5 Land Use, Land-Use Change, and Forestry (NIR Chapter 6)

This chapter describes the methods applied to estimate state-level GHG fluxes resulting from land use and land-use change within states according to changes within and conversions between all land use types, including forest land, cropland, grassland, wetlands, and settlements (as well as other land).[40] More information on national-level emissions and removals and associated methods is available in Chapter 6 of the national *Inventory,* available online at: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-6-Land-Use-Land-Use-Change-and-Forestry.pdf. Table 5-1 summarizes the different approaches used to estimate state-level LULUCF emissions and sinks completeness. State completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

See also Chapter 6.1 in the national *Inventory* for a description of how the U.S. land base is represented to identify land areas consistent with IPCC Guidelines. Work is underway to provide additional spatial and temporal resolution to the representation of the U.S. land base and will help refine methods for state-level estimates in subsequent annual publications of these data.

Table 5-1. Overview of Approaches for Estimating State-Level LULUCF Sector GHG Emissions and Sinks

Category	Gas	Approach	Geographic Completeness [a]
Forest Land Remaining Forest Land and Lands Converted to Forest Land	Carbon, CH_4, N_2O	Approach 1	Includes estimates from all states (except Hawaii) and tribal lands.[a] For Alaska, Lands Converted to Forest are included in the Forest Land Remaining Forest Land data.
Cropland and Lands Converted to Cropland	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands.[a]
Grassland and Lands Converted to Grassland			
C Stock Changes	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands.[a]
Non-CO_2 Emissions from Grassland Fires	CH_4, N_2O	Hybrid: • 1990–2014: Approach 1 • 2015–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands. [a]
Wetlands and Lands Converted to Wetlands			
Coastal Wetlands	Carbon, CH_4	Approach 1	Includes estimates from all states, the District of Columbia, and tribal lands with coastal wetlands (except Alaska and Hawaii).[a]
Peatlands	CO_2, CH_4, N_2O	Approach 2	Includes estimates from all states (except Hawaii) and tribal lands.[a]
Flooded Lands	CO_2, CH_4	Approach 1	Includes estimates from all states, the District of Columbia,

[40] U.S. Forest Service develops state-level estimates for the forest land as part of their *U.S. Forest Service 2023 Resource Bulletin* (published online at https://doi.org/10.2737/WO-RB-101), including the underlying state-level data.

Category	Gas	Approach	Geographic Completeness [a]
			tribal lands and territories (i.e., Puerto Rico), .[a]
Settlements and Land Converted to Settlements			
Soil Carbon	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands.[a]
Settlement Trees	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states,the District of Columbia, and tribal lands.[a]
Soil N_2O	N_2O	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Estimates from all states (except Alaska) and tribal lands.[a]
Landfilled Yard Trimmings and Food Scrap	Carbon	Approach 2	Estimates from all states, the District of Columbia, tribal lands and territories (i.e., Puerto Rico).[a]

[a] Emissions are likely occurring in other U.S. territories; however, due to a lack of available data and the nature of this category, this analysis includes emissions for only the territories indicated. Territories not listed are not estimated. Tribal Lands are included for estimates within the Conterminous U.S.s. See planned improvements of the national *Inventory*.

5.1.1 Forest Land Remaining Forest Land (NIR Section 6.2)

5.1.1.1 Background

Carbon is continuously cycled among the forest ecosystem carbon storage pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon) and the atmosphere because of biogeochemical processes in forests (e.g., photosynthesis, respiration, decomposition, disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, replanting). The net change in forest carbon, however, is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of all harvested biomass carbon to the atmosphere. Instead, harvesting transfers a portion of the carbon stored in wood to a "product pool." Once in a product pool, the carbon is emitted over time as CO_2 in the case of decomposition and as CO_2, CH_4, N_2O, carbon monoxide, and nitrogen oxide when the wood product combusts. Emissions of non-CO_2 gases from forest fires, both wild and prescribed, also occur, along with N_2O emissions from nitrogen additions to the soil and CO_2, CH_4, and N_2O emissions from drained organic soils.

5.1.1.2 Methods/Approach

To compile national estimates for the national *Inventory* of C stock changes from forest ecosystem carbon pools on forest land remaining forest land, as well as non-CO_2 emissions from fires and non-CO_2 emissions from drained organic soils on forest land remaining forest land and land converted to forest land, estimates for each state were produced and summed into a national total. This is described in Chapter 6, Section 6.2 (pages 6-25 through 6-48), of the national *Inventory*. Additional information on the methodologies and data is also provided in Annex 3.13.

Please note Hawaii is not included in the national total or available at the state level at this time. Emissions of non-CO_2 gases from forest fires and non-CO_2 emissions from drained organic soils include emissions from both forest land remaining forest land and land converted to forest land because it is not possible to report them separately at this time. Additionally, the estimates of the C stock change in harvested wood are not currently available at the state level. Work is underway to develop an approach for disaggregating the national estimates down to state level.

5.1.1.3 Uncertainty

The subcategories included in this state-level report include the C stock changes in forest ecosystem carbon storage pools, non-CO_2 gases from forest fires, and non-CO_2 emissions from drained organic soils. A brief overview of the uncertainty analyses for each of the subcategories included in the national *Inventory* is provided below. In addition, quantitative uncertainty estimates for individual states for 2021 for the C stock changes in forest ecosystem carbon storage pools and non-CO_2 gases from forest fires are provided in the USFS 2023 Resource Bulletin (Domke et al. 2023). Uncertainty analyses for the subcategories are:

- **C stock changes in forest ecosystem carbon storage pools.** The overall uncertainty associated with the 2021 national estimate of C stock changes in forest ecosystem carbon storage pools was calculated through a combination of sample-based and model-based approaches to uncertainty for forest ecosystem CO_2 flux using the IPCC Approach 1 (IPCC 2006). As described further in Chapter 6.2 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −12.3%/+12.3%. State-level estimates of uncertainty vary significantly among the states but, in general, tend to be higher than those provided for the United States in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as the state level. The potential for unique circumstances occurring within a state can reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.2 and Annex 3.13 of the national *Inventory*.
- **Non-CO_2 gases from forest fires (includes both forest land remaining forest land and land converted to forest land).** The overall uncertainty associated with the 2021 national estimate of non-CO_2 gases from forest fires was calculated through a Monte Carlo sampling approach, per IPCC Approach 2 (IPCC 2006), employed to propagate uncertainty based on the model and data applied for U.S. forest land. As shown in Chapter 6 of the national *Inventory*, levels of uncertainty in the national estimates in 2021 were −32%/+32% for CH_4 and −71%/+72% for N_2O. State-level estimates of uncertainty vary significantly among the states but, in general, tend to be higher than those provided in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as the state level. The potential for unique circumstances occurring within a state can reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national-level uncertainty and the quantities and assumptions employed to define and propagate uncertainty, see the uncertainty discussion in Section 6.2 and Annex 3.13 of the national *Inventory.*
- **Non-CO_2 gases from drained organic soils (includes both forest land remaining forest land and land converted to forest land).** The overall uncertainty associated with the 2021 national estimate of non-CO_2 gases from drained organic soils was calculated through IPCC Approach 1 (IPCC 2006). As described further in Chapter 6 of the national *Inventory*, levels of uncertainty in the national estimates in 2021 were −69%/+82% for CH_4 and −118%/+132% N_2O. State-level estimates of uncertainty vary significantly among the states but, in general, tend to be higher than those provided in the national *Inventory*. For more details on national-level uncertainty and the quantities and assumptions employed to define and propagate uncertainty, see the uncertainty discussion in Section 6.2 and Annex 3.13 of the national *Inventory.*

5.1.1.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.2 of the national *Inventory* (pages 6-38 through 6-39, 6-42, 6-45, and 6-48), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. In particular, EPA new National Forest Inventory data in most states were incorporated in the latest Inventory.

