

# **DRAFT Michigan Greenhouse Gas Inventory and Reference Case Projections 1990-2020**

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## Appendix A. Agriculture

### Overview

The emissions discussed in this appendix refer to non-energy methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also covered. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates (see Appendix B).

There are two livestock sources of greenhouse gas (GHG) emissions: enteric fermentation and manure management. Methane emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH<sub>4</sub> as a by-product. More CH<sub>4</sub> is produced in ruminant livestock because of digestive activity in the large fore-stomach. Methane and N<sub>2</sub>O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH<sub>4</sub> is produced because decomposition is aided by CH<sub>4</sub> producing bacteria that thrive in oxygen-limited conditions. Under aerobic conditions, N<sub>2</sub>O emissions are dominant. Emissions estimates from manure management are based on manure that is stored and treated on livestock operations. Emissions from manure that is applied to agricultural soils as an amendment or deposited directly to pasture and grazing land by grazing animals are accounted for in the agricultural soils emissions.

The management of agricultural soils can result in N<sub>2</sub>O emissions and net fluxes of carbon dioxide (CO<sub>2</sub>) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N<sub>2</sub>O emissions. Nitrogen additions drive underlying soil nitrification and denitrification cycles, which produce N<sub>2</sub>O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N<sub>2</sub>O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation. Both direct and indirect emissions of N<sub>2</sub>O occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application and indirect emissions occur when nitrogen leaches to groundwater or in surface runoff and is transported off-site before entering the nitrification/denitrification cycle. Methane and N<sub>2</sub>O emissions also result when crop residues are burned. Methane emissions occur during rice cultivation; however, rice is not grown in Michigan.

The net flux of CO<sub>2</sub> in agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO<sub>2</sub> into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere. Finally,

the practice of adding limestone and dolomite to agricultural soils (for neutralizing acidic soil conditions) results in CO<sub>2</sub> emissions.

## Emissions and Reference Case Projections

### *Methane and Nitrous Oxide*

GHG emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.<sup>1</sup> In general, the SIT methodology applies emission factors developed for the US to activity data for the agriculture sector. Activity data include livestock population statistics, crop production statistics, amounts of fertilizer applied to crops, and trends in manure management practices. The amount of manure methane captured through anaerobic digestion was assumed to follow current trends. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.<sup>2</sup>

Data on crop production in Michigan from 1990 to 2005 and the number of animals in the state from 1990 to 2005 were obtained from the United States Department of Agriculture (USDA) National Agriculture Statistical Service (NASS) and incorporated as defaults in SIT.<sup>3</sup> The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses). The estimates are reported in the agriculture sector but they represent emissions occurring on other land uses.

Crop production data from USDA NASS were available through 2005; therefore, N<sub>2</sub>O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and N<sub>2</sub>O and CH<sub>4</sub> emissions from agricultural residue burning were calculated through 2005. Emissions for the other agricultural crop production categories (i.e., synthetic and organic fertilizers) were also calculated through 2005. Data were not available to estimate nitrogen released by the cultivation of histosols (i.e., the number of acres of high organic content soils). Given that cultivation of organic soils is a source of CO<sub>2</sub> emissions in Michigan (see below), N<sub>2</sub>O emissions are also probably occurring.

There is some agricultural residue burning conducted in Michigan; however, emissions are estimated to be relatively small (<0.03 MMtCO<sub>2</sub>e). The default SIT method was used to calculate emissions. The SIT methodology calculates emissions by multiplying the amount (e.g., bushels

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<sup>1</sup> GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8. "Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004; Chapter 10. "Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004; and Chapter 11. "Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004.

<sup>2</sup> Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, published by the National Greenhouse Gas Inventory Program of the IPCC, available at (<http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>; and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (<http://www.ipcc-nggip.iges.or.jp/public/gp/english/>).

<sup>3</sup> USDA, NASS ([http://www.nass.usda.gov/Statistics\\_by\\_State/Michigan/index.asp](http://www.nass.usda.gov/Statistics_by_State/Michigan/index.asp)).

or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced and burned, the resultant dry matter, and the carbon/nitrogen content of the dry matter.

Emissions from enteric fermentation and manure management were projected based on forecasted animal populations. Dairy cattle forecasts were based on state-level projections of dairy cows from the Food and Agricultural Policy Research Institute (FAPRI).<sup>4</sup> Projections for all other livestock categories, except broilers and turkey, were estimated based on linear forecasts of the historical 1990-2005 populations. Both broiler and turkey population increased exponentially during the 1990-2000 period and leveled off in recent years. Therefore, the broilers and turkey populations were projected based on the more recent 2000-2005 historical data. Livestock population growth rates are shown in Table F1.

**Table F1. Growth Rates Applied for the Enteric Fermentation And Manure Management Categories**

Livestock Category	2005-2020 Annual Growth
Dairy Cattle	0.19%
Beef Cattle	-1.86%
Swine	-4.45%
Sheep	-7.22%
Goats	-1.88%
Horses	0.63%
Turkeys	4.29%
Layers	1.55%

Projections for agricultural burning and agricultural soils were based on linear extrapolation of the 1990-2005 historical data. Table F2 shows the 2005-2020 annual growth rates estimated for each category.

#### *Soil Carbon*

Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University and are reported in the US Inventory of Greenhouse Gas Emissions and Sinks<sup>5</sup> and the US Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the Intergovernmental Panel on Climate Change (IPCC) methodology for soil carbon adapted to conditions in the US. Preliminary state-level estimates of CO<sub>2</sub> fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the US Agriculture and Forestry Greenhouse Gas Inventory. The inventory also reports national estimates of CO<sub>2</sub> emissions from limestone and dolomite applications from the United

<sup>4</sup> FAPRI Agricultural Outlook 2006, Food and Agricultural Policy Research Institute, <http://www.fapri.iastate.edu/outlook2006>.

