Appendix E: Detailed Inventory Methods

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This Appendix describes detailed instructions on how to calculate emissions and removals for the categories in the Land-based Net Carbon Inventory (Inventory). The development of the statewide inventory requires multiple calculations and data processing steps. Tools and procedures for data collection and processing, and GHG inventory compilation are outlined in this document. The term "activity data" is used throughout this Appendix and refers to information about the scale or magnitude of human activities that contribute to greenhouse gas (GHG) emissions or removals over a specific period (2006 IPCC Guidelines).

Land Use Classification

Land Use Definitions

All land in Oregon must be classified and accounted for without duplication or omission. The Inventory applies IPCC definitions of land use categories, which are also used in the U.S. National Greenhouse Gas Inventory (NGHGI). Applying a consistent approach to the NGHGI enables comparisons across states and the use of national estimates to fill in gaps in state-level inventories. The approach is grounded in consistent land representation − defining and characterizing all the land in the State of Oregon − to ensure that emissions and removals associated with different land uses and land covers are accurately estimated, avoiding double counting or omissions.

IPCC guidance is to segment the total geographical area covered by the inventory into six (6) main land categories: Forest Land, Cropland, Grassland, Wetlands, Developed Land, and Other Land (typically barren land such as rock, ice, etc.). Land is further defined as land remaining in a land category (e.g., Forest Land remaining Forest Land) and land converted to another land category (Cropland converted to Forest Land). This allows for an inventory to reflect carbon dynamics and estimate carbon emissions and removals associated with different ecological/management systems and land use change. The state entity developing the inventory refines the definitions for each land category to ensure that all land can be classified into a discrete land category. Currently, land definitions are based on the National Land Cover Dataset (NLCD) classifications. They differ from the NGHGI which uses additional data sets (USDA National Resource Inventory (NRI) and USDA Forest Service Forest Inventory Analysis (FIA) program) for land classifications. Other notable forest inventories produced by federal (USDA) and state (Oregon Department of Forestry) differ in their estimated areas for land areas due to various reasons, with underlying dataset and classification schemes being primary sources of these differences. **See Appendix A for land classification definitions.**

NLCD is used because it provides a consistent land representation dataset with wall-to-wall coverage of the state area over the inventory time series, starting in 1990 to present. The main differences between the land category definitions employed by Oregon (through assignment of NLCD classes) and those adopted for use in the NGHGI include thresholds on vegetation cover and size of land tract for forests, threshold for the size of land tract for Developed Land, allocation of pastures and hay production, agroforestry, and wooded wetlands. All land in Oregon is designated as managed land following the convention established for land-based GHG inventories (Ogle, 2018).

Land Remaining Land & Land Converted to Another Land

For GHG accounting purposes, each land-use category is further subdivided into land remaining in that category (e.g., Forest Land remaining Forest Land) and land converted from one category to another (e.g., Cropland converted to Forest Land) as shown in Figure 1.

Figure 1: Land Categories and conversions

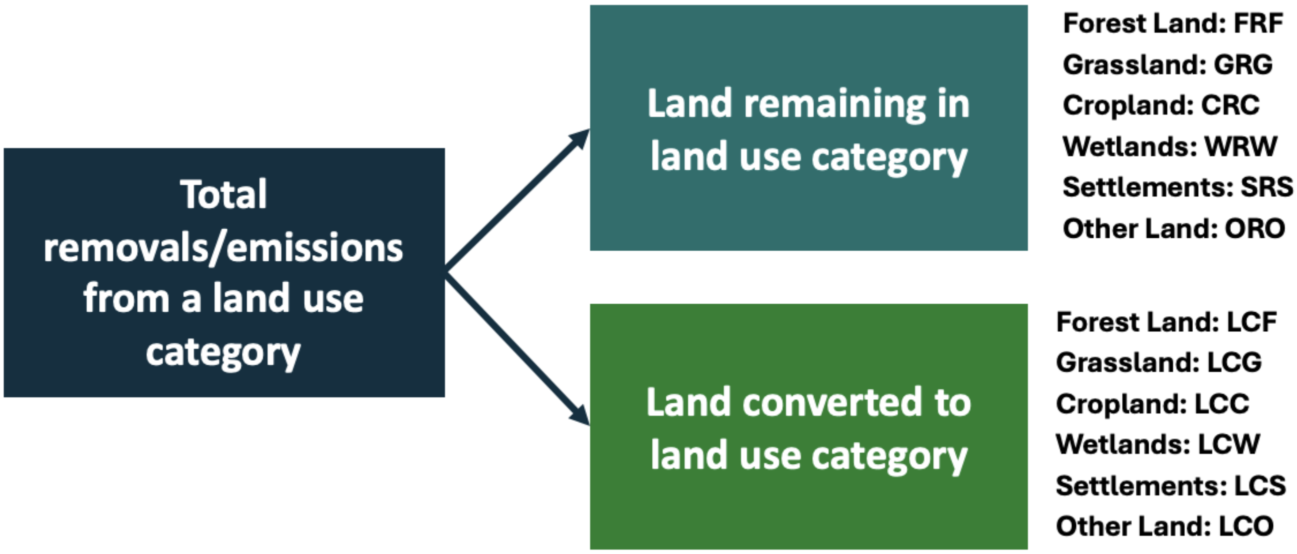

Figure 1. Categorization of land use types for the purpose of estimating total GHG emissions and removals. FRF=Forest Land Remaining Forest Land, etc., LCF = Land converted to Forest Land, etc.

Land converted to another land category is further subdivided into categories based on the land category prior to transition, e.g., cropland converted to Forest Land, grassland converted to Forest Land, and so on. Emissions and removals are estimated for each of these subcategories and included under the Forest Land category in the Inventory. The total emissions/removals for each land use category are the sum of those from the land remaining and land converted (i.e., land gained) subcategories. This subcategorization is utilized to account for the unique impact of land use change on carbon dynamics and to enable defining a transitional period after land is converted and has differing characteristics compared to land remaining in the same category. For example, land converted to Forest Land, where young trees are planted, will have higher carbon accumulation rates in biomass than a mature forest. Likewise, soil organic carbon also takes time to reach a new equilibrium after land management changes. The IPCC Guidelines recommend a default transition of 20 years.

Given the gaps in the data set, the following data interpretation and logic were applied (Table 1). This data interpretation was conducted on a pixel-by-pixel basis using ArcGIS ArcPy (Python programming language adapted for ArcGIS).

Table 1: 20-year Transition Tracking Approach

NLCD Years	1990	1996	2001	2006	2011	2016	2021
Land Pixel	Forest	Grassland	Grassland	Grassland	Grassland	Grassland	Forest
Pixel size	30x30m	30x30m	30x30m	30x30m	30x30m	30x30m	30x30m
IPCC Transi-tion	Considered first year of inventory	Considered first year of	Still in transition. Is	Still in transition. Is	Still in transition. Is	Transitioned. Is transition	Transitions again and therefore

	and assumes all land as "remaining"	transition. Is transition ≧ 20 years? No.	transition ≧ 20 years? No.	transition ≧ 20 years? No.	transition ≧ 20 years? No.	≧ 20 years? Yes.	considers first year of transition. Is transition ≧ 20 years? No.
Land Classifi-cation	Forest Remaining Forest	Land Converted to Grassland	Land Converted to Grassland	Land Converted to Grassland	Land Converted to Grassland	Grassland Remaining Grassland	Land Converted to Forest

To further stratify activity data from the NLCD datasets, the data is joined with the following datasets to apply relevant methodology and emission factors:

- Oregon ecoregions (based on U.S. EPA Level 3 ecoregion designation)
- USDA SSURGO Soils database
- USDA Forest Service Forest Type Groups map
- NOAA Coastal Change Analysis Program (C-CAP)
- PMEP Geographic Tidal extent boundary

The classification approach and interpretation of each of these datasets are described below and in the relevant category sections. Consistent land representation enables adjustments and reduces errors for all land categories before disaggregating data into the main land categories used in the inventory. This spatial analysis was conducted for the years 1990, 1996, 2001, 2006, 2011, 2016, and 2021. Even though NLCD publishes annual land use datasets, these years were selected because they align with C-CAP datasets, which are needed for classifications of coastal wetlands and are published at this frequency. Land area per category is then linearly interpolated for years in between for a complete time series emissions estimate.

The next activity data update should occur when the next C-CAP dataset is published to maintain a consistent cadence for the inventory. At that time, any other updated datasets used for land stratification should also be used. For years following the most recent spatial data join (i.e., 2021 as of December 2025), the areas for each land category are held constant until the next data set is published and processed to ensure consistency of total land area within the state boundaries. Estimates within each category may also hold the parameters constant or adjust based on additional information if available, as noted below in the sections for each land category. Note, for categories where activity data other than land area is used, estimates are based on annual data and extend for the entire period that the data is available. Once a new dataset is published and data is stratified according to outlined attributes, the emissions estimates should be recalculated based on the new data.