EPA updated GWPs for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.1.5 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state-level GHG estimates are the same as those in the national *Inventory*. To view the planned improvements to the methods and data for estimating emissions and removals from forest land remaining forest land, see the planned improvements discussion on pages 6-39 through 6-40, 6-42, and 6-48 of Chapter 6.2 in the national *Inventory* for a description of future work to improve these estimates. In addition, as noted by the USFS 2023 Resource Bulletin (Domke et al. 2023), investments are being made to leverage existing state-level forest products information to allow for the disaggregation of harvested wood product estimates at the state level in the future.

5.1.1.6 References

Domke, G.M., B.F. Walters, C.L. Giebink, E.J. Greenfield, J.E. Smith, M.C. Nichols, J.A. Knott, S.M. Ogle, J.W. Coulston, and J. Steller (2023) *Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, Urban Trees, and Harvested Wood Products in the United States, 1990–2021*. Resource Bulletin WO-101. U.S. Department of Agriculture. https://doi.org/10.2737/WO-RB-101.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of all references included in Chapter 6.2 (Forest Land Remaining Forest Land) of the national *Inventory* are found in Chapter 10 (References) and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.2 Land Converted to Forest Land (NIR Section 6.3)

5.1.2.1 Background

Land use conversions into forest land can result in C stock changes to all forest ecosystem carbon pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon). Section 5.1.2 provides estimates of C stock changes resulting from conversion of cropland, grassland, wetlands, settlements, and other lands to forest land (Domke et al. 2023).

5.1.2.2 Methods/Approach

The methods applied for estimating C stock changes in land converted to forest land are the same as those applied for forest land remaining forest land. This is described in Chapter 6, Section 6.3 (pages 6-49 through 6-56), of the national *Inventory*. Additional information on the methodologies and data is also provided in Annex 3.13 of the national *Inventory*. Please note that estimates for Hawaii are not included in the national total or available at the state level at this time. Forest ecosystem C stock changes from land conversion in Alaska are currently included in the forest land remaining forest land chapter because there are insufficient data to separate the changes at this time.

5.1.2.3 Uncertainty

The overall uncertainty associated with the 2021 national estimate of the C stock changes in forest ecosystem carbon storage pools for land converted to forest land is described in Chapter 6.3 of the national *Inventory* (EPA 2023). The uncertainty estimates were calculated through a combination of sample-based and model-based approaches to uncertainty for non-soil forest ecosystem CO_2 flux using IPCC Approach 1 (IPCC 2006), in combination with IPCC Approach 2 for mineral soils (described in Section 6.4, Cropland Remaining Cropland, of the *Inventory* report). Uncertainty estimates are provided for each land conversion category and carbon pool. The combined level of uncertainty in the national estimates in 2021 was −11%/+11%. State-level estimates of uncertainty are not available but are likely to vary significantly from the national estimates and, in general, tend to be higher than those provided for the United States in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as the state level, the potential for unique circumstances occurring within a state can reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.4 and Annex 3.13 of the national *Inventory.*

5.1.2.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.3 of the national *Inventory* (page 6-55 through 6-56), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.2.5 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to forest land, see the planned improvements discussion on page 6-56 of Chapter 6.3 in the national *Inventory*.

5.1.2.6 References

Domke, G.M., B.F. Walters, C.L. Giebink, E.J. Greenfield, J.E. Smith, M.C. Nichols, J.A. Knott, S.M. Ogle, J.W. Coulston, and J. Steller (2023) Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, Urban Trees, and Harvested Wood Products in the United States, 1990–2021. Resource Bulletin WO-101. U.S. Department of Agriculture. https://doi.org/10.2737/WO-RB-101.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.3 (Land Converted to Forest Land) of the national *Inventory* are found in Chapter 10 (References) and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.3 Cropland Remaining Cropland (NIR Section 6.4)

5.1.3.1 Background

Carbon in cropland ecosystems occurs in biomass, dead organic matter, and soils. However, carbon storage in cropland biomass and dead organic matter is relatively ephemeral and does not need to be reported according to the IPCC (2006), with the exception of carbon stored in perennial woody crop biomass, such as citrus groves and apple orchards, in addition to the biomass, downed wood, and dead organic matter in agroforestry systems. Within soils, carbon is found in organic and inorganic forms, but soil organic carbon is the main source and sink for atmospheric CO_2 in most soils.

The IPCC (2006) recommends reporting changes in soil organic C stocks due to agricultural land use and management activities for mineral and organic soils. Management of croplands and cropland soils has an impact on organic matter inputs and microbial decomposition, and thereby results in a net C stock change.

Cropland remaining cropland includes all cropland in an inventory year that has been cropland for a continuous time period of at least 20 years. This determination is based on the USDA NRI for nonfederal lands and the National Land Cover Database for federal lands. Cropland includes all land that is used to produce food and fiber, forage that is harvested and used as feed (e.g., hay and silage), and cropland that has been enrolled in the Conservation Reserve Program (i.e., considered set-aside cropland).

5.1.3.2 Methods/Approach

EPA compiles state-level emissions from cropland remaining cropland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.4 (pages 6-56 through 6-68), of the national *Inventory*. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2015 for soil organic carbon stock changes. The remaining years in the time series were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Estimates are included for all states except Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory*, .

5.1.3.3 Uncertainty

The overall uncertainty associated with national estimates from Cropland Remaining Cropland is described in Chapter 6 of the national *Inventory* (EPA 2023) and in further detail in Annex 3.12. Uncertainty for the Tier 2 and 3 approaches is derived using a Monte Carlo approach. The combined uncertainty for soil organic carbon stocks in cropland remaining cropland in 2021 is −406%/+406%.

5.1.3.4 Recalculations

No recalculations were applied for this current report, consistent with the national *Inventory* (see Section 6.4, page 6-67).

5.1.3.5 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions and removals from cropland remaining cropland, see the planned improvements discussion on pages 6-67 and 6-68 of Chapter 6.4 in the national *Inventory*.

5.1.3.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.4 (Cropland Remaining Cropland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annex-3-Additional-Source-or-Sink-Categories-Part-B.pdf.

5.1.4 Land Converted to Cropland (NIR Section 6.5)

5.1.4.1 Background

Land use change can lead to large losses of carbon to the atmosphere, particularly conversions from forest land. Moreover, conversion of forests to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally.

Land converted to cropland includes all cropland in an inventory year that (1) had been in at least one other land use during the previous 20 years and (2) is used to produce food, fiber or forage that is harvested and used as feed (e.g., hay and silage). For example, grassland or forest land converted to cropland during the past 20 years would be reported in this category. Recently converted lands are retained in this category for 20 years as recommended by IPCC (2006).

5.1.4.2 Methods/Approach

EPA compiles state-level emissions from land converted to cropland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.5 (pages 6-68 through 6-75), of the national *Inventory*. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level fluxes for the years 1990–2021 for biomass, standing dead, dead wood, and litter and for the years 1990–2015 for soil organic carbon stock changes. The remaining years in the time series for soil organic carbon stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Estimates are included for all states except Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory*.