<sup>5</sup> US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # 430-R-07-002, April 2007. Available at: <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>.

States Geological Survey (USGS).<sup>6</sup> Currently, these are the best available data at the state-level for this category.

**Table F2. Growth Rates Applied for the Agricultural Soils and Burning**

<b>Agricultural Category</b>	<b>2005-2020 Growth Rate</b>
Agricultural Burning	0.97%
Liming of Agricultural Soils	-1.48%
<b>Agricultural Soils – Direct Emissions</b>	
Fertilizers	-1.43%
Crop Residues	-0.01%
Nitrogen-Fixing Crops	-1%
Histosols	0%
Livestock	-3.20%
<b>Agricultural Soils – Indirect Emissions</b>	
Fertilizers	-1.64%
Livestock	-3.96%
Leaching/Runoff	-2.14%

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Michigan, Table F3 shows a summary of the latest estimates available from the USDA, which are for 1997.<sup>7</sup> These data show that changes in agricultural practices are estimated to result in net emission of 2.14 million metric tons (MMt) of CO<sub>2</sub> equivalent (CO<sub>2</sub>e) per year in Michigan; this is driven largely by the cultivation of organic soils and the plowout of grassland to annual cropland in Michigan. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of 2.14 MMtCO<sub>2</sub>e per year are assumed to remain constant.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in the National Inventory of Greenhouse Gas Emissions and the SIT.

<sup>6</sup> State-level annual application rates of limestone and dolomite to agricultural purposes were provided from the Minerals Yearbook “Crushed Stone” from the USGS website:  
[http://minerals.er.usgs.gov/minerals/pubs/commodity/stone\\_crushed/](http://minerals.er.usgs.gov/minerals/pubs/commodity/stone_crushed/).

<sup>7</sup> US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907, 164 pp. March 2004.  
[http://www.usda.gov/oce/global\\_change/gg\\_inventory.htm](http://www.usda.gov/oce/global_change/gg_inventory.htm); the data are in appendix B table B-11. The table contains two separate IPCC categories: “carbon stock fluxes in mineral soils” and “cultivation of organic soils.” The latter is shown in the second to last column of Table F3. The sum of the first nine columns is equivalent to the mineral soils category.

**Table F3. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices (MMtCO<sub>2</sub>e)**

Changes in cropland			Changes in Hayland				Other			Total <sup>4</sup>
Plowout of grassland to annual cropland <sup>1</sup>	Cropland management	Other cropland <sup>2</sup>	Cropland converted to hayland <sup>3</sup>	Hayland management	Cropland converted to grazing land <sup>3</sup>	Grazing land management	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
2.09	(0.07)	(0.07)	(1.72)	(0.07)	(0.51)	(0.00)	(0.15)	(0.46)	3.12	2.14

Based on USDA 1997 estimates. Parentheses indicate net sequestration.

<sup>1</sup> Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).

<sup>2</sup> Perennial/horticultural cropland and rice cultivation.

<sup>3</sup> Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.

<sup>4</sup> Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

## Results

Figure F1 and Table F4 show gross GHG emissions associated with the agricultural sector from 1990 through 2020. In 1990, enteric fermentation accounted for about 18.3% (1.53 MMtCO<sub>2</sub>e) of total agricultural emissions. Enteric fermentation emissions decreased slightly to 1.40 MMtCO<sub>2</sub>e between 1990 and 2005 due to the decline in livestock populations in this time period. While the dairy cattle population is projected to remain relatively constant, there is a decrease in the projected beef cattle population, and enteric fermentation emissions are estimated to decrease to 1.31 MMtCO<sub>2</sub>e in 2020.

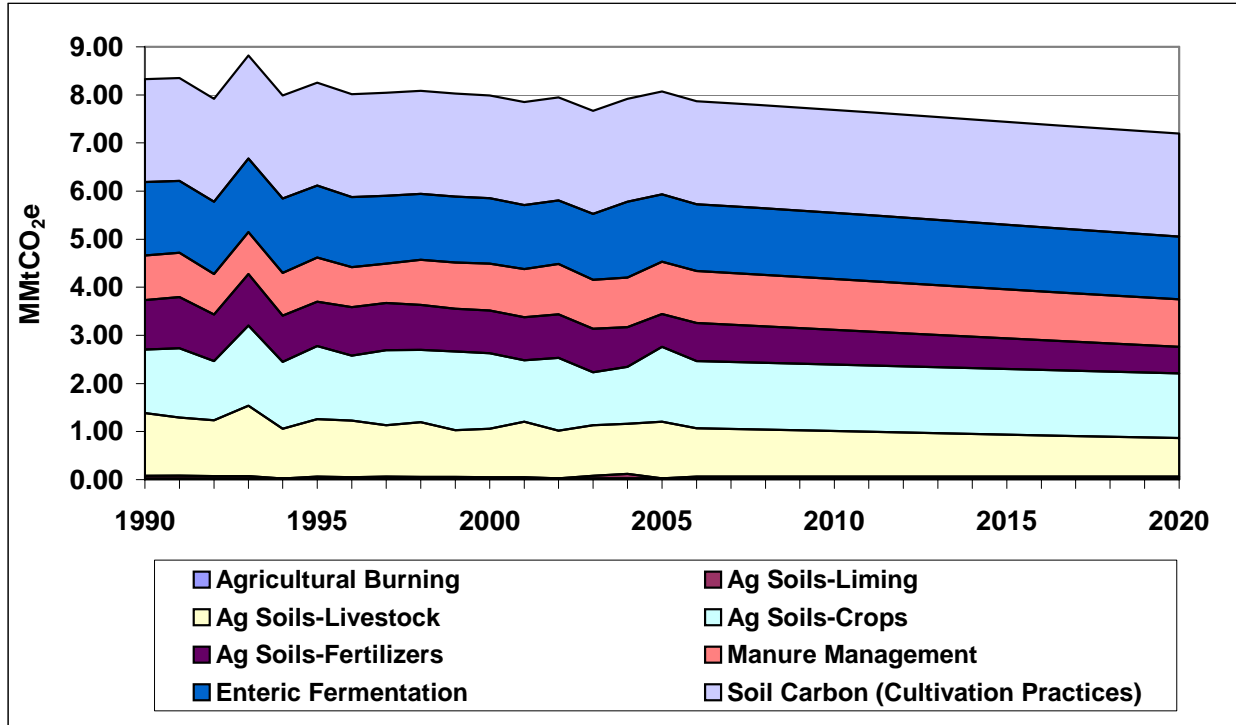
The manure management category accounted for 11.1% (0.92 MMtCO<sub>2</sub>e) of total agricultural emissions in 1990 and increased to 13.5% (1.09 MMtCO<sub>2</sub>e) in 2005. Manure management is projected to remain relatively constant at 13.7% (0.99 MMtCO<sub>2</sub>e) in 2020. This is largely due to the projection that the dairy cow population was to stay relatively unchanged between 2005 and 2020.