Ecoregions and Climate Zones

To stratify land across the state by climate characteristics, the U.S. EPA Ecoregion Level III was used. The EPA Ecoregion Level III system is part of a hierarchical framework developed by the U.S. EPA to classify areas of the United States based on their ecological similarities. Each Level III ecoregion represents an area with relatively homogeneous climate, landforms, soils, vegetation, hydrology, and wildlife. The system helps in environmental assessment, resource management, and policy development by organizing the country's landscape into regions that share similar ecological characteristics and processes. The U.S. EPA ecoregion map was adapted by the Oregon Department of Fish and Wildlife by combining the ecoregions 'Northern Basin and Range' and 'Snake River Plain' into one (henceforth named 'Northern Basin and Range') to align with a statewide conservation strategy. For inventory purposes, these ecoregions are used to determine emission parameters for various vegetation classes. Furthermore, ecoregions were also mapped to the IPCC climate zones to enable allocation of emission parameters at a more granular spatial scale. Table 2 summarizes Oregon's ecoregions and climate zones. This information remains static over time unless U.S. EPA ecoregions are revised in the future.

Table 2: Oregon Ecoregions and Climate Zones

Oregon Ecoregion	IPCC climate zone
Blue Mountains	Cool Temperate Dry
Coast Range	Warm Temperate Moist
Columbia Plateau	Warm Temperate Dry
Eastern Cascades Slopes and Foothills	Cool Temperate Dry
Klamath Mountains	Warm Temperate Moist
Northern Basin and Range	Cool Temperate Dry
West Cascades	Warm Temperate Moist
Willamette Valley	Warm Temperate Moist

Soil Characteristics

The USDA Soil Survey Geographic Database (SSURGO) is used to classify soil order into mineral and organic soils and obtain reference soil organic carbon (SOC) stock values unless otherwise specified. From the state-level SSURGO geodatabase, only soil taxonomy was used. The soil taxonomy is found in the table *component* within the geodatabase. This table was joined to the MUPOLYGON shapefile and then converted to a raster using NLCD as a resolution and boundary extent. In areas where no data is available in the SSURGO database, mineral soil taxonomy was assigned.

USDA soil taxonomic order was further assigned to an IPCC soil type to help select emission factors and methodology, as shown in Table 3. Reference SOC stock values at 30 cm depth are used as the reference for mineral soils for all land categories and are summarized in Table 3. The reference SOC stock value for Inland Wetland mineral soil was derived from Uhran et al. 2022, which provides estimates of SOC for the 1 m depth profile. Therefore, 30% of the published value was estimated to represent 30cm depth. A weighted average by area (2021 NLCD activity data) across all ecoregions-wetland classes was calculated, resulting in a value of 97 tonne C ha^{-1}.

The SSURGO dataset contains data collected via surveys and measurements over an extended period and is refreshed annually on July 1st. For the preparation of the 1990-2024 inventory, the 2024 dataset was used and should be properly archived locally by inventory compilers (Soil Survey Staff. Gridded Soil

Survey Geographic (gSSURGO) Database for OR. United States Department of Agriculture, Natural Resources Conservation Service. Available online at http://datagateway.nrcs.usda.gov/. 20240913 (202410 official release)). The most recent dataset should be utilized when conducting spatial data processing to prepare activity data.

Table 3: Mineral soil types and associated SOC reference values at 30 cm depth, by climate zone in tonne C ha^{-1}. (95% comment intervals are provided in parentheses)

Soil types	IPCC Soil categories	USDA taxonomic order	Cool Temperate, Dry	Warm Temperate, Dry	Warm Temperate, Moist	Reference
Mineral	High-activity clay	Alfisols, Mollisols, Vertisols	42 (±2.7)	37 (±2.2)	51 (±2.0)	USDA Methods of Entity-Scale Inventory 2024
Mineral	Low-activity clay	Aridisols, Inceptisols, Ultisols	45 (±5.9)	25 (±2.7)	40 (±2.4)	USDA Methods of Entity-Scale Inventory 2024
Mineral	Sandy	Entisols	24 (±9.4)	16 (±4.7)	30 (±3.9)	USDA Methods of Entity-Scale Inventory 2024
Mineral	Volcanic	Andisols	124 (±22.3)	124 (±22.3)	124 (±22.3)	USDA Methods of Entity-Scale Inventory 2024
Mineral	Spodic Soils	Spodisols	86 (±12.7)	86 (±12.7)	107 (±16.3)	USDA Methods of Entity-Scale Inventory 2024
Mineral	Wetland	*All*	97 (±9.4)	97 (±9.4)	97 (±9.4)	Derived from Uhran et al. 2022

Land Category Specific Attributes

Additional data sets were overlaid onto the NLCD maps for state-specific characteristics. Table 4 summarizes the spatially explicit data used to further stratify Oregon's lands.

Table 4: Land-specific datasets used to stratify land categories

Type of Attribute	Publisher	Year	Land Type Relevancy
Soil taxonomy	SSURGO	2024	All Lands
Ecoregions	EPA	N/A	All Lands
Forest Type Groups	USFS Forest Inventory & Analysis (FIA)	2025 (data surveyed from 2014-2018)	Forest Land
C-CAP	NOAA	1996, 2001, 2006, 2010, 2016, 2021	Wetlands
PMEP (Tidal Extent)	Pacific Marine and Estuarine Fish Habitat Partnership (PMEP)	2010, 2011	Wetlands

Tidal Connectivity	The Nature Conservancy (TNC)	2011-2026	Wetlands
Aquatic Setting (Tidal Connectivity)	PMEP, Oregon Coastal Management Program	2011-2019	Wetlands
MHHWS (Tidal Extent)	Nate Herold, NOAA	N/A	Wetlands
Tree canopy cover	NLCD	1990, 1996, 2001, 2006, 2010, 2016, 2021	Developed Land
Oregon counties	N/A	N/A	Cropland

Forest Type Group

For Forest Land, the US Forest Service map was overlaid on the NLCD maps to assign the forest group to the NLCD land forest classes (USDA Forest Service Forest Inventory & Analysis Program. Science by Barry T. Wilson (USFS) Cartography by Emily Meriam (ESRI), https://www.arcgis.com/home/item.html?id=10760c83b9e44923bd3c18efdaa7319d). The following forest type groups occur in Oregon:

- Alder/maple
- Aspen/birch
- Douglas-fir
- Elm/Ash/Cottonwood
- Fir/spruce/mountain hemlock
- Hemlock/Sitka spruce
- Lodgepole pine
- Mixed Conifer Group
- Other Western Hardwoods
- Other western softwoods
- Pinyon/juniper
- Ponderosa pine
- Tanoak/laurel
- Western Larch
- Western oak
- Western white pine

The forest type group attribute is used to determine carbon density parameters for estimating carbon fluxes on Forest Land remaining Forest Land, as well as to Forest Land converted to other land categories. This map was considered atemporal and therefore used to classify Forest Land across the whole time series, but may be updated occasionally. If available, the updated map should be used in future activity data preparation, with its vintage properly documented.

Tidal Connection and Extent

For Wetlands, the first step was determining two attributes of land: Oregon's tidal extent and tidal connectivity.

Two layers were joined to create the tidal extent (PMEP and MHHWS). This extent determines the division between coastal (tidal) areas and inland (non-tidal) areas. Additionally, to create the tidal connectivity geospatial layer, four layers were overlaid to determine connectivity.

1. *estuary_restoration_data.gdb* – Used field "Tidal Connect" to attribute connectivity.
2. *coos_final_sept_2025.gdb* - Used field "Tidal Connect" to attribute connectivity.
3. *oregon_tidal_connectivity_wetland.gpkg* – Used field "DIKED_YN" (value = "Yes") to determined diked wetlands.
4. *fixed_reproj_colriv_tconn.gpkg* – Used field "AQUATIC_CARTO" values *2.1. A107* and *2.3.A107* to determine diked and disconnected areas.

The values from #1 and #2 override the values in #3 and #4, where "Disconnected" labels are found, as these are updated layers. Where gaps in the updated layers exist, values from #3 and #4 are used to identify tidal connectivity. A final harmonized raster layer was created using this logic, where values are labeled "Connected" or "Disconnected."