5.1.4.3 Uncertainty

The overall uncertainty associated with national estimates from land converted to cropland is described in Chapter 6 of the national *Inventory* (EPA 2023) and in further detail in Annex 3.12 and Annex 3.13 (Forestland Converted to Cropland). The uncertainty analyses for mineral soil organic C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is used in the cropland remaining cropland analysis. The combined uncertainty for total carbon stocks in land converted to cropland in 2021 was −94%/+94%.

5.1.4.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.5 of the national *Inventory* (page 6-74), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.4.5 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates, given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to cropland, see the planned improvements discussion on page 6-75 of Chapter 6.5 in the national *Inventory*.

5.1.4.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.5 (Land Converted to Cropland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annex-3-Additional-Source-or-Sink-Categories-Part-B.pdf.

5.1.5 Grassland Remaining Grassland (NIR Section 6.6)

5.1.5.1 Background

Carbon in grassland ecosystems occurs in biomass, dead organic matter, and soils. Soils are the largest pool of carbon in grasslands and have the greatest potential for longer-term storage or release of carbon. Biomass and dead organic matter carbon pools are relatively ephemeral compared to the soil carbon pool, with the exception of carbon stored in tree and shrub biomass that occurs on grasslands.

The 2006 IPCC Guidelines recommend reporting changes in biomass, dead organic matter, and soil organic C stocks with land use and management. C stock changes for aboveground and belowground biomass, dead wood, and litter pools are reported for woodlands (i.e., a subcategory of grasslands), and may be extended to include agroforestry management associated with grasslands in the future. For soil organic carbon, the 2006 IPCC Guidelines (IPCC 2006) recommend reporting changes due to (1) agricultural land use and management activities on mineral soils and (2) agricultural land use and management activities on organic soils.

Grassland remaining grassland includes all grassland in an inventory year that had been grassland for a continuous time period of at least 20 years. Grassland includes pasture and rangeland that are primarily, but not exclusively, used for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or inter-seeding of legumes. Woodlands are also considered grassland and are areas of continuous tree cover that do not meet the definition of forest land.

Non-CO_2 emissions from grassland fires are also included. These emissions do not currently include emissions from burning perennial biomass (a national *Inventory* planned improvement).

5.1.5.2 Methods/Approach

EPA compiles state-level emissions from grassland remaining grassland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6.6 (pages 6-76 through 6-88) of the national *Inventory* For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2021 for biomass, standing dead, dead wood, and litter, as well s for the years 1990–2015 for soil organic carbon stock changes. The remaining years in the time series for soil organic C stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Estimates are included for all states except Alaska.

Additional information on national *Inventory* methodologies and data is also provided in Annex 3.12 of the national *Inventory*.

5.1.5.3 Uncertainty

The overall uncertainty associated with national estimates from grassland remaining grassland is described in Chapter 6 of the national *Inventory* (EPA 2023) and in further details in Annex 3.12. The uncertainty analyses for mineral soil organic carbon stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is used in cropland remaining cropland analysis. Uncertainty estimates are also developed for biomass burning in grassland using a linear regression autoregressive moving-average model to estimate the upper and lower bounds of the emissions estimate. The combined uncertainty for flux associated with C stock changes occurring in grassland remaining grassland in 2021 was −1,417%/+1,417%.

5.1.5.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.6 of the national *Inventory* (page 6-83), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.5.5 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions and removals from grassland remaining grassland, see the planned improvements discussion on pages 6-83 and 6-84 of Chapter 6.6 in the national *Inventory.*

5.1.5.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of references included in Chapter 6.6 (Grassland Remaining Grassland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annex-3-Additional-Source-or-Sink-Categories-Part-B.pdf.

5.1.6 Land Converted to Grassland (NIR Section 6. NIR Section 6.7)

5.1.6.1 Background

Land use change can lead to large losses of carbon to the atmosphere, particularly conversions from forest land. Moreover, conversion of forests to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally.

Land converted to grassland includes all grassland in an inventory year that had been in at least one other land use during the previous 20 years. For example, cropland or forest land converted to grassland during the past 20 years would be reported in this category. Recently converted lands are retained in this category for 20 years as recommended by IPCC (2006).

5.1.6.2 Methods/Approach

EPA compiles state-level emissions from land converted to grassland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.7 (pages 6-88 through 6-96), of the national *Inventory*. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2021 for biomass, standing dead, dead wood, and litter, and for the years 1990–2015 for soil organic carbon stock changes. The remaining years in the time series for soil organic carbon stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Estimates are included for all states except Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory*.

5.1.6.3 Uncertainty

The overall uncertainty associated with national estimates from Land Converted to Grassland is described in Chapter 6 of the national *Inventory* (EPA 2023) and in further details in Annex 3.12. The uncertainty analyses for mineral soil organic C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is used in cropland remaining cropland analysis. The combined uncertainty for total carbon stocks in land converted to grassland in 2021 was −149%/+149 %.

5.1.6.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.7 of the national *Inventory* (page 6-95), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.6.5 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to grassland, see the planned improvements discussion on pages 6-95 and 6-96 of Chapter 6.7 in the national *Inventory*.

5.1.6.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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Full citations of references included in Chapter 6.7 (Land Converted to Grassland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annex-3-Additional-Source-or-Sink-Categories-Part-B.pdf.

5.1.7 Wetlands Remaining Wetlands (NIR Section 6.8)

This section presents methods for estimating state-level CO_2, CH_4, and N_2O emissions and removals from management of wetlands consistent with the national *Inventory*, specifically:

- Coastal wetlands remaining coastal wetlands (CO_2, CH_4)
- Peatlands remaining peatlands (CO_2, CH_4, and N_2O)
- Flooded land remaining flooded land (CH_4)

5.1.7.1 Coastal Wetlands Remaining Coastal Wetlands

5.1.7.1.1. Background

Consistent with ecological definitions of wetlands, the United States has historically included under the category of wetlands those coastal shallow water areas of estuaries and bays that lie within the extent of the wetland representation. The national *Inventory* includes all privately owned and publicly owned coastal wetlands (i.e., mangroves and tidal marsh) along the oceanic shores on the conterminous United States but does not include coastal wetlands remaining coastal wetlands in Alaska or Hawaii. Soil and biomass carbon stocks from seagrasses are not currently included in the national *Inventory* because of insufficient data on distribution, change through time, and carbon stocks or carbon stock changes as a result of anthropogenic influence. Additionally, the estimates of N_2O emissions from aquaculture are only available at the national level because of data limitations and have not been included in the current state estimates.

Under the coastal wetlands remaining coastal wetlands category, the following emissions and removals subcategories are quantified at the state level:

- C stock changes and CH_4 emissions on vegetated coastal wetlands remaining vegetated coastal wetlands.
- C stock changes on vegetated coastal wetlands converted to unvegetated open water coastal wetlands.
- C stock changes on unvegetated open water coastal wetlands converted to vegetated coastal wetlands.

5.1.7.1.2. Methods/Approach

To compile national estimates of C stock changes and CH_4 emissions from coastal wetlands remaining coastal wetlands for the national *Inventory*, estimates for each state and the District of Columbia with coastal wetlands were produced and summed into a national total. A description of the methods and data used to estimate state-level emissions is provided in Chapter 6, Section 6.8 (pages 6-103 through 6-121).

States (plus the District of Columbia) with coastal wetlands currently included in the national *Inventory* are Alabama, California, Connecticut, Delaware, Florida, Georgia, Louisiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, South Carolina, Texas, Virginia, and Washington. Please note that estimates for Hawaii and Alaska are not included in the national total or available at the state level at this time.