The largest source of emissions in the agricultural sector is the agricultural soils category, which includes crops (legumes and crop residues), fertilizer, manure application, application of limestone and dolomite, and indirect sources (leaching, runoff, and atmospheric deposition). Agricultural soils is projected to decrease from 1990 to 2020, with 1990 emissions accounting for 44.6% (3.71 MMtCO<sub>2</sub>e) of total agricultural emissions and 2020 emissions estimated to be about 37.9% (2.73 MMtCO<sub>2</sub>e) of total agricultural emissions.

As noted previously, cultivation of soils is estimated to be a net emissions source in Michigan. The emissions for this category are estimated to account for 25.7% of total agricultural emissions in 1990 and about 29.7% of total emissions in 2020. Since data are not yet available from USDA to determine if emissions are increasing or decreasing, emissions of 2.14 MMtCO<sub>2</sub>e per year are assumed to remain constant throughout the inventory and forecast period.

The only standard IPCC source category missing from this report is N<sub>2</sub>O emissions from the cultivation of histosols; there were no activity data available for Michigan.

**Figure F1. Gross GHG Emissions from Agriculture, 1990-2020**



Source: CCS calculations based on approach described in text.

Notes: Ag Soils – Crops category includes: incorporation of crop residues and nitrogen fixing crops (no cultivation of histosols estimated); emissions for agricultural residue burning are too small to be seen in this chart.

**Table F4. Gross GHG Emissions from Agriculture in Michigan**

Source	1990	1995	2000	2005	2010	2015	2020
Enteric Fermentation	1.53	1.50	1.36	1.40	1.38	1.34	1.31
Manure Management	0.92	0.92	0.97	1.09	1.06	1.02	0.99
Ag Soils-Fertilizers	1.03	0.92	0.89	0.69	0.72	0.64	0.55
Ag Soils-Crops	1.32	1.52	1.57	1.55	1.38	1.36	1.35
Ag Soils-Livestock	1.30	1.19	1.01	1.18	0.95	0.87	0.80
Ag Soils-Liming	0.06	0.04	0.02	0.00	0.03	0.03	0.03
Agricultural Burning	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Soil Carbon (Cultivation Practices)	2.14	2.14	2.14	2.14	2.14	2.14	2.14
<b>TOTAL</b>	<b>8.33</b>	<b>8.25</b>	<b>7.99</b>	<b>8.07</b>	<b>7.69</b>	<b>7.44</b>	<b>7.20</b>

## Key Uncertainties

Emissions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors which are derived from several variables including manure production levels, volatile solids content, and CH<sub>4</sub> formation potential). Each of these factors has some level of uncertainty. Also, animal populations fluctuate throughout the year, and thus using point estimates introduces uncertainty into the average annual estimates of these populations. In addition, there is uncertainty associated with the original population survey methods employed by USDA. The largest contributors to uncertainty in emissions from manure management are the emission factors, which are derived from limited data sets.

As mentioned above, for emissions associated with changes in agricultural soil carbon levels, the only data currently available are for 1997. When newer data are released by the USDA, these should be reviewed to represent current conditions as well as to assess trends. In particular, given the potential for some CRP acreage to retire and possibly return to active cultivation prior to 2020, the emissions could be appreciably affected.

Uncertainties in the estimates of emissions from liming result from both the emission factors and the activity data. It is uncertain what fraction of agricultural lime is dissolved by nitric acid – a process that releases CO<sub>2</sub> – and what portion reacts with carbonic acid (H<sub>2</sub>CO<sub>3</sub>), resulting in the uptake of CO<sub>2</sub>. Also, there is uncertainty in the limestone and dolomite data (reported to USGS) as some producers do not distinguish between them, and report them both as limestone.

Another contributor to the uncertainty in the emission estimates is the forecast assumptions. The growth rates for most categories are assumed to continue growing at historical 1990-2005 growth rates. These historic trends may not reflect future projections.

## Appendix B. Waste Management

### Overview

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management – methane (CH<sub>4</sub>) emissions from municipal and industrial solid waste landfills (LFs), accounting for CH<sub>4</sub> that is flared or captured for energy production (this includes both open and closed landfills);
- Solid waste combustion – CH<sub>4</sub>, carbon dioxide (CO<sub>2</sub>), and nitrous oxide (N<sub>2</sub>O) emissions from the combustion of solid waste in incinerators or waste to energy plants; and
- Wastewater management – CH<sub>4</sub> and N<sub>2</sub>O from municipal wastewater and CH<sub>4</sub> from industrial wastewater (WW) treatment facilities.