Once the tidal extent layer was created, C-CAP values were superposed to create a tidal extent layer with C-CAP attributes. This layer is used to spatially identify and classify NLCD wetland areas into coastal wetlands. Hence, wetland areas which do not overlay with the tidal extent layer and therefore considered inland wetlands. To apply appropriate, currently available, emission factors in estimating emissions, NLCD wetland sub-classes classified as coastal are assigned to a category based on the NOAA Coastal Change Analysis Program (C-CAP; NOAA). The C-CAP maps are available from 1996, 2001, 2006, 2010, 2016, and 2021 for the entire state of Oregon at 30m resolution. Updated maps are released approximately every 5 years. The wetlands used in the C-CAP dataset include:

- Open water
- Palustrine aquatic bed
- Palustrine forested wetland
- Palustrine scrub/shrub wetland
- Palustrine emergent wetland (persistent)
- Estuarine aquatic bed
- Estuarine forested wetland
- Estuarine scrub/shrub wetland
- Estuarine emergent wetland

It was noted during preliminary analysis and comparison between the NLCD and C-CAP datasets that NLCD tends to classify certain areas as wetland that C-CAP identifies as cultivated land (Cultivated Crops, Pasture Hay), and in some cases, NLCD maps wetland where C-CAP designates a shoreline. As a result, NLCD reports a larger total coastal wetland area compared to C-CAP. It's likely that these are former tidal wetlands that are used for farming or other purpose that have been diked or are historically diked and are now seasonally wetted. Therefore, the areas where C-CAP classified land as Cultivated Crops or Pasture Hay and NLCD classified the same land as Woody or Herbaceous Wetland, special wetland subclassed called 'agricultural (crop)' and 'grazing (pasture)' wetland were created. These new subclasses were included in the total area of the wetland category.

Tree Canopy

Tree Canopy layer from NLCD was used to derive mean tree coverage on Developed Land. In ArcGIS, *Zonal Statistics as Table* geoprocessing tool was used to calculate mean tree cover percentage on Developed Land. Values were calculated for NLCD classes considered Developed Land (i.e., Developed, High Intensity, Developed, Low Intensity, Developed, Medium Intensity, Developed, Open Space) for each year of the NLCD datasets used for the inventory.

General Methodology

Choosing A Methodological Tier

The complexity of the quantification methodology used to estimate emissions and removals depends on data availability (2006 IPCC Guidelines, Vol. 4, Ch. 1, Box 1.1). Table 5 summarizes the IPCC's methodological tier structure and outlines trade-offs for their selection. Different tiers may be chosen for different sub-categories depending on data availability. Choice of tier can change over time as a result of changes in availability of data and advanced methodologies.

Table 5: IPCC guidelines tiers and trade-offs and considerations when determining the calculation method.

Tier	Methodological description	Trade-offs and considerations
1	Employs default emission factors and default estimation methods, available in IPCC guidelines	Simplest to use, not location-specific; may not be sufficient to capture mitigation efforts of some activities; is generally less accurate than the results under the other tiers
2	May use the same methodologies as Tier 1, or country or state-specific methodologies where proven to be more accurate than IPCC default parameters; applies emission factors and parameters based on location-specific data	Requires national or state data and research results to justify methodological decisions; estimates reflect location-specific ecosystem characteristics and climatic regions; should be used for key categories
3	Employs empirical or process-based estimation models to estimate or predict GHG emissions	More sophisticated and complex, requiring detailed and long-term data, high levels of human and financial resources to develop models and body of science to underpin modelling; provides greater accuracy for estimates and levels of uncertainty

Data Selection

Available datasets are reviewed and evaluated for their relevance and inclusion in the inventory. State-level data was identified and prioritized, where available and relevant, through a series of consultations with Oregon agencies' staff. The complete table of datasets assessed and included in the inventory is provided in Appendix D. In addition, each land category section identifies specific data sets, and their respective sources, utilized.

IPCC Methodological Approaches

IPCC Guidelines indicate the basis for estimating GHG emissions is to multiply activity data that represents activities associated with emissions or removals, by an appropriate emission factor or a set of emission parameters that represent emissions or removals associated with a given activity. The approaches differ for estimating non-CO_2 emissions and CO_2 emissions and removals from carbon dynamics. Generic equations are provided below.

To calculate non-CO_2 emissions, for example, from biomass burning or managed soils, activity data is multiplied by an appropriate emission factor as indicated by the equation below[1]:

Equation 1: Non-CO_2 Emissions to the Atmosphere

$$\text{Emissions} = AD \times EF$$

Where:

Emissions	= Tonnes of emissions
AD	= Activity data relating to the emissions source
EF	= Emission factor for a specific gas and source category (tonne of emissions per unit of AD)

Calculations are conducted for each emission category and GHG and can then be converted to units of carbon dioxide equivalent (CO_2e) based on each GHG's global warming potential (GWP) (see further below on GWPs).

For estimating CO_2 emissions and removals from carbon stock changes, IPCC Guidelines provide two different approaches: the Stock Difference Approach and the Gain-Loss Approach. Calculating the total annual carbon stock change using the **Stock Difference Approach** is done by applying Equation 2[2]:

Equation 2: Carbon stock change in a given pool as an annual average difference between estimates at two points in time

$$\Delta C = (C(t_2) - C(t_1)) / (t_2 - t_1)$$

Where:

ΔC	= annual carbon stock change in the pool, tonne C yr^{-1}
C_{t1}	= carbon stock in the pool at time t_1, tonne C
C_{t2}	= carbon stock in the pool at time t_2, tonne C
t_1	= time point 1, at which carbon stock is estimated (previous year)
t_2	= time point 2, at which carbon stock is estimated (estimated year)

The stock-difference approach estimates carbon stock change in a given pool as an annual average difference between estimates at two points in time.

Calculating the total annual carbon stock change using the **Gain-Loss Approach** is done by applying Equation 3[3]:

Equation 3: Annual carbon stock change in a given pool as a function of gains and losses

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

[1] 2006 IPCC Guidelines, Vol. 4, Ch. 2, Equation 2.6
[2] 2006 IPCC Guidelines, Vol. 4, Ch. 2, Equation 2.5
[3] 2006 IPCC Guidelines, Vol. 4, Ch. 2, Equation 2.4

ΔC = annual carbon stock change in the pool, tonne C yr^{-1}

ΔC_G = annual gain of carbon, tonne C yr^{-1}

ΔC_L = annual loss of carbon, tonne C yr^{-1}

Net carbon stock change is the summation of carbon stock change in each relevant carbon pool, which depends on the ecosystem.

The following is a complete list of carbon pools considered when estimating carbon stocks and fluxes on land:

- Above-ground biomass (AGB)
- Belowground biomass (BGB)
- Deadwood (DW)
- Litter (LI)
- Soil organic carbon (SOC)
- Harvested wood products (HWP)

In some calculations, DW and LI are combined into a pool termed dead organic matter (DOM). HWP is typically associated with carbon stored in timber harvested from Forest Land.

To estimate soil organic carbon (SOC) flux on mineral soils for lands remaining in the same category or converted, Equation 4 is used.

[insert Equation 4 here]

This document presents, for each category included in the Inventory, the required activity data and emission parameters to estimate emissions or removals. The sections below detail activity data sources and processing steps, emission parameters and processing steps, as well as steps to take to complete the Inventory for each land category.

Time Series Consistency

A consistent time series in a GHG inventory is achieved by applying the same methodologies, definitions, data sources, and assumptions across all years, so that changes in emissions and removals reflect real trends rather than methodological artifacts. When improvements to methods, activity data, or emission factors are introduced, the IPCC recommends recalculating the entire time series back to the base year to maintain comparability over time. Where full recalculation is not possible, inventory compilers should document methodological changes clearly, explain any resulting breaks in the time series, and assess their impact on trends. Transparent documentation, version control, and systematic quality assurance/quality control (QA/QC) are essential to support transparency and reproducibility of the inventory for policy analysis and tracking progress toward climate targets.

Because this is the first inventory prepared in Oregon state, time series consistency and recalculations are not discussed further, but will need to be provided in each section if and when improvements or changes in the methodology occur.

Uncertainty

Uncertainty is a fundamental consideration in GHG inventories. The accuracy of emission and removal estimates relies on the quality of activity data, the accuracy of emission factors, and the extent to which all relevant land categories are stratified and characterized. The IPCC guidelines provide default values and Tier 1 methodologies to enable entities, regardless of data availability, to produce reliable estimates. However, it is good practice to use location-specific data and derive emission parameters that reflect local conditions, allowing the application of higher-tier methods wherever possible, in order to reduce uncertainty and improve the accuracy and transparency of the greenhouse gas inventory. IPCC Guidelines also emphasize the need for continuous improvement in data collection, reporting, and methodological refinement. This involves documenting sources of uncertainty, prioritizing data collection in areas with the greatest gaps, and recalculating historical inventories when new methods or data become available, in order to maintain consistency in time series. Each section below outlines the main sources of uncertainty to be considered and recommended improvements.