5.1.7.1.3. Uncertainty

Uncertainty estimates for each of the emissions and removals categories are only available at the national level. A brief overview of the uncertainty analyses for each of the subcategories included in the national *Inventory* is provided below:

- **C stock changes and CH_4 emissions on vegetated coastal wetlands remaining vegetated coastal wetlands.** Underlying uncertainties in the estimates of soil and biomass C stock changes and CH_4 emissions include uncertainties associated with Tier 2 literature values of soil C stocks, biomass C stocks, and CH_4 flux; assumptions that underlie the methodological approaches applied; and uncertainties linked to interpretation of remote sensing data. Uncertainty specific to vegetated coastal wetlands remaining vegetated coastal wetlands include differentiation of palustrine and estuarine community classes, which determines the soil C stock and CH_4 flux applied. Uncertainties for soil and biomass C stock data for all subcategories are not available and thus assumptions were applied using expert judgment about the most appropriate assignment of a C stock to a disaggregation of a community class. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.8 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −24.1%/+24.1% for biomass C stock change, −8.7%/+18.7% for soil C stock change, and −29.9%/+29.9% for CH_4 emissions. The combined uncertainty across all sub-sources is −37.0%/+37.0%, which is primarily driven by the uncertainty in the CH_4 estimates because there is high variability in CH_4 emissions when the salinity is less than 18 parts per trillion. State-level estimates of uncertainty will vary significantly among the states but, in general, tend be higher than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.8 of the national *Inventory*.
- **C stock changes on vegetated coastal wetlands converted to unvegetated open water coastal wetlands.** Underlying uncertainties in the estimates of soil and biomass C stock changes are associated with country-specific (Tier 2) literature values of these stocks, while the uncertainties with the Tier 1 estimates are associated with subtropical estuarine forested wetland dead organic matter stocks. Assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data are also included in this uncertainty assessment. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.8 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −24.1%/+24.1% for biomass C stock change, −25.8%/+25.8% for dead organic matter C stock change, and −15%/+15% for soil C stock change. The

combined uncertainty across all sub-sources is −32%/+32%, which is primarily driven by the uncertainty in the soil C stock change estimates. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.8 of the national *Inventory*.

- **C stock changes on unvegetated open water coastal wetlands converted to vegetated coastal wetlands.** Underlying uncertainties in estimates of soil and biomass C stock changes include uncertainties associated with country-specific (Tier 2) literature values of these C stocks and assumptions that underlie the methodological approaches applied and uncertainties linked to interpreting remote sensing data. Uncertainty specific to coastal wetlands includes differentiation of palustrine and estuarine community classes that determine the soil C stock applied. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.8 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −20%/+20% for biomass C stock change, −25.8%/+25.8% dead organic matter C stock change, and −18.1%/+18.1% for soil C stock change. The combined uncertainty across all sub-sources is −33.8%/+33.8%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.8 of the national *Inventory*.

5.1.7.1.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.8 of the national *Inventory* (pages 6-110, 6-115, and 6-119), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.7.1.5. Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from coastal wetlands remaining coastal wetlands, see the planned improvements discussions on pages 6-111, 6-115, and 6-119 of Chapter 6.8 in the national *Inventory*.

While the N_2O flux from aquaculture has not been estimated for this initial version of the national *Inventory* by state, EPA intends to include these data in future annual publications.

5.1.7.1.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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Full citations of the references included in Chapter 6.8 (Wetlands Remaining Wetlands) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.7.2 Peatlands Remaining Peatlands

5.1.7.2.1. Background

This section describes methods to estimate state-level CO_2, CH_4, and N_2O emissions from peatlands remaining peatlands (managed peatlands).

Managed peatlands are peatlands that have been cleared and drained for peat production. The production cycle of a managed peatland has three phases: land conversion in preparation for peat extraction (e.g., clearing surface biomass, draining); extraction (which results in the emissions reported under peatlands remaining peatlands); and abandonment, restoration, rewetting, or conversion of the peatland to another use. Onsite and offsite emissions also result from managed peatlands. Onsite emissions from managed peatlands occur as the land is cleared of vegetation and the underlying peat is exposed to sun and weather. Offsite CO_2 emissions from managed peatlands occur from waterborne carbon losses and the horticultural and landscaping use of peat.

5.1.7.2.2. Methods/Approach

State-level estimates were compiled using Approach 2 and are based on the national-level methods included in Chapter 6.8, Wetlands Remaining Wetlands, of the national *Inventory.* State-level peat production was estimated using Bureau of Mines and USGS Minerals Yearbooks from 1990–2020, covering the contiguous 48 states and the District of Columbia. For Alaska, the method is the same as the national-level method; the national *Inventory* historically breaks out peat production and emissions separately for Alaska. Hawaii and Puerto Rico are not estimated because peat production data were not available, and regional data provided in the USGS yearbooks did not include these states as peat producers.

For annual state-level peat production for 1990–2021, the primary activity data used to estimate emissions were calculated as follows given that no single data source covers all years:

- For 1990–1993, state-level annual peat production data were obtained from the Bureau of Mines Minerals Yearbooks (Bureau of Mines 1990, 1991, 1992, 1993). These data were available for only select states and the Bureau of Mines also reported a total national production value. The Bureau of Mines state peat production data were summed by year to obtain total known state peat production. States with no individual peat production data and that are not within a peat-producing region are assumed to not be producing peat. State production values were normalized to sum to the national production value.
- For 1994–1997, state-level annual peat production data were obtained from the USGS Minerals Yearbooks for those years (USGS 2020). Regional total data became available in 1994. To determine peat production for states within a "peat-producing region" (i.e., Northeast, Great Lakes, Southeast, West) but no individual reported peat production data, individual state values were summed and then subtracted from the available regional total peat production value to determine the peat production not accounted for in the regional data. The peat production for states with individual reported peat production data and peat production estimated from region-based peat production data were then summed. This value was subtracted from the total national peat production of the contiguous 48 states available from the USGS annual Minerals Commodities Summary (2020). States with no individual peat production data and that are not within a peat-producing region are assumed to not be producing peat. State production values were normalized to sum to the national production value.
- For 1998–2020, state-level annual peat production data were obtained from the USGS Minerals Yearbooks (USGS 2020, USGS 2022a, USGS 2022b) from the respective years. To determine peat

production for states within a peat-producing region (i.e., East, Great Lakes, West) but with no individual reported peat production data, individual state values were summed and then subtracted from the available regional total peat production value to determine the peat production not accounted for in the regional data. Note that between 1997 and 1998, peat-producing regions changed from Northeast, Great Lakes, Southeast, and West to East, Great Lakes, and West. States placed within these regions varied from year to year. The peat production for states with individual reported peat production data and peat production estimated from region-based peat production data were then summed. States with no individual peat production data and that are not within a peat-producing region are assumed to not be producing peat. State production values were normalized to sum to the national production value.

- State-level peat production in 2021 was estimated as an average fraction of total peat production for the previous 10 years because 2021 USGS data were not available when the national *Inventory* was developed. There is annual variability in the peat production values, which lends itself to using an average, rather than relying solely on the previous year,2020, to estimate peat production. An average percentage was estimated by calculating the average fraction of total U.S. peat production over the past 10 years for a given state. This average fraction was then multiplied by the 2021 total U.S. peat production of the conterminous 48 states available from the USGS annual Minerals Commodities Summary (USGS, 2022c).
- Data Appendix E-8 of this report provides state-level peat production data as well as state-level estimated peat area across the time series for all 50 states and the District of Columbia.