### Inventory and Reference Case Projections

#### *Solid Waste Management*

For solid waste management, the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software was used to estimate emissions. Annual disposal volumes for the state for 1996-2005 were obtained from the Michigan Department of Environmental Quality (MDEQ).<sup>8</sup> These reports from MDEQ also included volumes of waste disposed of in Michigan that originated from other states or Canada. Emissions were estimated for only the waste that originated in Michigan. Waste volumes were converted to mass using the conversion factor of 3 tons per cubic yard of waste.<sup>9</sup> The default annual waste disposal data from SIT were used for the years 1990-1995.

Emissions for industrial solid waste landfills were estimated using the SIT default activity data and emission factors. The activity data are based on national data indicating that industrial landfilled waste is emplaced at approximately 7% of the rate of municipal solid waste (MSW) emplacement. It was assumed that this additional industrial waste emplacement occurs beyond that already addressed in the emplacement rates for MSW sites described above.

The amount of CH<sub>4</sub> captured for flaring and use in landfill gas-to-energy (LFGTE) plants was estimated with SIT defaults that are based on data collected from vendors of flaring equipment, a database of landfill gas-to-energy (LFGTE) projects compiled by the EPA, and a database maintained by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases.<sup>10</sup> The amount of landfill gas flared in Michigan may be underestimated if MI flaring and LFGTE controls have been underreported to the EPA and EIA.

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<sup>8</sup> Annual Reports of Solid Waste Landfilled, Michigan Department of Environmental Quality, <http://www.michigan.gov/deq/0,1607,7-135-3312-47581--,00.html>.

<sup>9</sup> Michigan Department of Environmental Quality, Waste and Hazardous Materials Division, "Combined Solid Waste Landfill Waste Receipt Report," lists conversion factor for MSW as 3 cubic yards per ton, <http://www.deq.state.mi.us/documents/deq-whm-stsw-SolidWasteLandfillWasteReceiptReportEQP5500.xls>.

<sup>10</sup> See Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005, Chapter 8 Waste, US EPA, Report #430-R-07-002, April 2007 (<http://epa.gov/climatechange/emissions/usinventoryreport.html>).

Growth rates were estimated by using the historic (1996-2005) growth rates of total net emissions from landfills. The annual growth rates are 2.6% for MSW landfills and 3.2% for industrial landfills. The years 1996 through 2005 were used to calculate these growth rates since these are the years for which State-provided data were used to replace the SIT defaults, so the data used to calculate these growth rates are from a consistent non-default source.

#### *Solid Waste Combustion*

SIT defaults were used to estimate emissions from solid waste combustion. An annual growth rate of 4.1% for 2005-2020 was estimated based on the historic (1995-2005) growth rate.

Open burning of MSW at residential or municipal sites can also contribute GHG emissions. If data are available, future inventory work should attempt to capture this source of emissions.

#### *Wastewater Management*

GHG emissions from municipal wastewater treatment were also estimated. For municipal wastewater treatment, emissions are calculated in EPA's SIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N<sub>2</sub>O and CH<sub>4</sub>. The key SIT default values are shown in Table G1 below. Municipal wastewater emissions were projected based on the historic growth rate for 1990-2005 for a growth rate of 0.76% per year.

**Table G1. SIT Key Default Values for Municipal Wastewater Treatment**

<b>Variable</b>	<b>Default Value</b>
BOD	0.09 kilogram (kg) /day-person
Amount of BOD anaerobically treated	16.25%
CH <sub>4</sub> emission factor	0.6 kg/kg BOD
Michigan residents not on septic	75%
Water treatment N <sub>2</sub> O emission factor	4.0 g N <sub>2</sub> O/person-yr
Biosolids emission factor	0.01 kg N <sub>2</sub> O-N/kg sewage-N

Source: US EPA State Greenhouse Gas Inventory Tool (SIT) – Wastewater Module.

For industrial wastewater emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. The SIT default activity data were used to estimate emissions for red meat production; however, default data were not available for the other sectors. Emissions were projected to 2020 based on the 1990-2005 annual growth rate (1.9%).

## **Results**

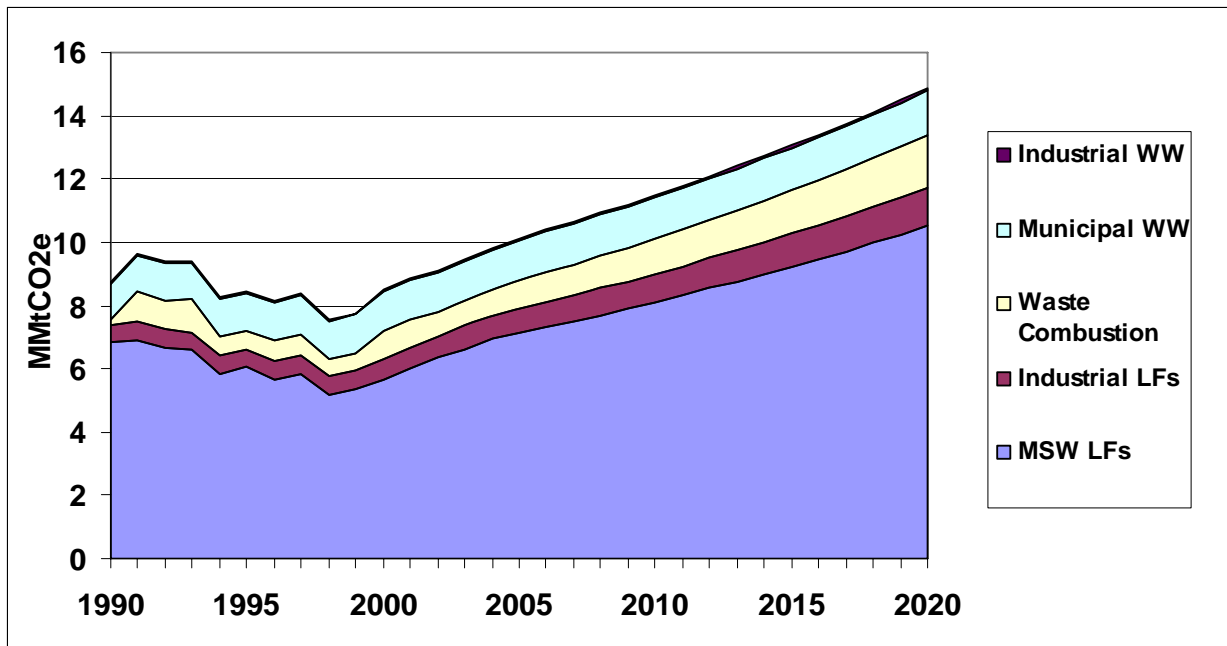
Figure G1 and Table G2 show the emission estimates for the waste management sector. Overall, the sector accounts for 10.1 MMtCO<sub>2</sub>e in 2005, and emissions are estimated to be 14.9 MMtCO<sub>2</sub>e/yr in 2020. The largest contributor to waste management emissions is the solid waste sector, in particular, municipal landfills. In 2005, municipal landfills accounted for 70% of total waste management emissions. By 2020, the contribution from these sites is expected to increase