Molecular and Other Conversions

The following conventions and conversions will be used in the inventory estimates:

- Negative values = net removals (i.e., from atmosphere)
- Positive values = net emissions (i.e., to atmosphere)

In greenhouse gas inventories, carbon dioxide (CO_2) emissions may be derived from changes in carbon stocks, also called carbon fluxes. Carbon fluxes are often quantified in terms of the mass of carbon (C). However, for reporting purposes, carbon stock changes need to be expressed in terms of CO_2 emissions. Therefore, C must be converted to CO_2, which includes both carbon and oxygen atoms. To convert C to CO_2, a molecular weight ratio is applied: the molecular weight of CO_2 (44 g/mol) divided by the molecular weight of carbon (12 g/mol). This ratio (44/12) accounts for the additional mass contributed by the oxygen atoms, ensuring that reported emissions reflect the total molecular mass of carbon dioxide rather than just the carbon content.

- C to CO_2 conversion: 1 CO_2 = 44/12 x C

Nitrous oxide (N_2O) emissions are often first estimated and expressed in terms of nitrous oxide–nitrogen (N_2O–N), which represents only the nitrogen component of the N_2O molecule. However, for reporting in a GHG inventory, emissions must be reported as the full N_2O molecule, which includes both nitrogen and oxygen atoms. To convert from N_2O–N to N_2O, a molecular weight ratio is applied: the molecular weight of N_2O (44 g/mol) divided by the molecular weight of the nitrogen atoms it contains (28 g/mol). This ratio (44/28) accounts for the additional mass contributed by the oxygen atoms, ensuring that reported emissions reflect the total molecular mass of nitrous oxide rather than just its nitrogen fraction.

- N_2O–N to N_2O conversion: 1 N_2O = 44/28 x N_2O–N

Units

All GHG emissions and removals are estimated in units of tonnes (metric tons) of each individual GHG. Emission parameters are provided in this document both in the units they were originally measured and published and in the unit of tonne $acre^{-1}$ or tonne $acre^{-1}$ $year^{-1}$. Additional conversion steps are noted where needed. The following conversions are commonly used:

- 1 acre (ac) = 2.47 hectare (ha)

- 1 dry short ton = 0.907 tonne (tonne)
- Fraction of C in biomass = 0.5

Global Warming Potential

Non-CO_2 emissions need to be converted to CO_2 equivalent (CO_2e) using their associated Global Warming Potential (GWP). As a default, the 100-year time horizon values from the IPCC Fifth Assessment Report (AR5) will be used. Values from AR5 as well as AR6, and AR4 are shown in Table 6. All emissions and removals are reported in the units of million metric tonnes of CO_2e (MMTCO2e).

Table 6: GWP Values

IPCC Assessment Report	Methane 20-year	Methane 100-year	Nitrous Oxide 20-year	Nitrous Oxide 100-year
2007 IPCC Fourth Assessment Report (AR4)	72	25	289	298
2014 IPCC Fifth Assessment Report (AR5)	84	28	264	265
2021 IPCC Sixth Assessment Report (AR6)	81.2	27.9	273	273

Category: Forest Land

Four GHG emission and removal categories are estimated under the Forest Land category:

- CO_2 emissions and removals from forest carbon stock changes on forest land remaining forest land (biomass, deadwood, litter, soil)
- CO_2 emissions and removals from forest carbon stock changes on land converted to forest land (biomass, mineral soils)
- N_2O emissions from application of fertilizer to soil
- CO_2 emissions and removals from harvested wood products

CO_2 emissions and removals from forest carbon stock changes are estimated separately for Forest Land remaining Forest Land and land converted to Forest Land. All other categories are estimated at the level of Forest Land.

For Forest Land remaining Forest Land category, the CO_2 emissions occur when trees are harvested. For inventory purposes, all the CO_2 stock is assumed to be emitted. Living trees remove CO_2 from the atmosphere through the process of photosynthesis and accumulate carbon as biomass as they grow. The growth rate of trees is used to estimate annual carbon accumulation (density), which is used to quantify CO_2 removal from the atmosphere. This inventory used CO_2 accumulation rates from FIA measurement sites in Oregon. CO_2 emissions associated with loss of biomass from wildfires are captured in the biomass flux category to the extent that FIA data is able to capture changes in carbon density and accumulation. CH_4 and N_2O emissions from biomass burning are addressed in section on biomass burning emissions.

For the land converted to Forest Land category, it is assumed that the trees are planted or regenerated from seed pools from existing forests. Growth curves are used to estimate CO_2 accumulations in trees and are used to estimate CO_2 removal from the atmosphere per unit area per year.

In most soils, an increase in available N enhances nitrification and denitrification rates, which then increase the production of N_2O. Application of synthetic N fertilizer results in N_2O emissions from soils on Forest Land. In addition to the direct emissions of N_2O from managed soils that occur through a direct pathway, from the soils to which N is applied, emissions of N_2O also take place through two indirect pathways: N volatilization/deposition and N leaching/runoff. Fertilization occurs primarily on Douglas-fir commercial forests in Oregon.

The carbon in wood harvested as timber is not released immediately into the atmosphere. Instead, some carbon in harvested wood transfers to carbon in the Harvested Wood Product (HWP) pool. Once harvested wood becomes a wood product, the stored carbon is emitted over time, mostly in the form of CO_2 as it decomposes. When wood products are disposed of in solid waste disposal sites (SWDS), the carbon contained in the wood may have one of two fates: being released through decomposition as a result of solid waste management methods or being stored in SWDS long-term. The HWP pool includes both wood products in use and products discarded to SWDS. Carbon fluxes in the HWP pool occur through the addition of harvested wood to the pool, and loss of carbon as CO_2 emissions from the pool as a result of decay and combustion of wood products. The net balance of carbon flux determines the amount of emission or removal of $CO_2$from the HWP pool at a given point in time.

Emissions and removals from the HWP pool are reported under the Forest Land category. Oregon Department of Forestry (ODF) uses a production approach model consistent with the Tier 3 Production Approach in the IPCC Guidelines (2006 IPCC Guidelines, Vol. 4, Ch. 12) to account for HWP carbon fluxes. This approach includes all timber harvested and processed in Oregon, even if it's ultimately used and/or disposed of outside of the state. The methodology is considered to be Tier 3 because it uses a detailed state-specific model. This inventory applies the ODF methodology and calculations are conducted using a web-based tool HWP C vR.[4]

Forest Land: Activity Data

Land Classification for Estimating Carbon Stock Change in Forest Land

Land is classified as Forest Land and stratified into forest type groups using NLCD and FIA Forest type group data. That methodology also further categorizes and quantifies the amount of Forest Land remaining Forest Land and land converted to Forest Land over time. To summarize, the Forest Land category considers three out of the 16 NLCD landcover land classes: Deciduous Forest, Evergreen Forest, and Mixed Forest.

Further forest classification is based on FIA Forest type groups, which are more specific than NLCD forest classification and contain 16 forest type groups (Figure 2). In addition, data on carbon densities are derived from FIA plots at the forest type group level. For this inventory, it is assumed that there is no change in Forest type groups over the inventory time series.

NLCD data classifies land based on cover rather than use. When a forest area is harvested, the imagery-based classification identifies the area as grassland/herbaceous or shrub/scrub, depending on vegetation cover and height at the time of satellite imagery acquisition, rather than maintaining its forest classification. IPCC Guidelines require land to be permanently converted to another land type to qualify as a land use change. To distinguish between temporary forest harvest (cyclic management) and permanent forest conversion, a forest mask is currently necessary. Other state and federal agencies

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[4] https://groomanalyticsllc.shinyapps.io/HWP-C-vR/

estimate forest land area different than what is estimated in this inventory in substantial part due to differences in the definitions of land cover and land use between datasets used, such as NLCD.

