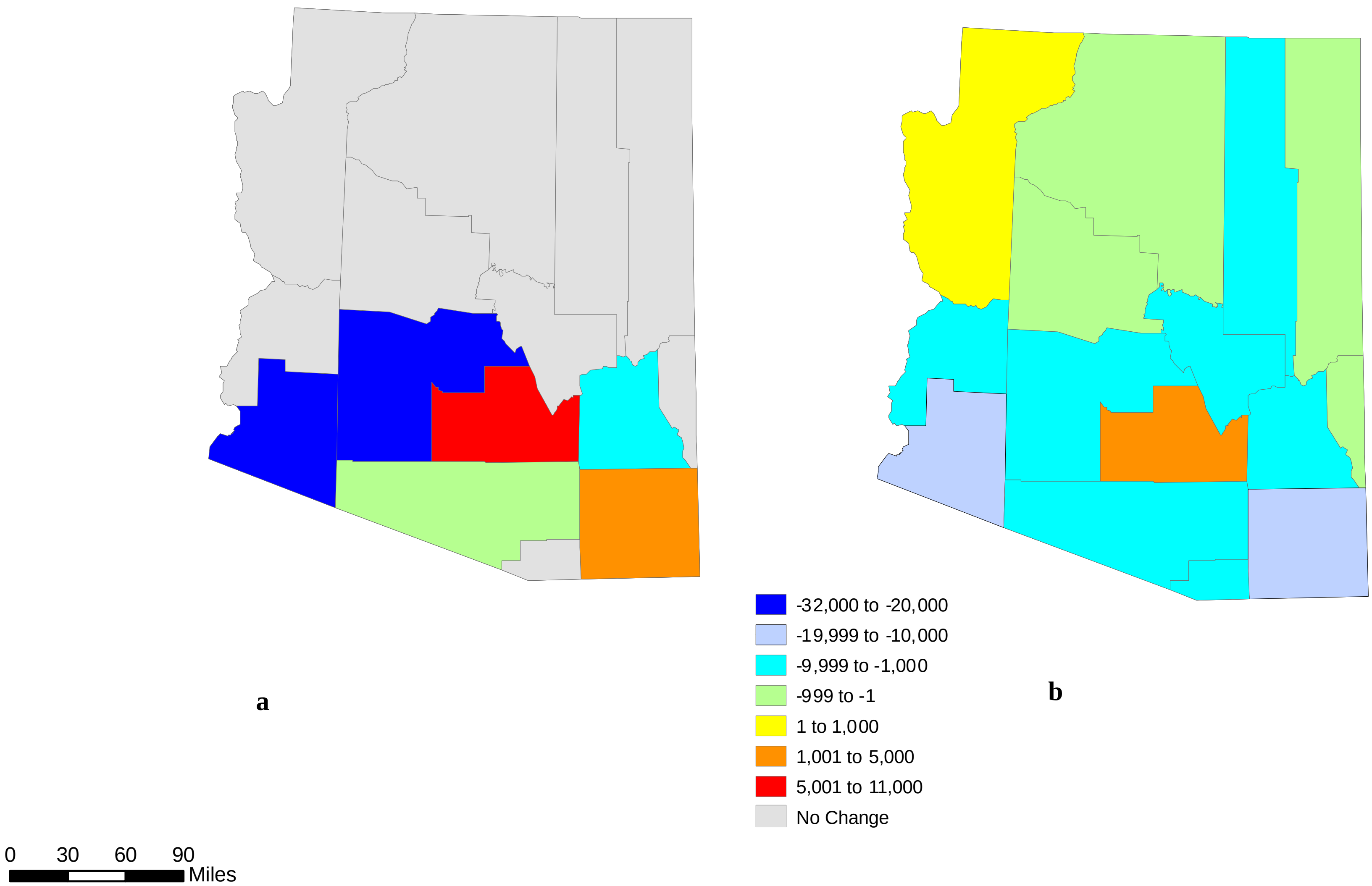

Figure 3-8. county-scale change in carbon stocks, 1987 to 1997, in (a) high-carbon crops (orchards and vineyards, and in (b) low-carbon crops (non-woody crops in Arizona. Values in tons of carbon