slightly to about 71%. Industrial landfills accounted for about 8% of waste management emissions in 2005, and also in 2020.

In 2005, about 13% of the waste management sector emissions were contributed by municipal wastewater treatment systems and 0.6% of emissions were contributed by industrial wastewater. Note that these estimates are based on the default parameters listed in Table G1 above, and might not adequately account for emissions, existing controls, or management practices (e.g. anaerobic digesters served by a flare or other combustion device). By 2020, municipal and industrial wastewater treatment sectors are expected to contribute about 10% and 0.5% of the waste management sector emissions.

Emissions from waste combustion accounted for 9% of total waste management emissions in 2005 and are projected to account for 11% in 2020.

**Figure G1. Michigan GHG Emissions from Waste Management, 1990-2020**



Source: Based on approach described in text.

Notes: LF – landfill; WW – wastewater; LFGTE – landfill gas to energy.

**Table G2. Michigan GHG Emissions from Waste Management (MMtCO<sub>2</sub>e)**

Source	1990	1995	2000	2005	2010	2015	2020
MSW Landfills	6.84	6.04	5.63	7.12	8.11	9.23	10.50
Industrial Landfills	0.54	0.57	0.65	0.76	0.89	1.05	1.22
Waste Combustion	0.18	0.61	0.91	0.91	1.11	1.36	1.66
Municipal Wastewater	1.13	1.19	1.25	1.27	1.32	1.37	1.42
Industrial Wastewater	0.04	0.05	0.05	0.06	0.06	0.07	0.08
<b>Total</b>	<b>8.73</b>	<b>8.47</b>	<b>8.50</b>	<b>10.12</b>	<b>11.49</b>	<b>13.07</b>	<b>14.88</b>

## Key Uncertainties

Waste emissions were estimated based on default data, except for MSW annual disposal data for 1996-2005. There is a discontinuity between the default annual MSW disposal in 1995 (8.8 million tons) and the MDEQ annual MSW disposal data for 1996 (12.2 million tons), which suggests that the default data underestimates the MSW disposal. The default data are based on a per capita approach to estimating waste tonnage. In addition, this inventory was calculated using default data in all of the historical years for MSW controls. A more accurate approach would involve allocating the MDEQ landfill emplacement volumes by the portion of waste going to uncontrolled landfills, landfills with flares, and LFGTE facilities, so that control factors could more accurately be applied. The methods also do not adequately account for the points in time when controls were applied at individual sites. The modeling also does not account for uncontrolled landfills that will need to apply controls during the period of analysis due to triggering requirements of the federal New Source Performance Standards/Emission Guidelines.

For industrial landfills, emissions were estimated using national defaults (with industrial landfill wastes buried at 7% of the rate of MSW emplacement). A review of the draft waste inventory emissions by MDEQ waste staff has identified that the data used to represent MSW annual disposal rates for 1996 through 2005 actually include waste landfilled at industrial landfills. In addition, some of this industrial waste includes nondegradable waste, which should not be included in this inventory. As a result, the total landfill emissions presented here overestimate emissions from landfills in Michigan.

For the wastewater sector, the key uncertainties are associated with the application of SIT default values for the parameters listed in Table G1 above (e.g. fraction of the Michigan population on septic; fraction of BOD which is anaerobically decomposed). The SIT defaults were derived from national data.

For industrial wastewater, emissions were only estimated for the red meat industry using default data; default data for fruits and vegetables, poultry, and pulp and paper were not available. Therefore, emissions from industrial wastewater are likely to be underestimated.

This emission inventory for the waste management sector will be revised to address the issues discussed above. In addition, the MCAC and the agriculture, forestry, and waste technical work group will be asked to provide guidance on whether emissions from waste imported into or exported out of Michigan should be included in this inventory, as well as to provide additional data, where available, that can be used to refine this waste management inventory.

## Appendix C. Forestry & Land Use

### Overview

Forestland emissions refer to the net carbon dioxide (CO<sub>2</sub>) flux<sup>11</sup> from forested lands in Michigan, which account for about 53% of the state's land area.<sup>12</sup> The dominant forest type in Michigan is Maple-beech-birch which makes up about 38% of forested lands. Other common forest types are Aspen-birch at 17% of forested land, Spruce-fir at 15%, White-red-jack pine at 11%, Oak-hickory at 10%, and Elm-ash-cottonwood at 9% of forested land.

Through photosynthesis, CO<sub>2</sub> is taken up by trees and plants and converted to carbon in biomass within the forests. Carbon dioxide emissions occur from respiration in live trees, decay of dead biomass, and combustion (both wildfires and biomass removed from forests for energy use). In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. Carbon dioxide flux is the net balance of CO<sub>2</sub> removals from and emissions to the atmosphere from the processes described above.