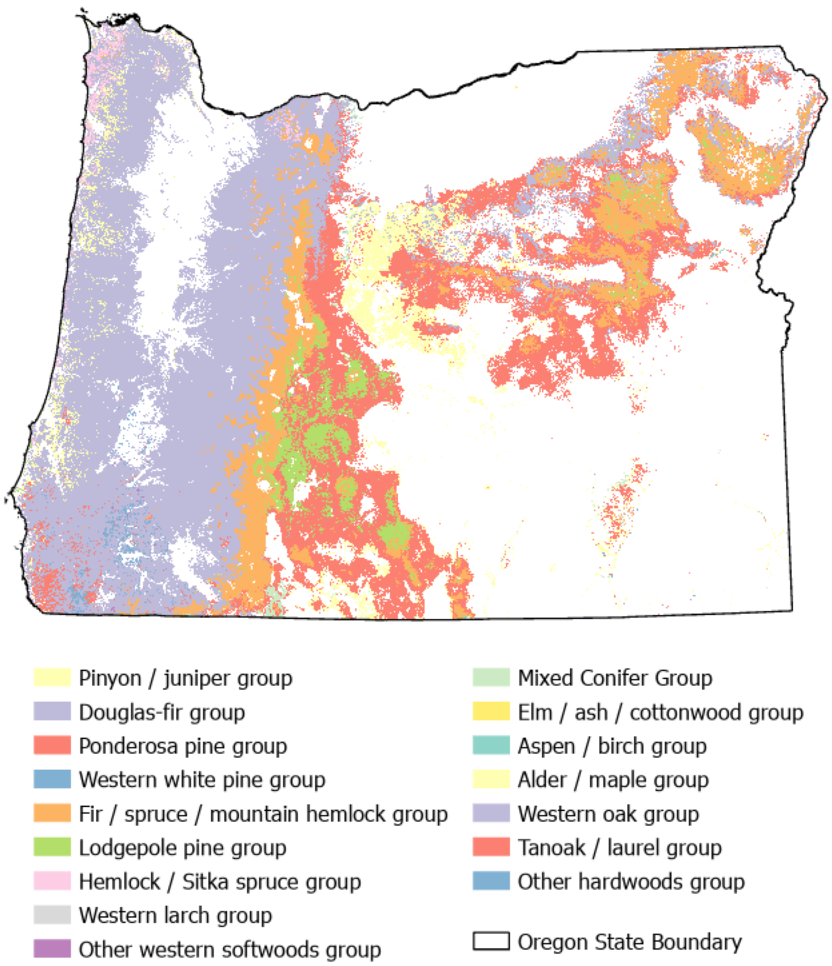
Oregon lacks an officially recognized state forest mask. Therefore, for this inventory, a forest mask was developed using the percent tree cover map from the year 2000 in the Global Forest Change dataset (Hansen, M. C., et al. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342: 850–853. Data available at http://earthenginepartners.appspot.com/science-2013-global-forest). NLCD-classified forest cover loss occurring within this tree cover mask was then reclassified as temporary harvest rather than land conversion and was excluded from land conversion calculations. Grassland converted to Forest Land areas are excluded from inventory calculations until improvements in classification of functional transitions can be made. Summary of land area activity data is provided in Table 7. These land areas may differ from those estimated by other notable inventories, such as those produced by the USDA and ODF, due to differences in underlying datasets and definitions of land cover/land use.

Forest Land was further stratified by soil taxonomic order to estimate soil carbon fluxes due to land conversions. Full activity data is available in the data library.

Table 7: Area of Forest Land Remaining Forest Land and Land Converted to Forest Land in hectares

Year	Forest land remaining Forest Land	Land converted to Forest Land
1990	10,441,994	-
1996	9,874,651	286,965
2001	9,174,819	348,807
2006	9,117,056	331,575
2011	8,911,881	287,234
2016	8,994,079	351,927
2021	8,841,816	270,544

Figure 2: FIA Forest Type Groups in Oregon



Fertilizer Application for Estimating N_2O Emissions

Fertilization occurs primarily on Douglas-fir commercial forests in Oregon. Historically, fertilizer is applied about five years before an anticipated harvest and after a commercial thinning. Over time, there has been an observed decrease in fertilization due to shorter rotations and the increasing cost of fertilizer. ODF maintains a Forest Activity Electronic Reporting and Notification System (FERNS) for landowners to submit notifications of management activities, including application of fertilizer. The notification submission and data record include chemical type and acreage. It should be noted that the acreage signifies intent to apply, not necessarily the actual application area or amount. The FERN database was queried by ODF staff to obtain the area of Forest Land where fertilizer application is likely occurring. Area is used to estimate the amount of Nitrogen applied to soil in Forest Land needed to estimate N_2O emissions. The sum of the area for each year from FERNS starting in 2014 is provided in Table 8. For years 1990-2013, area was estimated based on the average for the years 2014-2024.

Table 8: Fertilizer application area in acres and amount of N applied in pounds and kg

Year	Area	N applied (lbs)#	N applied (kg)
1990-2013*	62,139	12,427,836	5,637,172
2014	50,629	10,125,800	4,592,986
2015	84,413	16,882,600	7,657,819
2016**	89,980	17,996,000	8,162,848
2017	95,547	19,109,400	8,667,878
2018	71,602	14,320,400	6,495,624
2019	65,228	13,045,600	5,917,385
2020	29,136	5,827,200	2,643,173
2021	44,223	8,844,600	4,011,843
2022	42,463	8,492,600	3,852,179
2023	44,116	8,823,200	4,002,136
2024	66,194	13,238,800	6,005,019

** indicates 2014-2024 average; ** indicates linear extrapolation. # The N rate of application is considered to be 200 lbs of N per acre.*

The application rate of fertilizer is used to calculate the amount of N applied. A default fertilization rate of 200 lbs N as urea per acre is used based on best practices in Oregon.[5] The amount of N applied is further converted into the units of kilograms.

Timber Harvest for Estimating Carbon from Harvested Wood Products

The activity data needed for estimating HWP C is the amount of carbon contained in various products and end uses that are derived from timber harvest. Starting with timber harvest volume, a variety of intermediate ratios are needed to derive the activity date. Specifically, four sets of inputs are required to run the HWP C model:

1. Annual timber harvest volume
2. Annual timber product ratios that allocate harvest to different timber product classes
3. Annual primary product ratios allocating the timber products to a variety of primary products and residue uses
4. End-use ratios that allocate the primary products to a larger set of end-use products.

Annual Timber Harvest Volume

Timber harvest volumes are collected and managed by the ODF[6] from 1906 to the current year. While the state disaggregates timber harvest by ownership classes (federal, state, tribal, private, etc.) for some

[5] Briggs, D. 2007. Management Practices on Pacific Northwest West-Side Industrial Forest Lands, 1991-2005: With Projections to 2010. SMC Working Paper Number 6. Stand Management Cooperative, College of Forest Resources, University of Washington, Seattle. 84

[6] Contact person: Brandon R. Kaetzel, PhD, Brandon.KAETZEL@odf.oregon.gov

of the years, this information is not consistently available. Timber harvest volumes in Oregon are reported in thousand board feet (mbf) Scribner, log rule and mbf lumber tally, and converted to cubic feet (cf) of logs using conversion factors from literature and an ordinary least squares regression equation as described in the Oregon Harvested Wood Products Carbon Inventory 1906 – 2018 Report. Conversion factors to cubic feet from each of these volume units are provided in the model documentation.[7]

Annual Timber Product Ratios

To model carbon fluxes, information on timber fate is needed to characterize the proportion of timber used to produce particular products, assign typical product lifespan for products, and determine a disposal pathway and associated decay rates. Timber product ratios for timber harvest to timber product class (e.g., softwood sawtimber, softwood pulpwood, etc.) are based on literature and are provided in the model documentation. There are 40 primary product classes with ratios.

Annual Primary Products Ratios

Ratios for converting timber product class to primary product class (e.g., softwood lumber, softwood plywood, etc.) are based on literature and are provided in the model documentation. There are 64 primary product classes with ratios. Mill residues are included as primary wood products, with some entering solid waste disposal sites (SWDS) immediately, some being burned for energy, and some being converted into products that rely on mill residues as raw material, such as particleboard and paper.

End Use Product Ratios

The fate of HWP C is highly dependent on the end use of the primary products. For example, the release of carbon from lumber used in new home construction has a longer duration than carbon released from lumber used for shipping containers, which is released into the atmosphere more quickly through combustion and decay. Fuelwood products are assumed to have full emissions with energy capture in the year they were produced. Annual primary product output is distributed to specific end-use categories within the HWP C model according to annual wood product consumption estimates. The HWP model has 224 different possible end uses for HWP per harvest year (e.g., softwood lumber/new housing/single family, softwood lumber/manufacturing/furniture, softwood lumber/packaging and shipping, etc.). All product use ratios are provided in the model documentation.

Forest Land: Emission Factors

Carbon Density and Accumulation for Estimating Forest Carbon Stock Change on Forest Land Remaining Forest Land

The emission parameters used for forest carbon stock change are the amount of carbon stored in each carbon pool per unit of land, i.e., tonne of carbon per hectare (tonne C ha^{-1}). The forest carbon densities reported here are used to estimate carbon fluxes on Forest Land remaining Forest Land.

The US Forest Service (USFS) maintains FIA plots to measure and monitor carbon densities across the country. Carbon densities for the following carbon pools are derived from FIA plots located in Oregon using the USFS's web-based application EVALIDator (https://apps.fs.usda.gov/fiadb-api/evalidator) (Table 10):

- Above-ground biomass carbon
- Below-ground biomass carbon
- Deadwood

[7] https://groomanalyticsllc.shinyapps.io/HWP-C-vR/

- Litter
- Soil organic carbon from mineral soils

USFS uses biomass carbon stock data collected at the FIA sites over time to calculate biomass accumulation rates, which are reported in dry short tons per acre per year for above-ground and below-ground biomass pools. These biomass accumulations are converted into carbon accumulations using the default assumption that carbon makes up 50% percent of biomass. In addition, short tons per acre are converted to tonnes per hectare using the conversion factor. The carbon accumulation rates are used to calculate annual carbon emissions or removal for each forest type group in Forest Land remaining Forest Land. Accumulation rates for the other carbon pools are not available. The IPCC assumption under Tier 1 is that the average transfer rate into dead organic matter (deadwood and litter) is assumed to equal the average transfer rate out, so the net stock change is zero. Likewise, IPCC states that when using Tier 2 or 3 activity data, it is not necessary to compute carbon stock changes for mineral soils.