Following peat production estimation, peat production area was calculated using a standard conversion factor from mass of peat production to land area required for that mass of peat production: 100 metric tons of peat per hectare per year (Vacuum method, Canada) (Cleary et al. 2005).

To estimate state-level emissions from peatlands remaining peatlands, national assumptions were applied to estimate the percentage of nutrient-rich versus the percentage of nutrient-poor peat soil, which affects emissions. Six separate calculations were then performed to yield CO_2, CH_4, and N_2O emissions estimates:

- Emissions factors for offsite CO_2 emissions from horticulture use (which differentiates between rich and poor peat) and dissolved organic carbon were applied to peat production, and the areas of peat production were calculated to yield offsite CO_2 emissions. Because of a lack of peat application data, offsite peat was assumed to be applied proportionally to U.S. domestic state population in two separate components: horticulture use (which includes peat application in Hawaii, Alaska, and Puerto Rico) and dissolved organic carbon. Offsite CO_2 emissions were distributed proportionally by the percentage of the total U.S. population (1990–1999: U.S. Census Bureau 2002; 2000–2009: U.S. Census Bureau 2011; 2010–2021: U.S. Census Bureau 2021a, 2021b, 2022, Instituto de Estadísticas de Puerto Rico 2022), as it is assumed that horticulture use is positively correlated to population. EPA intends to continue reviewing this assumption; see the planned improvements below.
- An IPCC (2013a) emissions factor for onsite CO_2 emissions of drained organic soils was applied to peat production to yield onsite CO_2 emissions.
- IPCC (2013a) emissions factors for direct CH_4 emissions for drained land surfaces and drainage ditches created from peat extraction were applied to the peat production area to yield onsite CH_4 emissions.
- An IPCC (2013a) emissions factor for onsite N_2O emissions was applied to the peat production area of nutrient-rich peat soil only to yield on-site N_2O emissions.

5.1.7.2.3. Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2, CH_4, and N_2O from peatlands remaining peatlands were calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 6 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2020 were −16%/+16% for CO_2, −58%/+80% for CH_4, and −52%/+53% for N_2O. State-level estimates have a higher uncertainty due to apportioning national data to the state level and due to the assumption that any state without data on peat production is a non-producing state. These assumptions were required due to a general lack of data confirming that states are either producing or non-producing. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.8 of the national *Inventory*.

5.1.7.2.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in the national *Inventory,* given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates (see Section 6.8, page 6-102, of the national Inventory). In particular, the lower 48 states' peat production estimates were updated using the peat section of the *Mineral Commodity Summaries 2022*. The 2022 edition updated 2018 and 2020 national peat estimates (which are used to estimate state peat production). Changes also occurred in estimates for state peat production for onsite and offsite CO_2 emissions due to revised population data for 2010–2020. Additionally, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013b). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.7.2.5. Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates, given that the underlying methods for state GHG estimates are based on those used in the national *Inventory*. In addition, the methodology used to estimate state-level emissions will be reviewed and revised over time to identify other data and update assumptions (e.g., data on consumption, data and approaches for proxy peat production to better refine where peat is produced). Planned improvements include:

- EPA plans to investigate estimating emissions for Hawaii, Puerto Rico, and applicable territories, pending data availability. Emissions from offsite horticulture use are currently not estimated in non-conterminous states and territories, even though peat spreading is not limited to conterminous states.
- EPA will continue monitoring for data sources to reduce or eliminate the disparity between estimated state peat production and the national peat production estimate, especially for production values in 1990–2000. Some amount of normalization is currently performed for most years throughout the time series.

To find information on planned improvements to refine methods for estimating emissions and removals from wetlands remaining wetlands (coastal wetlands remaining coastal wetlands and peatlands remaining peatlands), see the planned improvements discussion on pages 6-103 described in the national *Inventory* at the link provided above.

5.1.7.2.6. References

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EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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Full citations of other references relevant to Chapter 6.8 (Wetlands Remaining Wetlands) and 6.9 (Land Converted to Wetlands) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.8 Flooded Land Remaining Flooded Land (NIR Section 6.8)

5.1.8.1 Background

Flooded lands are defined as (1) water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation, such as constructing a dam; (2) water bodies where human activities have changed the hydrology of existing natural water bodies, thereby altering water residence times and/or sedimentation rates, and in turn causing changes to the natural emission of GHGs; and (3) water bodies that have been created by excavation, such as canals, ditches, and ponds (IPCC 2019). Flooded lands include water bodies with seasonally variable degrees of inundation, but these water bodies would be expected to retain some inundated area throughout the year under normal conditions.

Flooded lands are broadly classified as “reservoirs” or “other constructed water bodies” (IPCC 2019). Reservoirs are defined as flooded land greater than 8 hectares and include the seasonally flooded land on the perimeter of permanently flooded land (i.e., inundation areas). IPCC guidance (IPCC 2019) provides default emissions factors for reservoirs and several types of other constructed water bodies, including freshwater ponds and canals/ditches.

Land that has been flooded for more than 20 years is defined as flooded land remaining flooded land and land flooded for 20 years or less is defined as land converted to flooded land. The distinction is based on literature reports that CH_4 and CO_2 emissions are high immediately following flooding (as labile organic matter is rapidly degraded) but decline to a steady background level approximately 20 years after flooding. Emissions of CH_4 are estimated for flooded land remaining flooded land, but CO_2 emissions are not included as they are primarily the result of decomposed organic matter entering the waterbody from the catchment or contained in inundated soils and are included elsewhere in the IPCC guidelines (IPCC 2006).

5.1.8.2 Methods/Approach

EPA compiles state-level emissions from flooded land remaining flooded land using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6.8 (pages 6-121 through 6-129) of the national *Inventory.* For this report, the state-level estimates were developed using Approach 1. Estimates of emissions from reservoirs and associated inundation areas and other constructed waterbodies that include freshwater ponds and canals/ditches include all states and the District of Columbia.

5.1.8.3 Uncertainty

The overall uncertainty associated with national estimates from reservoirs and other constructed water bodies is described in Chapter 6 of the national *Inventory* (EPA 2023). Uncertainty for both reservoirs and other constructed waterbodies is developed using IPCC Approach 2. The total uncertainty for reservoirs is −1 %/+1.7%, and the total uncertainty for other constructed water bodies is −0.7%/+1%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.8 of the national *Inventory*.

5.1.8.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.8 of the national *Inventory* (pages 6-128, 6-129, and 6-138), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.8.5 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates, given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions from flooded land remaining flooded land, see the planned improvements discussion on pages 6-129, 6-138, and 6-139 of Chapter 6.8 in the national *Inventory*.

5.1.8.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

IPCC (2019) *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. E.C. Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, S. Ngarize A. Osako, Y. Pyrozhenko, P. Shermanau, and S. Federici (eds).