3.4. Chapter 3 Conclusions

Agricultural land in Arizona in 1997 represented 1.5% of the total land area, and non-woody crops were 93% of all agricultural land. Both woody and non-woody cropland are concentrated in the southern counties, with non-woody cropland totaling up to 9% of the total land area but woody cropland making up less than 0.5% of the land area in these counties. Statewide, there was a loss of agricultural land of 6.6% between 1987 and 1997, including a 7.2% decrease in non-woody cropland and a 2.3% increase in woody cropland. All land uses lost area over the period through conversion to urban development/transportation.

Total carbon stocks in all agricultural land types in Arizona were estimated at 1 million tons. Between 1987 and 1997, there was a total loss of about 99,000 tons of carbon, or 9.4% of the carbon stored in agricultural lands in 1987 (7.2% loss of the carbon stocks in non-woody crops and 13.1% of the carbon stocks in woody crops). The greatest losses came from conversion of fruit orchards and non-woody crops to urban development, and the greatest gains from conversion of rangeland to fruit orchards and non-woody crops. In CO_2 equivalent terms, total agricultural carbon stocks in Arizona in 1997 were 3.5 $MMTCO_2eq$, and the net loss 1987–1997 disregarding non-CO_2 greenhouse gas emissions was 0.4 $MMTCO_2eq$—equivalent to an annual source of 0.04 $MMTCO_2eq$. At the county level of analysis, all but two counties lost carbon through conversion of non-woody cropland to other land uses, but only five lost carbon through conversion of woody cropland. The greatest losses were in Maricopa and Yuma counties.

Non-CO_2 greenhouse gas emissions from N_2O (emitted from agricultural soils after fertilizer application) and CH_4 (from livestock and manure management) dwarf the annual CO_2 source from agricultural land conversion in Arizona.

Table 3-13 summarizes changes in agricultural land area and carbon stocks for Arizona between 1987 and 1997.

Table 3-13. Summary of agricultural land area and changes in area, carbon stocks, and changes in stocks, for Arizona 1987–1997

Parameter	Units	Arizona
Proportion of agricultural land to total land	%	1.5
Change in agricultural land area, 1987–1997	Hectares (%)	-30,759 (6.6%)
Change in woody cropland area		+687 (2.3%)
Change in non-woody cropland area		-31,446 (7.2%)
Total carbon stocks in agricultural land, 1997	$MMTCO_2e$	3.5
Change in carbon stocks in agricultural land	$MMTCO_2e$	-0.4
Estimated net annual source (emissions) from agricultural lands, disregarding non-CO_2 greenhouse gas emissions	$MMTCO_2e$	-0.04
From woody cropland		-0.02
From non-woody cropland		-0.02
Estimated net annual source from non-CO_2 greenhouse gas emissions, 2000	$MMTCO_2e$	4.2

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5.0 Glossary

AVHRR	Advanced Very High Resolution Radiometer
CH_4	methane
CO_2	carbon dioxide
CRP	Conservation Reserve Program
DBH	diameter at breast height
FIA	U.S. Forest Service Forest Inventory and Analysis
FIADB	forest inventory and analysis database
GHG	greenhouse gas
GIS	geographic information system
GPS	global positioning system
km	kilometer
$MMTCO_2e$	million metric tons CO_2 equivalent
N_2O	nitrous oxide
NASS	National Agriculture Statistics Service
NDVI	normalized differential vegetation index
NOAA	National Oceanic and Atmospheric Administration
NRCS	U. S. Department of Agriculture - National Resources Conservation Service
NRI	National Resource Inventory
OSU	Oregon State University
t CO_2e	tons of CO_2 equivalent
µm	micrometer
USDA	United States Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WESTCARB	West Coast Regional Carbon Sequestration Partnership