For this inventory, FIA plot data available for all inventory years between 2001 and 2021 for Oregon were extracted for each forest group type, and mean carbon densities were calculated by each forest group type for the time intervals set by the analysis years between 2001 and 2021. Plot data is not available for all forest group types for each inventory year; therefore, carbon densities were calculated with data available from the nearest year. For the years prior to 2001, mean carbon density values from 2001-2006 were used. USFS's methodology for data collection from FIA plots was modified in 2001, therefore there might be some difference in actual forest carbon stocks and fluxes for earlier years (1990-2000). This may have resulted in an overestimation of carbon stocks and removals between 1990-2000 because federal restrictions on harvesting in federal lands were put into place during this period. In cases where data was not available for the 2001-2006 period, data from 2006-2011 was used for all previous years. Only carbon densities and accumulation rates for the period 2016-2021 are listed below in Table 9 and Table 10, respectively. The forthcoming Technical Manual for the state will include carbon densities and accumulation rates by each inventory time period.

For each cycle of the inventory, the inventory team should query the FIA database for the most recent plot data (steps outlined in the forthcoming Technical Manual). In the future, if possible, it would be useful to explore ways to validate this assumption and/or adjust as needed. It is also recommended to directly coordinate with USFS PNW-FIA analysts.

Table 9: Oregon forest type groups, carbon densities for estimating carbon stocks in Forest Land remaining Forest Land for inventory time period 2017–2021. All values are in tonne C ha^{-1}. Values in parentheses represent standard error.

Forest Type Group	AGB	BGB	DW	LI	SOC	Total
Alder / maple	89.92 (5.12)	17.32 (1.15)	3.86 (2.25)	6.94 (0.1)	141.01 (1.86)	259.05
Aspen / birch	28.32 (6.62)	4.84 (1.15)	325.91 (2.34)	9.55 (0.54)	144.02 (2.3)	512.64
Douglas-fir	142.23 (2.88)	32.17 (0.7)	1.09 (0.49)	11.03 (0.05)	134.68 (0.46)	321.19
Elm / ash / cottonwood	69.43 (26.88)	14.07 (5.61)	2.54 (1.15)	7.3 (0.22)	129.88 (3.87)	223.22

Fir / spruce / mountain hemlock	103.52 (4.01)	20.72 (0.9)	1.79 (0.51)	13.88 (0.17)	132.61 (0.52)	272.53
Hemlock / Sitka spruce	154.86 (8.59)	36.35 (2.15)	9.17 (3.96)	18.68 (0.18)	150.42 (1.25)	369.48
Lodgepole pine	37.91 (1.19)	7.14 (0.21)	0.33 (0.11)	10.31 (0.13)	118.97 (0.56)	174.66
Mixed Conifer	6.5 (0.39)	0.92 (0.07)	9.96 (1.91)	7.24 (0.24)	127.62 (1.1)	152.24
Other hardwoods	177.43 (7.18)	25.21 (1.33)	0 (4.27)	9.84 (0.2)	125.76 (3.82)	338.25
Other western softwoods	52.59 (0.62)	10.2 (0.12)	11.61 (0.02)	10.74 (0.21)	127.83 (0.62)	212.98
Pinyon / juniper	13.51 (0)	2.35 (0)	0.05 (0)	5.9 (0)	127.49 (0)	149.31
Ponderosa pine	3.88 (1.99)	0.55 (0.44)	0.03 (0.12)	4.12 (0.15)	111.88 (0.21)	120.45
Tanoak / laurel	51.33 (9.46)	9.97 (1.95)	0.23 (5.81)	11.89 (0.29)	122.31 (3.28)	195.73
Unknown	118.9 (0)	22.62 (0)	6.1 (0)	7.47 (0)	146.46 (0)	301.56
Western larch	71.55 (4.06)	14.53 (1)	12.34 (6.72)	14.06 (0.23)	117.09 (0.82)	229.58
Western oak	50.58 (7.15)	9.32 (1.41)	35.24 (33.51)	6.55 (0.22)	123.46 (2.2)	225.15
Western white pine	15.01 (2.92)	2.84 (0.68)	1.74 (1.05)	9.09 (0.4)	126.16 (5.39)	154.84

Table 10: Oregon forest type groups, carbon densities for estimating carbon accumulations in Forest Land remaining Forest Land for inventory time period 2017-2021. All values are in tonne C ha^{-1}. Values in parentheses represent standard error.

Forest type group	AGB	BGB	Total
Alder / maple	1.24 (0.13)	0.28 (0.02)	1.52
Aspen / birch	-4.18 (4.45)	-0.95 (1.02)	-5.13
Douglas-fir	2.22 (0.13)	0.52 (0.03)	2.74
Elm / ash / cottonwood	1.93 (0.59)	0.41 (0.12)	2.34
Fir / spruce / mountain hemlock	0.72 (0.09)	0.14 (0.02)	0.86

Hemlock / Sitka spruce	2.35 (0.19)	0.57 (0.04)	2.93
Lodgepole pine	0.57 (0.04)	0.1 (0.01)	0.67
Mixed Conifer	-1.51 (0.37)	-0.33 (0.08)	-1.84
Other hardwoods	4.81 (0.62)	0.52 (0.13)	5.33
Other western softwoods	-0.3 (0.02)	-0.05 (0.01)	-0.35
Pinyon / juniper	0.08 (0)	0.02 (0)	0.1
Ponderosa pine	0.03 (0.06)	0.01 (0.01)	0.04
Tanoak / laurel	0.73 (0.44)	0.15 (0.09)	0.88
Unknown	-0.55 (0.32)	-0.09 (0.07)	-0.64
Western larch	0.94 (0.11)	0.19 (0.02)	1.13
Western oak	-0.07 (0.75)	-0.04 (0.16)	-0.11
Western white pine	0.04 (0.28)	0.06 (0.04)	0.1

() represents Standard Error

Land Converted to Forest Land

Carbon Densities for Pre-Conversion Land Use Types

Carbon densities for land use types prior to conversion to Forest Land are provided in Table 11. When cropland is converted to Forest Land, pre-transition biomass is assumed to be lost in the year of transition. In all other lands converted to Forest Land, natural regeneration is assumed. For conversions from Wetland, pre-conversion biomass stock for forested wetlands is assumed. For conversions from Developed Land, pre-conversion biomass stock for open space is assumed. The post-conversion biomass accumulation rates were derived by synthesizing published Pacific Northwest data with IPCC methodologies. Aboveground biomass accumulation (3.0-3.5 tonne C ha^{-1} yr^{-1}) was based on FIA inventory measurements showing the Pacific Northwest West region youngest age class accumulates 3.0 tonne C ha^{-1} yr^{-1} (Hoover, CM, Smith JE, 2003). Belowground biomass was estimated using the IPCC default root-shoot ratio of 0.29 for temperate conifers, adding approximately 0.9 tonne C ha^{-1} yr^{-1}. Soil organic carbon changes (1.0-2.0 tonne C ha^{-1} yr^{-1}) were calculated assuming linear transition over 20 years per IPCC guidelines (Oregon Department of Forestry). Dead organic matter accumulation was estimated as 10-15% of living biomass. The statewide average of 4.75 tonne C ha^{-1} yr^{-1} represents total ecosystem carbon accumulation (biomass + soil + dead organic matter) weighted between Western Oregon (4.0-5.5 tonne C ha^{-1} yr^{-1}) and Eastern Oregon (2.5-4.0 tonne C ha^{-1} yr^{-1}) young forest rates.

Table 11: Pre-conversion and post-conversion biomass C density

Category	Pre-conversion biomass stock	Reference	Post-conversion biomass accumulation rate
Cropland converted to Forest Land	4.7 tonne C ha^{-1}	Table 5.9, 2019 Refinement, Vol 4, Chap 5	4.75 tonne C ha^{-1} yr^{-1}
Wetland (inland only) converted to Forest Land	104.3 tonne C ha^{-1}	Derived from FIA (detailed in the Wetland section)	4.75 tonne C ha^{-1} yr^{-1}
Grassland to Forest Land	N/A	NA	N/A
Other Land converted to Forest Land	0	2016 IPCC Guidelines, Vol 4, Chap 9	4.75 tonne C ha^{-1} yr^{-1}
Developed Land converted to Forest Land	75.4 tonne C ha^{-1}	Derived from Urban FIA (detailed in the Developed Land section)	4.75 tonne C ha^{-1} yr^{-1}

Soil Organic Carbon in Mineral Soils

Fluxes in SOC in mineral soils (not inclusive of histosols taxonomic order) are expected to occur when land is converted to Forest Land. For mineral soils, the IPCC default assumption is that it takes 20 years for the system to reach a new equilibrium from the time land use changes. IPCC Tier 1 parameters are used to estimate SOC selected from the parameters listed in Table 12. For all land categories except wetlands, SOC_{ref} values disaggregated by climate zone and soil type are used (Table 3). For wetlands converted to Forest Land, SOC_{ref} of 97 tonne C ha^{-1} at 30cm depth is used. This value is based on a weighted average across ecoregions of soil carbon stock for mineral soils for inland wetlands. This value is indicative of 30% of carbon stock at 1m depth.