The forestry sector CO<sub>2</sub> flux is categorized into two primary subsectors:

- *Forested Landscape*: this consists of carbon flux occurring on lands that are not part of the urban landscape. Fluxes covered include net carbon sequestration, carbon stored in harvested wood products (HWP) or landfills, and emissions from forest fires.
- *Urban Forestry and Land Use*: this covers carbon sequestration in urban trees, flux associated with carbon storage from landscape waste and food scraps in landfills, and nitrous oxide (N<sub>2</sub>O) emissions from settlement soils (those occurring as a result of application of synthetic fertilizers).

### Inventory and Reference Case Projections

#### *Forested Landscape*

For over a decade, the United States Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO<sub>2</sub> fluxes for the official *US Inventory of Greenhouse Gas Emissions and Sinks*. The national estimates are compiled from state-level data. The Michigan forest CO<sub>2</sub> flux data in this report come from the national analysis and are provided by the USFS. See the footnotes below for the most current documentation for the forest carbon modeling.<sup>13</sup> Additional forest carbon information is in the form of specific carbon conversion factors.<sup>14</sup>

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<sup>11</sup> "Flux" refers to both emissions of CO<sub>2</sub> to the atmosphere and removal (sinks) of CO<sub>2</sub> from the atmosphere.

<sup>12</sup> Total forested acreage is 19.3 million acres in 1997. Acreage by forest type available from the USFS at: <http://www.fs.fed.us/ne/global/pubs/books/epa/states/MI.htm>. The total land area in Michigan is 36 million acres (<http://www.50states.com/Michigan.htm>).

<sup>13</sup> The most current citation for an overview of how the USFS calculates the inventory based forest carbon estimates as well as carbon in harvested wood products is from the US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # USEPA #430-R-07-002, April 2007, available at: <http://epa.gov/climatechange/emissions/usinventoryreport.html>. Both Annex 3.12 and Chapter 7

The forest CO<sub>2</sub> flux methodology relies on input data in the form of plot-level forest volume statistics from the Forest Inventory Analysis (FIA). FIA data on forest volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level survey data to give estimates of C density [megagrams (Mg) per hectare] for a number of separate C pools. Additional background on the FORCARB system is provided in a number of publications.<sup>15</sup>

Carbon dioxide flux is estimated as the change in carbon mass for each carbon pool over a specified time-frame. Forest biomass data from at least two points in time are required. The change in carbon stocks between time intervals is estimated for specific carbon pools (Live Tree, Standing Dead Wood, Understory, Down & Dead Wood, Forest Floor, and Soil Organic Carbon) and divided by the number of years between inventory samples. Annual increases in carbon density reflect carbon sequestration in a specific pool; decreases in carbon density reveal CO<sub>2</sub> emissions or carbon transfers out of that pool (e.g., death of a standing tree transfers carbon from the live tree to standing dead wood pool). The amount of carbon in each pool is also influenced by changes in forest area (e.g., an increase in area could lead to an increase in the associated forest carbon pools and the estimated flux). The sum of carbon stock changes for all forest carbon pools yields a total net CO<sub>2</sub> flux for forest ecosystems.

In preparing these estimates, USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests also include differences in ownership class: those in the national forest (NF) system and those that are not federally-owned (private and other public forests). Additional details on the forest carbon inventory methods can be found in Annex 3 to the US EPA's 2007 GHG inventory for the US.<sup>16</sup>

Carbon pool data for four FIA cycles to estimate flux for three different periods were available for Michigan. The carbon pool data for four points are shown in Table H1 below. Note that prior to 1993, FIA had a variable schedule for taking Michigan forest inventory samples. Beginning in 2000, Michigan transitioned from periodic to annual inventories as modifications to the FIA program were applied. The annual inventories are on a 5-year cycle and sample 20% of the state

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LULUCF are useful sources of reference. See also Smith, J.E., L.S. Heath, and M.C. Nichols (in press), *US Forest Carbon Calculation Tool User's Guide: Forestland Carbon Stocks and Net Annual Stock Change*, Gen Tech Report, Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

<sup>14</sup> Smith, J.E., and L.S. Heath (2002). "A model of forest floor carbon mass for United States forest types," Res. Pap. NE-722. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 37 p., or Jenkins, J.C., D.C. Chojnacky, L.S. Heath, R.A. Birdsey (2003), "National-scale biomass estimators for United States tree species", *Forest Science*, 49:12-35.

<sup>15</sup> Smith, J.E., L.S. Heath, and P.B. Woodbury (2004). "How to estimate forest carbon for large areas from inventory data", *Journal of Forestry*, 102: 25-31; Heath, L.S., J.E. Smith, and R.A. Birdsey (2003), "Carbon trends in US forest lands: A context for the role of soils in forest carbon sequestration", In J. M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal, editors. *The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect*. CRC Press, New York; and Woodbury, Peter B.; Smith, James E.; Heath, Linda S. 2007, "Carbon sequestration in the US forest sector from 1990 to 2010", *Forest Ecology and Management*, 241:14-27.

<sup>16</sup> Annex 3 to EPA's 2007 report, which contains estimates for calendar year 2005, can be downloaded at: <http://www.epa.gov/climatechange/emissions/downloads06/07Annex3.pdf>.

forests each year. Michigan completed its first annual inventory cycle in 2004. The 2005 carbon pool data represents 20% of the next 5-year inventory cycle that is yet to be completed.