Full citations of references included in Chapter 6.8 (for flooded land remaining flooded land) of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.9 Land Converted to Wetlands (NIR Section 6.9)

This section describes methods for estimating state-level CO_2 and CH_4 emissions from managing wetlands, as consistent with the national *Inventory,* specifically:

- Land converted to coastal wetlands (CO_2 and CH_4)
- Land converted to flooded land (CO_2 and CH_4)

5.1.9.1 Land Converted to Coastal Wetlands

5.1.9.1.1. Background

Land converted to vegetated coastal wetlands occurs as a result of inundation of unprotected low-lying coastal areas with gradual sea-level rise, flooding of previously drained land behind hydrological barriers, and active restoration and creation of coastal wetlands through removing hydrological barriers. Land use conversions into coastal wetlands can result in C stock changes to all coastal wetland carbon pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon) and emissions of CH_4 if inundated with fresh water. This section provides estimates of CO_2 and CH_4 emissions and removals resulting from converting cropland, grassland, wetlands, settlements, and other lands to vegetated coastal wetlands.

5.1.9.1.2. Methods/Approach

To compile national estimates of C stock changes and CH_4 emissions from land converted to vegetated coastal wetlands for the national *Inventory*, estimates for each state with coastal wetlands and the District of Columbia were produced and summed into a national total. A description of the methods and data used to estimate state-level emissions is provided in Chapter 6, Section 6.9 (pages 6-139 through 6-145) of the national *Inventory.* Please note that estimates for Hawaii and Alaska are not included in the national total or available at the state level at this time.

States (plus the District of Columbia) with coastal wetlands currently included in the national *Inventory* are Alabama, California, Connecticut, Delaware, Florida, Georgia, Louisiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, South Carolina, Texas, Virginia, and Washington.

5.1.9.1.3. Uncertainty

Underlying uncertainties in estimates of soil carbon removal factors, biomass change, dissolved organic matter, and CH_4 emissions include error in uncertainties associated with Tier 2 literature values of soil carbon removal estimates, biomass stocks, dissolved organic matter, and IPCC default CH_4 emissions factors; uncertainties linked to interpretating remote sensing data; and assumptions that underlie the methodological approaches applied. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.9 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −20%/+20% for biomass C stock change, −25.8%/+25.8% for dead organic matter C stock change, −18.7%/+18.7% for soil C stock change, and −29.9%/+29.9% CH_4 emissions. The combined uncertainty across all subcategories is −42.6%/+42.6%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the uncertainty discussion in Section 6.9 of the national *Inventory*.

5.1.9.1.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.9 of the national *Inventory* (page 6-144), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series

5.1.9.1.5. Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to vegetated coastal wetlands, see the planned improvements discussions on pages 6-44 and 6-145 of Chapter 6.9 in the national *Inventory*.

5.1.9.1.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of the references included in Chapter 6.9 (Lands Converted to Coastal Wetlands) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.9.2 Land Converted to Flooded Land

5.1.9.2.1. Background

Land that has been flooded for less than 20 years is defined as land converted to flooded land. The distinction is based on literature reports that CO_2 and CH_4 emissions are high immediately following flooding (as labile organic matter is rapidly degraded) but decline to a steady background level approximately 20 years after flooding. Both CO_2 and CH_4 emissions are inventoried for both reservoirs and associated inundation areas and freshwater ponds within the other constructed waterbodies subcategory of land converted to flooded land.

5.1.9.2.2. Methods/Approach

To compile national estimates of C stock changes and CH4 emissions from land converted to flooded land for the national Inventory, estimates for each state and the District of Columbia were produced and summed into a national total. A description of the methods and data used to estimate state-level emissions is provided in Chapter 6, Section 6.9 (pages 6-145 through 6-160) of the national Inventory.

5.1.9.2.3. Uncertainty

The overall uncertainty associated with national estimates of CO_2 and CH_4 from reservoirs and other constructed water bodies on flooded land remaining flooded land is described in Chapter 6.9 of the national *Inventory* (EPA 2023). Uncertainty for both reservoirs and other constructed water bodies is developed using IPCC Approach 2. The total uncertainty for CO_2 and CH_4 emissions from reservoirs is −14.9%/+16.8%, and the total uncertainty for CO_2 and CH_4 emissions from other constructed waterbodies is −2.1%/+2.6%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.9 of the national *Inventory*.

5.1.9.2.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.9 of the national *Inventory* (pages 6-153 and 6-160), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.9.2.5. Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to flooded land, see the planned improvements discussions on pages 6-153, 6-154, and 6-160 of Chapter 6.9 in the national *Inventory*.

5.1.9.2.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.).

Full citations of the references included in Chapter 6.9 (for land converted to flooded land) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10 Settlements Remaining Settlements (NIR Section 6.10)

This section presents methods used to estimate state-level CO_2, CH_4, and N_2O emissions and removals from settlements remaining settlements consistent with the national *Inventory*. Settlements are land uses where human populations and activities are concentrated. The section is organized to address the following subcategories:

- CO_2 emissions from drained organic soils (CO_2)
- Changes in C stocks in settlement trees (CO_2)
- N_2O emissions from settlement soils (N_2O)
- C stock changes in landfilled yard trimmings and food scraps (CO_2)

5.1.10.1 Soil C Stock Changes

5.1.10.1.1. Background

Soil organic C stock changes for settlements remaining settlements occur in both mineral and organic soils. However, the United States does not estimate changes in soil organic C stocks for mineral soils in settlements remaining settlements. This approach is consistent with the assumption of the Tier 1 method in the 2006 IPCC Guidelines (IPCC 2006) that inputs equal outputs, and therefore the soil organic C stocks do not change. In contrast, drainage of organic soils can lead to continued losses of carbon for an extended period of time.

Drainage of organic soils is common when wetland areas have been developed for settlements. Organic soils, also referred to as Histosols, include all soils with more than 12%–20% organic carbon by weight, depending on clay content. The organic layer of these soils can be very deep (i.e., several meters), and form under inundated conditions that result in minimal decomposition of plant residues. Drainage of organic soils leads to aeration of the soil that accelerates decomposition rate and CO_2 emissions. Due to the depth and richness of the organic layers, carbon loss from drained organic soils can continue over long periods of time, which vary depending on climate and composition (i.e., decomposability) of the organic matter. See Chapter 6 of the national *Inventory* for more information (EPA 2023).

5.1.10.1.2. Methods/Approach

EPA compiles state-level estimates of soil C stock changes using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.10 (pages 6-161 through 6-164) of the national *Inventory*. EPA used a hybrid of Approach 1 and Approach 2 for state-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series were only estimated at the national scale using a linear extrapolation method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Estimates are included for all states except Alaska.

5.1.10.1.3. Uncertainty

The overall uncertainty associated with national estimates from soil C stock changes is described in Chapter 6 of the national *Inventory* (EPA 2023). Uncertainty for the Tier 2 approach is derived using a Monte Carlo approach. The uncertainty for total soil C stock changes in 2020 is −54%/+54%.

5.1.10.1.4. Recalculations

No recalculations were applied for this current report, consistent with the national *Inventory* (see Section 6.9, page 6-163).

5.1.10.1.5. Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from soil C stock changes, see the planned improvements discussions on pages 6-163 and 6-164 of Chapter 6.10 in the national *Inventory*.

5.1.10.1.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of the references included in Chapter 6.10 (for soil C stock changes) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10.2 Changes in C Stocks in Settlement Trees

5.1.10.2.1. Background

In settlement areas, the anthropogenic impacts on tree growth, stocking, and mortality are particularly pronounced (Nowak 2012) in comparison to forest lands where non-anthropogenic forces can have more significant impacts. Trees in settlement areas of the United States are a significant sink over the time series. Dominant factors affecting carbon flux trends for settlement trees are changes in the amount of settlement area (increasing sequestration due to more settlement lands and trees) and net changes in tree cover (e.g., tree losses versus tree gains through planting and natural regeneration), with percent tree cover trending downward recently. In addition, changes in species composition, tree sizes, and tree densities affect base carbon flux estimates. Annual sequestration increased by 35% between 1990–2021 due to increases in settlement area and changes in tree cover. Trees in settlements often grow faster than forest trees because of their relatively open structure (Nowak and Crane 2002). Because tree density in settlements is typically much lower than in forested areas, the C storage per hectare of land is in fact smaller for settlement areas than for forest areas. Also, percent tree cover in settlement areas is less than in forests, and this tree cover varies significantly across the United States (e.g., Nowak and Greenfield 2018a).