Currently, data is lacking to estimate C fluxes associated with conversions from grassland to forest, however, even when area data becomes available, it is assumed that there is no flux when grasslands are converted to forests because they have the same stock change factor of 1, representative of soil natural conditions. Stock change parameters for cropland are disaggregated by climate zone assuming long-term cultivated land with conventional tillage and medium inputs is converted. The wetland supplement provides stock change factor, Flu, for inland mineral soils for conversion to cropland. The same value is assumed for Forest Land. For developed land converted to forest, it is assumed that land in the open space class transitions to forests.

Table 12: Soil Carbon stock change factors for Forest Land (unitless). Values in parentheses represent two standard deviations, expressed as a percent of the mean

Converted from/to	Climate	F_{LU}	F_{MG}	F_I	Reference
Grassland	All	1	1	-	Table 6.2 (2019 IPCC Refinement, Vol 4, Chap 6)
Cropland	Cool Temperate Dry	0.77 (±14%)	1	1	Table 5.5 (2019 IPCC Refinement, Vol 4, Chap 5)
Cropland	Warm Temperate Dry	0.76 (±12%)	1	1	Table 5.5 (2019 IPCC Refinement, Vol 4, Chap 5)

Cropland	Warm Temperate Moist	0.69 (±16%)	1	1	Table 5.5 (2019 IPCC Refinement, Vol 4, Chap 5)
Wetlands	All	1	-	-	Table 5.3, (2013 Wetland Supplement)
Developed (assuming open space is converted)	All	1.14 (±11%)	1	-	Table 6.2 (2019 IPCC Refinement, Vol 4, Chap 6)
Forest	All	1	-	-	Section 4.2.3.2 (2019 IPCC Refinement, Vol 4, Chap 4)
Forest when converted from wetlands	All	0.71 (±40%)	-	-	Table 5.3, (2013 Wetland Supplement)

N_2O Emissions from Fertilizer Application

IPCC default emission parameters will be used for estimating N_2O emissions from application of urea on Douglas-fir plantations. The values are summarized in Table 13.

Table 13: Emission factors for N_2O emissions. Values in parentheses represents uncertainty range and is variable depending on the emissions factor.

Emission factor	Value	Unit	Reference
EF_1 direct emissions	0.010 (0.002 – 0.018)	kg N_2O-N (kg N)$^{-1}$	Table 11.1 (2019 IPCC Refinement)
EF_4 indirect volatilization	0.010 (0.002-0.018)	kg N_2O–N (kg NH_3–N + NO_x–N volatilised)$^{-1}$	Table 11.3 (2019 IPCC Refinement)
EF_5 indirect leaching	0.011 (0.000-0.20)	kg N_2O–N (kg N leaching/runoff)$^{-1}$	Table 11.3 (2019 IPCC Refinement)
$Frac_{GASF}$ (urea)	0.15 (0.03-0.43)	(kg NH_3–N + NO_x–N) (kg N applied)$^{-1}$	Table 11.3 (2019 IPCC Refinement)
$Frac_{LEACH}$	0.24 (0.01-0.73)	kg N (kg N additions or deposition by grazing animals)$^{-1}$	Table 11.3 (2019 IPCC Refinement)

Harvested Wood Product Use and Disposal Decay Rates

The emission parameters in HWP carbon accounting are values that describe how carbon decays over time throughout the use and disposal of HWP, i.e., half-life decay values.

End use product half life

The amount of carbon remaining in use during each inventory year is calculated based on the products' half-lives and the number of years that have passed between the year of harvest and the inventory year. An end-use product's half-life value is the decay rate at which carbon in the PIU category passes into the discarded-products category, representing the transition between the two pools.

Discard disposition ratios

The model's disposal of carbon in paper and solid wood products to dumps and landfill categories is based on discarded products disposition ratios. Carbon in discarded products falls into one of five disposition categories:

- Burned
- Recovered (recycled/reused)
- Compost
- Landfills
- Dumps (open air disposal sites)

The proportion of discarded products that ends up in each of these five categories is different for paper vs. solid wood products, and changes over time. The model assumes that carbon from discarded products that are burned or composted is emitted without energy capture due to a lack of reliable data to support the alternative.

Carbon in the recovered category reenters the PIU category in the year of recovery. Carbon in products discarded to landfills and dumps are subject to decay determined by their respective half-lives. Only a fraction of the discarded products pool in landfills is subject to decay and associated with emission of carbon. The portion of the discarded products pool not subject to decay is considered "fixed carbon." For a given year, the carbon remaining in SWDS is the sum of fixed carbon and the carbon remaining after decay.

Forest Land: Methodology

Carbon Fluxes on Forest Land Remaining Forest Land

Carbon flux from Forest Land remaining Forest Land is estimated as the sum of annual changes in carbon stocks across five carbon pools for each of the 16 forest group types. The total change in carbon stocks for all forests is calculated by summing the changes across all forest group types. Equation 4 is used to calculate the total carbon flux from Forest Land remaining Forest Land.

Equation 4: Total carbon flux from Forest Remaining Forest

$$\Delta C_{FF} = \sum \Delta C_{FF,i} \text{ (for i = 1 to n)}$$

Where:

ΔC_{FF} = total annual carbon stock change for Forest Remaining Forest, tonne C yr^{-1}

$\Delta C_{FF,i}$ = annual carbon stock change for forest group type i, tonne C yr^{-1}

i = forest group type (i = 1 to n, where n = 16)

The annual carbon stock change for each forest group type is calculated as the sum of stock changes in all five carbon pools using Equation 5.

Equation 5: Annual carbon stock change for each forest group type

$$\Delta C_{FF,i} = \Delta C_{AB,i} + \Delta C_{BB,i} + \Delta C_{DW,i} + \Delta C_{LI,i} + \Delta C_{SOC,i}$$

Where:

$\Delta C_{FF,i}$ = annual carbon stock change for forest group type *i*, tonne C yr^{-1}

Subscripts denote the following carbon pools:

AB = aboveground biomass

BB = belowground biomass

DW = dead wood

LI = litter

SOC = soil organic carbon

Carbon Fluxes on Land Converted to Forest Land

CO_2 Flux from Biomass

When land is converted to Forest from other land use types, the change in carbon stocks is calculated as the sum of three components: (1) increase in carbon stocks due to biomass growth following conversion, (2) immediate change in carbon stocks resulting from the conversion itself (calculated as the difference between biomass stocks immediately after and before conversion), and (3) decrease in carbon stocks due to biomass losses from harvesting and disturbances. Equation 6 calculates the annual change in biomass carbon stocks during the post-conversion period, while Equation 7 calculates the immediate change in biomass carbon stocks at the time of conversion to Forest. Both equations must be applied separately for each land use type being converted to Forest, with results summed across all land use types to determine the total annual carbon flux from land conversion to Forest.

Equation 6: Annual change in biomass carbon stocks on land converted to Forest Land (Eq. 2.15 in Vol. 4, Chap. 2, 2006 IPCC GL)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass on land converted to Forest Land, tonne C yr^{-1}

ΔC_G = annual increase in carbon stocks in biomass due to growth on land converted to Forest Land, tonne C yr^{-1}

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to Forest Land (calculated once in year of conversion), tonne C yr^{-1}

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting and disturbances on land converted to Forest Land, tonne C yr^{-1} (this parameter is assumed to 0 due to lack of data in this inventory)

NOTE: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Equation 7: Initial change in biomass carbon stocks in land converted to Forest Land (adapted from Eq. 2.16 in Vol. 4, Chap. 2, 2006 IPCC GL)

$$\Delta C_{CONVERSION} = \sum_i [(C_{AFTER,i} - C_{BEFORE,i}) \times Area_{CONVERTED,i}]$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks at time of conversion, tonne C yr^{-1}

$C_{AFTER,i}$ = biomass carbon stock on land use type *i* immediately after conversion to Forest Land, tonne C ha^{-1}

$C_{BEFORE,i}$ = biomass carbon stock on land use type *i* immediately before conversion to Forest Land, tonne C ha^{-1}

$Area_{CONVERTED,i}$ = area of land use type *i* converted to Forest Land, ha

i = land use type converted to Forest Land

NOTE: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

CO_2 flux from mineral soils

Mineral soil C fluxes are calculated using a Tier 1 approach using carbon factors from the 2019 Refinement to the 2006 IPCC Guidelines.