The underlying FIA data, as shown in Table H1, display a net increase in forested area for all sample years: 912 thousand acres between 1980 and 1993, 31 thousand acres between 1993 and 2004, and 27 thousand acres between 2004 and 2005. This results in a net increase in forested area of 943 thousand acres in the 1980-2004 period. Most of the forested lands in Michigan are considered timberland, meaning they are unreserved productive forest land producing, or capable of producing, crops of industrial wood. The timberland area is shown to have increased by 1.1 million acres between 1980 and 1993 while it only increased 130 thousand acres between 1993 and 2004, and 61 thousand acres between 2004 and 2005. This increase in timberland area resulted in the tremendous increase in carbon (177 million metric tons) from forested areas between 1980 and 1993. The decrease in carbon stocks between 1993 and 2004 may possibly be due to the slower growth in timberland area during this period. It is also important to note that the 1993 data included modeled plots and there are other changes in inventory sampling methods between 1993 and 2004 reporting years, which may lead to bias or error in the estimates. The slight increase in carbon stocks between 2004 and 2005 is consistent with the increase in timberland during this period.

**Table H1. USFS Forest Carbon Pool Data for Michigan**

Forest Pool	1980 (MMtC)	1993 (MMtC)	2004 (MMtC)	2005 (MMtC)
Live Tree – Above Ground	383.6	474.9	467.1	471.5
Live Tree – Below Ground	76.3	93.8	92.6	93.4
Understory	12.8	13.1	13.5	13.4
Standing Dead	33.4	36.2	35.1	35.3
Down Dead	35.5	43.6	42.8	43.2
Forest Floor	145.4	160.2	152.2	152.9
Soil Carbon	1159.9	1202.4	1170.5	1166.4
<b>Totals</b>	<b>1,847</b>	<b>2,024</b>	<b>1,974</b>	<b>1,976</b>
Forest Area	1980 (10 <sup>3</sup> acres)	1993 (10 <sup>3</sup> acres)	2004 (10 <sup>3</sup> acres)	2005 (10 <sup>3</sup> acres)
All Forests	18,369	19,281	19,312	19,339
Timberland	17,493	18,616	18,746	18,807

MMtC = million metric tons of carbon. Positive numbers indicate net emission. Multiply MMtC by 3.667 (44/12) to convert to MMtCO<sub>2</sub>.

Totals may not sum exactly due to independent rounding.

Data source: Smith, James, et al. *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (<http://www.nrs.fs.fed.us/pubs/2394>), November 2007.

In addition to the forest carbon pools, additional carbon is stored in biomass removed from the forest for the production of HWP. Carbon remains stored in the durable wood products pool or is

transferred to landfills where much of the carbon remains stored over a long period of time. The USFS uses a model referred to as WOODCARB2 for the purposes of modeling national HWP carbon storage.<sup>17</sup> State-level information for Michigan was provided to CCS by USFS<sup>18</sup>.

As shown in Table H2, about 2.6 million metric tons (MMt) of CO<sub>2</sub> per year (yr) is estimated by the USFS to be sequestered annually (1980-2005) in wood products. Also, as shown in this table, the total flux estimate including all forest pools fluctuates between -53 MMtCO<sub>2</sub>e/yr and 16 MMtCO<sub>2</sub>e/yr between 1980 and 2005.<sup>19</sup> This fluctuation is largely due to significant differences in forest carbon pools from each cycle period as well as the increase in soil organic carbon source. Note that from 1980 to 1993, soil carbon was considered a net sink.

**Table H2. USFS Annual Forest CO<sub>2</sub> Fluxes for Michigan**

<b>Forest Pool</b>	<b>1980-1993 Flux (MMtCO<sub>2</sub>/yr)</b>	<b>1993-2004 Flux (MMtCO<sub>2</sub>/yr)</b>	<b>2004-2005 Flux (MMtCO<sub>2</sub>/yr)</b>
Forest Carbon Pools (non-soil)	-38.04	6.81	-42.28
Soil Organic Carbon	-11.98	11.67	26.67
Harvested Wood Products	-2.60	-2.60	-2.60
<b>Totals</b>	<b>-52.61</b>	<b>15.88</b>	<b>-18.20</b>
<b>Totals (excluding soil carbon)</b>	<b>-40.64</b>	<b>4.21</b>	<b>-44.88</b>

Totals may not sum exactly due to independent rounding.

Data source: Smith, James, et al. US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change (<http://www.nrs.fs.fed.us/pubs/2394>), USFS, November 2007.

Based on discussions with the USFS, CCS recommends excluding the soil carbon pool from the overall forest flux estimates due to a high level of uncertainty associated with these estimates. The forest carbon flux estimates provided in the summary tables at the front of this report are those without the soil carbon pool.

For historic emission estimates, CCS used the 1980-1993 and 1993-2004 carbon fluxes to represent forest carbon flux prior to 2005. Current flux estimates (2004-2005) are those based on 2005 sample year stocks. For the reference case projections (2005-2020), the forest area and carbon densities of forestlands were assumed to remain at the same levels as in 2005. Information is not available on the near term effects of climate change and their impacts on forest productivity. Nor were data readily-available on projected losses in forested area.

Biomass burned in forest fires emits CO<sub>2</sub>, methane (CH<sub>4</sub>), and N<sub>2</sub>O, in addition to many other

<sup>17</sup> Skog, K.E., and G.A. Nicholson (1998), "Carbon cycling through wood products: the role of wood and paper products in carbon sequestration", *Forest Products Journal*, 48(7/8):75-83; or Skog, K.E., K. Pingoud, and J.E. Smith (2004), "A method countries can use to estimate changes in carbon stored in harvested wood products and the uncertainty of such estimates", *Environmental Management*, 33(Suppl. 1): S65-S73.

<sup>18</sup> Obtained from the Harvested Wood Product model developed by Ken Skog, USFS

<sup>19</sup> Jim Smith, USFS, *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (<http://www.nrs.fs.fed.us/pubs/2394>), November 2007.

gases and pollutants. Since CO<sub>2</sub> emissions are captured under total carbon flux calculations, CCS used the United States Environmental Protection Agency’s (US EPA) State Greenhouse Gas Inventory Tool (SIT) to estimate CH<sub>4</sub> and N<sub>2</sub>O emissions. No default data were available for area burned by forest type, so CCS used available state data (1992-2005) from Michigan Department of Natural Resources (MDNR).<sup>20</sup> An average of the wildfire acres burned data was used for the years 1990-2005 and the forest type of “other temperate forests” was assumed in the SIT to calculate historical emissions. Projected emissions for 2005-2020 were assumed to be held constant at 2005 emissions.