5.1.10.2.2. Methods/Approach

To compile national estimates of CO_2 emissions and removals from C stock changes from settlement trees for the national *Inventory*, estimates for all 50 states and the District of Columbia were produced and summed into a national total. In this case, EPA is applying an Approach 1 method (i.e., using methods consistent with the national

Inventory). A description of the methods and data used to estimate changes in C stocks in settlement trees is found in Chapter 6, Section 6.10 (pages 6-164 through 6-172), of the national *Inventory* (EPA 2023).

5.1.10.2.3. Uncertainty

Uncertainty associated with changes in C stocks in settlement trees includes the uncertainty associated with settlement area, percent tree cover in developed land and how well it represents percent tree cover in settlement areas, and estimates of gross and net carbon sequestration for each of the 50 states and the District of Columbia. Additional uncertainty is associated with the biomass models, conversion factors, and decomposition assumptions used to calculate carbon sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there is likely some overlap between the settlement tree carbon estimates and the forest tree carbon estimates (e.g., Nowak et al. 2013). IPCC Approach 2 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.10 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 for C stock change are −51%/+51%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the uncertainty discussion in Section 6.10 of the national *Inventory*.

5.1.10.2.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.10 of the national *Inventory* (pages 6-171 and 6-172), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.10.2.5. Planned Improvements

The planned improvements are consistent with those planned for improving national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To review planned improvements to refine methods for estimating changes in settlement tree C stocks, see the planned improvements discussion on page 6-172 of Section 6.10 in the national *Inventory* for a description of future work to further refine these estimates.

5.1.10.2.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Nowak, D.J. (2012) Contrasting natural regeneration and tree planting in 14 North American cities. Urban Forestry and Urban Greening. 11: 374– 382

Nowak, D.J. and D.E. Crane (2002) Carbon storage and sequestration by urban trees in the United States. Environmental Pollution 116(3):381–389

Nowak, D.J. and E.J. Greenfield (2018a) U.S. urban forest statistics, values and projections. Journal of Forestry. 116(2):164–177

Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra (2002) Brooklyn's Urban Forest. General Technical Report NE290. U.S. Department of Agriculture Forest Service, Newtown Square, PA

Nowak, D.J., E.J. Greenfield, R.E. Hoehn, and E. Lapoint (2013) Carbon storage and sequestration by trees in urban and community areas of the United States." Environmental Pollution 178: 229-236

Full citations of the references included in Chapter 6.10 (for changes in C stocks in settlement trees) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10.3 N_2O Emissions from Settlement Soils

5.1.10.3.1. Background

Of the synthetic nitrogen fertilizers applied to soils in the United States, approximately 1–2% are currently applied to lawns, golf courses, and other landscaping within settlement areas, and contribute to soil N_2O emissions. The area of settlements is considerably smaller than other land uses that are managed with fertilizer, particularly cropland soils, and therefore, settlements account for a smaller proportion of total synthetic fertilizer application in the United States. In addition to synthetic nitrogen fertilizers, a portion of surface-applied biosolids (i.e., treated sewage sludge) is used as an organic fertilizer in settlement areas, and drained organic soils (i.e., soils with high organic matter content, known as Histosols) also contribute to emissions of soil N_2O.

Nitrogen additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on site due to the nitrogen additions in the form of synthetic fertilizers and biosolids, as well as enhanced mineralization of nitrogen in drained organic soils. Indirect emissions result from fertilizer and biosolids nitrogen that is transformed and transported to another location in a form other than N_2O (i.e., NH_3 and nitrogen oxide volatilization, nitrate leaching and runoff), and later converted into N_2O at the offsite location. The indirect emissions are assigned to settlements because the management activity leading to the emissions occurred in settlements (EPA 2023).

5.1.10.3.2. Methods/Approach

EPA compiles state-level estimates of N_2O emissions from settlement soils using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.10 (pages 6-172 through 6-175) of the national *Inventory* . EPA applied a hybrid Approach 1 and Approach 2 for state-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2015 for synthetic nitrogen and nitrogen inputs from drained organic soils. The remaining years in the time series were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Soil N_2O emissions for additions of biosolid nitrogen are only estimated at the national scale for the entire time series. For this source of nitrogen, soil N_2O emissions were disaggregated to the state level based on the proportion of the U.S. population occurring in each state. Estimates are included for all states except Alaska.

5.1.10.3.3. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.10 of the national *Inventory* (page 6-175), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.10.3.4. Uncertainty

The overall uncertainty associated with national estimates from N_2O emissions from settlement soils is described in Chapter 6 of the national *Inventory* (EPA 2023). As described:

- The amount of N_2O emitted from settlement soils depends not only on nitrogen inputs and area of drained organic soils, but also on a large number of variables that can influence rates of nitrification and denitrification, including organic carbon availability; rate, application method, and timing of nitrogen input; oxygen gas partial pressure; soil moisture content; pH; temperature; and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O emissions is complex and highly uncertain. The IPCC default methodology does not explicitly incorporate any of these variables, except variation in the total amount of fertilizer nitrogen and biosolids application, which then leads to uncertainty in the results.
- Uncertainties exist in both the fertilizer nitrogen and biosolids application rates in addition to the emissions factors. Uncertainty in the area of drained organic soils is based on the estimated variance from the NRI survey. For biosolids, there is uncertainty in the amounts of biosolids applied to nonagricultural lands and used in surface disposal. These uncertainties are derived from variability in several factors, including nitrogen content of biosolids, total sludge applied in 2000, wastewater existing flow in 1996 and 2000, and the biosolids disposal practice distributions to nonagricultural land application and surface disposal. In addition, there is uncertainty in the direct and indirect emissions factors that are provided by IPCC (2006).

Uncertainty is propagated through the calculations of N_2O emissions from fertilizer nitrogen and drainage of organic soils based on a Monte Carlo analysis. The overall levels of uncertainty for national *Inventory* direct N_2O emissions from soils and indirect N_2O emissions are −57%/+85% and −78%/+223%, respectively.

5.1.10.3.5. Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating N_2O emissions from settlement soils, see the planned improvements discussions on page 6-175 of Chapter 6.10 in the national *Inventory*.

5.1.10.3.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of the references included in Chapter 6.10 (for N_2O emissions from soils) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10.4 Changes in Yard Trimmings and Food Scrap C Stocks in Landfills

5.1.10.4.1. Background

In the United States, yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are put in landfills. Carbon contained in landfilled yard trimmings and food scraps can be stored for very long periods. C stock changes in yard trimmings and food scraps and associated CO_2 emissions and removals are reported under settlements remaining settlements because the bulk of the carbon, which comes from yard trimmings, originates from settlement areas. While the majority of food scraps originate from cropland and grassland, in the national *Inventory* they are reported with the yard trimmings in the settlements remaining settlements section. Additionally, landfills are considered part of the managed land base under settlements and reporting these C stock changes that occur entirely within landfills fits most appropriately in the settlements remaining settlements section.