*Urban Forestry & Land Use*

GHG emissions from urban forestry and land use for 1990 through 2005 were estimated using the EPA SIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for this sector.<sup>21</sup> In general, the SIT methodology applies emission factors developed for the US to activity data for the urban forestry sector. Activity data include urban area, urban area with tree cover, amount of landfilled yard trimmings and food scraps, and the total amount of synthetic fertilizer applied to settlement soils (e.g., parks, yards, etc.). This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.<sup>22</sup> Table H3 displays the emissions and reference case projections for Michigan.

**Table H3. Urban Forestry Emissions and Reference Case Projections (MMtCO<sub>2</sub>e)**

	1990	2000	2005	2010	2020
Urban Trees	-1.67	-2.03	-2.20	-2.20	-2.20
Landfilled Yard Trimmings and Food Scraps	-8.49	-1.76	-1.81	-1.81	-1.81
N <sub>2</sub> O from Settlement Soils*	0.10	0.10	0.11	0.11	0.11
<b>Total</b>	<b>-10.06</b>	<b>-3.69</b>	<b>-3.91</b>	<b>-3.91</b>	<b>-3.91</b>

\*Data for settlement soils was obtained from AAPFCO (2006) Commercial Fertilizers 2005. Association of American Plant Food Control Officials and The Fertilizer Institute. University of Kentucky, Lexington, KY.

Changes in carbon stocks in urban trees are equivalent to tree growth minus biomass losses resulting from pruning and mortality. Net carbon sequestration was calculated using data on crown cover area. The default urban area data in SIT (which varied from 7,272 square kilometers [km<sup>2</sup>] to 9,590 km<sup>2</sup> between 1990 and 2005) was multiplied by the state estimate of the percent of urban area with tree cover (30% for Michigan) to estimate the total area of urban tree cover. These default SIT urban area tree cover data represent area estimates taken from the US Census

<sup>20</sup> Wildfire acres burned data obtained from personal communication with Donald Johnson of Michigan Department of Natural Resources, Forest, Mineral, & Fire Management Division.

<sup>21</sup> GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8.

<sup>22</sup> Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, published by the National Greenhouse Gas Inventory Program of the IPCC, available at (<http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm>; and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (<http://www.ipcc-nggip.iges.or.jp/public/gp/english/>).

and coverage for years 1990 and 2000.<sup>23</sup> Estimates of urban area in the intervening years (1990-1999) and subsequent years (2001-2005) are interpolated and extrapolated, respectively.

Estimates of net carbon flux of landfilled yard trimmings and food scraps were calculated by estimating the change in landfill carbon stocks between inventory years. The SIT estimates for the amount of landfilled yard trimmings decreased significantly during the 1990's. CCS believes that this is consistent with changes in the waste management industry during this period. Therefore, the forecast was based on an extrapolation of the flux from 2000-2005, which show relatively constant rates of landfilling these materials.

Settlement soils include all developed land, transportation infrastructure, and human settlements of any size. Projections for urban trees and settlement soils were kept constant at 2005 levels. Table H4 provides a summary of the estimated flux for the entire forestry and land use sector.

**Table H4. Forestry and Land Use Flux and Reference Case Projections (MMtCO<sub>2</sub>e)**

	1990	1995	2000	2005	2010	2020
Forested Landscape (excluding soil carbon)	-40.64	4.21	4.21	-44.88	-44.88	-44.88
Urban Forestry and Land Use	-10.06	-5.83	-3.69	-3.91	-3.91	-3.91
Forest Wildfires	0.02	0.02	0.02	0.02	0.02	0.02
<b>Sector Total</b>	<b>-50.67</b>	<b>-1.60</b>	<b>0.55</b>	<b>-48.76</b>	<b>-48.76</b>	<b>-48.76</b>

### Key Uncertainties

Emissions from wildfires in Michigan were estimated based on State acres burned data from 1992-2005. 1990 and 1991 acres burned data were not available so the emissions were based on the average of 1992-2005 emissions. Future forecasts are hard to estimate given the large swings in fire activity from year to year. Emissions from wildfires in Michigan are very small and they do not impact the estimated flux significantly.

It is important to note that there were methodological differences in the four FIA cycles (used to calculate carbon pools and flux) that can produce different estimates of forested area and carbon density. For example, the FIA program modified the definition of forest cover for the woodlands class of forestland (considered to be non-productive forests). Earlier FIA cycles defined woodlands as having a tree cover of at least 10%, while the newer sampling methods used a woodlands definition of tree cover of at least 5% (leading to more area being defined as woodland). In woodland areas, the earlier FIA surveys might not have inventoried trees of certain species or with certain tree form characteristics (leading to differences in both carbon density and forested acreage). Given that the forested land in Michigan is dominated by timberlands (productive forests), CCS does not believe that the definitional differences noted above have had a significant impact on the forest flux estimates provided in this report.

<sup>23</sup> Dwyer, John F.; Nowak, David J.; Noble, Mary Heather; Sisinni, Susan M. 2000. Connecting people with ecosystems in the 21st century: an assessment of our nation's urban forests. Gen. Tech. Rep. PNW-GTR-490

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. The modifications to FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. In addition, the FIA program has moved from periodic to annual inventory methods – FIA now has Michigan on a continuous 5-year cycle. The effect of these changes in survey methods has not been estimated by the USFS.

Much of the urban forestry & land use emission estimates rely on national default data and could be improved with state-specific information.