5.1.10.4.2. Methods/Approach

State-level C stocks were compiled using Approach 2 by allocating net national changes in C stocks and associated emissions and removals to states, the District of Columbia, and U.S. territories based on their fraction of total U.S. land area classified as urban area. “Urban area” is defined by the USDA as land area containing densely populated areas with at least 50,000 people (urbanized areas) and densely populated areas with 2,500 to 50,000 people (urban clusters). EPA assumed “urban area” matched the definition of “settlements area” for the purpose of state-level estimates. This approach was applied due to unavailability of state-level activity data on mass of yard trimmings and food scraps discarded to managed landfills, and the assumption that most yard trimmings and food scraps would be generated in densely populated areas. EPA used settlement area estimates from the USDA Economic Research Service’s Major Land Uses data. The total settlements area in the United States includes all U.S. states and the District of Columbia but excludes territories such as Puerto Rico.

State emissions were calculated using the following stepwise process:

1. EPA obtained U.S. settlements area data from the USDA (2017). For years without U.S. settlements area data (2013–2021), settlements area data were forecast using 2002–2012 data to capture the most recent available trends.
2. The fraction of total settlements area was calculated for each state, including the District of Columbia, by dividing the state settlements area by the U.S. total settlements area.
3. The state fraction of settlements area was multiplied by the total national yard trimmings and food scraps C stocks from the 1990–2021 national *Inventory* to estimate state-level yard trimming and food scrap C stocks. This calculation was also performed for grass, leaves, branches, and food scraps to yield state-level C stocks for each subcategory.

Data Appendix E-9 to this report provides activity data related to total land in urban areas and percent of total land area that occurs in urban areas by state (including the District of Columbia and Puerto Rico) across the time series. These data are used in the calculations of carbon storage in landfilled yard trimmings and food scraps in each state.

5.1.10.4.3. Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 from changes in yard trimmings and food scraps C stocks were calculated using the Approach 2 methodology (IPCC 2006). As described further in Chapter 6 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −72%/+56% for CO_2. State-level estimates have a higher uncertainty due to apportioning the national estimates to states based on their fraction of the settlements area. These assumptions were required because of a general lack of available state-level data on yard trimmings and food scraps. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.10 of the national *Inventory*.

5.1.10.4.4. Recalculations

Changes that resulted from recalculations to the state-level estimates in 2020 were due to expected forecasted data changes and are reflected in the national *Inventory*; see Section 6.10, page 6-181.

5.1.10.4.5. Planned Improvements

EPA will review and revise the state-level methodology over the time series, and as appropriate, assess if other information would better reflect state-level activity (e.g., mass of yard trimmings and food scraps discarded to managed landfills) to improve the accuracy of the estimates. EPA will monitor updates to the USDA urban area data. Sources of settlements area data for Puerto Rico and other U.S. territories are also needed to provide a more accurate estimate of net C stock changes in the United States. Additional planned improvements are consistent with those planned for improving national estimates given that the underlying methods for state GHG estimates are the derived from those in the national *Inventory*. For example, updated data are expected in a new release of the *Advancing Sustainable Materials Management: Facts and Figures* report for 2019, 2020, and 2021. The discussion of planned improvements to refine methods for estimating changes in C stocks in landfilled yard trimmings at the national level starts on page 6-181 of Chapter 6.10 in the national *Inventory*.

5.1.10.4.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks..

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

USDA (U.S. Department of Agriculture) (August 2017) Urban Area, 1945–2012, by State: Densely-populated areas with at least 50,000 people (urbanized areas) and densely-populated areas with 2,500 to 50,000 people (urban clusters). U.S. Department of Agriculture, Economic Research Service. Available online at: https://www.ers.usda.gov/data-products/major-land-uses/

Full citations of all other references relevant to estimating landfilled yard trimmings and food scraps C stock changes included in Chapter 6.10 (Settlements Remaining Settlements) are listed in Chapter 10 (References) of the national *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.11 Land Converted to Settlements (NIR Section 6.11)

5.1.11.1 Background

Land converted to settlements includes all settlements in an inventory year that had been in at least one other land use during the previous 20 years. For example, cropland, grassland, or forest land converted to settlements during the past 20 years would be reported in this category. Converted lands are retained in this category for 20 years as recommended by IPCC (2006). The national *Inventory* includes all settlements in the United States except Alaska. Areas of drained organic soils on settlements in federal lands are also not included in the national *Inventory*.

Land use change can lead to large losses of carbon to the atmosphere, particularly conversions from forest land. Moreover, conversion of forests to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally, although this source may be declining globally according to a recent assessment.

The IPCC (2006) recommends reporting changes in biomass, dead organic matter, and soil organic C stocks due to land use change. All soil organic C stock changes are estimated and reported for land converted to settlements, but there is limited reporting of other pools in the national *Inventory*. Loss of aboveground and belowground biomass, dead wood, and litter carbon are reported for forest land converted to settlements, but not for other land use conversions to settlements (EPA 2023).

5.1.11.2 Methods/Approach

EPA compiles state-level estimates of land converted to settlements using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.10 (pages 6-182 through 6-188), of the national *Inventory.* EPA used a hybrid Approach 1 and Approach 2 for state-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2021 for biomass, standing dead, dead wood, and litter, and for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series for soil organic C stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2021. Estimates are included for all states except Alaska.

5.1.11.3 Uncertainty

The overall uncertainty associated with national estimates from land converted to settlements is described in Chapter 6 of the national *Inventory* (EPA 2023). As described:

- The uncertainty analysis for carbon losses for forest land converted to settlements is conducted in the same way as the uncertainty assessment for forest ecosystem carbon flux in the forest land remaining forest land category. For additional details, see the uncertainty analysis in Annex 3.13.
- The uncertainty analysis for mineral soil organic C stock changes and annual carbon emission estimates from drained organic soils in land converted to settlements is estimated using a Monte Carlo approach, which is also described in the cropland remaining cropland section of the national *Inventory*.

The overall level of uncertainty for national *Inventory* land converted to settlements estimates is −34%/+34%.

5.1.11.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.11 of the national *Inventory* (page 6-187), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.11.5 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to settlements, see the planned improvements discussions on pages 6-187 and 6-188 of Chapter 6.11 in the national *Inventory*.

5.1.11.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of the references included in Chapter 6.11 (Land Converted to Settlements) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.12 Other Land Remaining Other Land (NIR Section 6.12) and Land Converted to Other Land (NIR Section 6.13)

Other Land is a land use category that includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land use categories (i.e., forest land, cropland, grassland, wetlands, and settlements). Following the guidance provided by the IPCC (2006), C stock changes and non-CO_2 emissions are not estimated for other land because these areas are largely devoid of biomass, litter, and soil carbon pools. However, C stock changes and non-CO_2 emissions are estimated for land converted to other land during the first 20 years following conversion to account for legacy effects. While the magnitude of these area changes is known (see national *Inventory,* page 6-11*,* Table 6-5), research is ongoing to track carbon across other land remaining other land and land converted to other land. Until reliable and comprehensive estimates of carbon across these land use and land use change categories can be produced, it is not possible to separate CO_2, CH_4, or N_2O fluxes on land converted to other land from fluxes on other land remaining other land. Emissions and removals from other lands and lands converted to other lands will be included in future versions of this publication when they are integrated into the national *Inventory*. See Chapters 6.12 and 6.13 on page 6-189 of the national *Inventory* (EPA 2023).

5.1.12.1 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.