Equation 8: Soil organic carbon flux on mineral soils in land converted to Forest Land (i.e., equation 2.25 in Volume 4, Chap 2 of 2006 IPCC GL)

$$\Delta C_{MINERAL} = (SOC_0 - SOC_{(0-T)})/D$$

$$SOC = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_I$$

Where:

$\Delta C_{MINERAL}$ = annual change in mineral soil organic carbon stock, tonne C

SOC_0 = C stock at the end of the period

$SOC_{(0-T)}$ = C stock at the beginning of the period

D = the default time period for the transition between equilibrium SOC values, 20 years

SOC_{Ref} = reference C stock

F_{LU}, F_{MG}, F_I = stock change factors for land use, management practice, and input levels of organic matter, respectively

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Managed Soils

Both direct and indirect N_2O emissions are estimated. Direct N_2O emissions occur on-site where fertilizer is applied. Indirect N_2O emissions occur after N is transported elsewhere or volatilized, e.g., through leaching or atmospheric deposition. Equation 9 is used to calculate annual direct emissions.

Equation 9: Direct N_2O Emissions from Soils

$$N_2O\text{–}N_{direct} = F_{SN} \times EF_1$$

Where:

$N_2O\text{–}N_{direct}$ = direct N_2O–N emissions from managed soils, kg N_2O–N yr^{-1}

F_{SN} = amount of synthetic fertilizer N applied to soils, kg N yr^{-1}

EF_1 = emission factor for direct N_2O emissions from N inputs to soils

Note: To report emissions in N_2O, convert N_2O-N to N_2O by multiplying values by 44/28.

Annual indirect N_2O emissions from volatilization and atmospheric deposition are estimated using Equation 10.

Equation 10: Indirect N_2O emissions from volatilization and atmospheric deposition from soils

$$N_2O\text{–}N_{vol} = F_{SN} \times Frac_{GASF} \times EF_4$$

Where:

$N_2O\text{–}N_{vol}$ = indirect N_2O–N emissions from volatilization, kg N_2O–N yr^{-1}

F_{SN} = amount of synthetic fertilizer N applied to soils, kg N yr^{-1}

FracGASF = fraction of applied N that volatilizes as NH_3 and NO_x

EF_4 = emission factor for N_2O–N from atmospheric deposition

Note: To report emissions in N_2O, convert N_2O-N to N_2O by multiplying values by 44/28.

Annual indirect N_2O emissions from leaching and runoff are estimated using Equation 11.

Equation 11: Indirect N_2O emissions from leaching and run-off deposition from soils

$$N_2O\text{–}N_{leach} = F_{SN} \times Frac_{LEACH} \times EF_5$$

Where:

$N_2O\text{–}N_{leach}$ = indirect N_2O–N emissions from leaching and run-off, kg N_2O–N yr^{-1}

F_{SN} = amount of synthetic fertilizer N applied to soils, kg N yr^{-1}

$Frac_{LEACH}$ = fraction of applied N lost through leaching/runoff

EF_5 = emission factor for N_2O–N from N leached/runoff

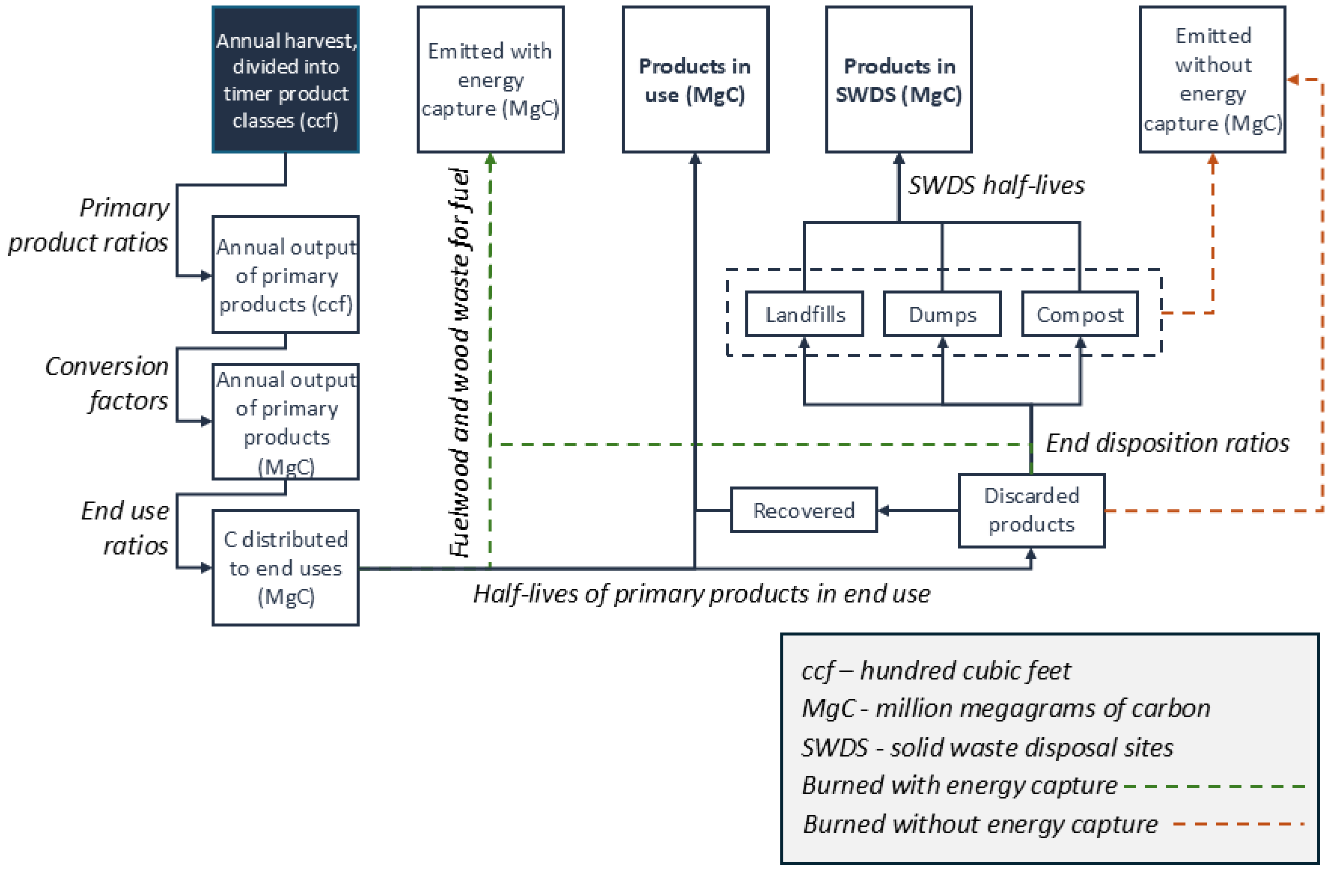
Note: To report emissions in N_2O, convert N_2O-N to N_2O by multiplying values by 44/28.

Total N_2O emissions are calculated by summing direct and indirect emissions.

Harvested Wood Products

A detailed description of the methodology and calculations for HWP is available.[8,9] Figure 3 shows a schematic representation of carbon flows through the harvested wood products pool, application of assumed ratios and conversion factors, to the ultimate fate as emissions.

Figure 3: HWP Model Schematic (adapted from Stockmann et. al. 2012)



The amount of carbon remaining in use during each inventory year is calculated based on the products' half-lives and the number of years that have passed between the year of harvest and the inventory year.

An end-use product's half-life value is the decay rate at which carbon in the PIU category passes into the discarded-products category, representing the transition between the PIU and SWDS pools. The amount

8 Stockmann, K.D., Anderson, N.M., Skog, K.E. et al. Estimates of carbon stored in harvested wood products from the United States forest service northern region, 1906-2010. Carbon Balance Manage 7, 1 (2012).https://doi.org/10.1186/1750-0680-7-1

9 Loeffler, D.; Anderson, N.; Stockmann, K.; Morgan, T.A.; Tase, N.A. 2019. Harvested wood products. In: Christensen, G.A.; Gray, A.N.; Kuegler, O.; Tase, N.A.; Rosenberg, M.; Loeffler, D.; Anderson, N.; Stockmann, K.; Morgan, T.A. AB 1504 California forest ecosystem and harvested wood product carbon inventory: 2017 reporting period. Final report. [Missoula, MT: University of Montana]. U.S. Department of Agriculture Forest Service agreements 18-CO-11052021-214 and 17-CO-11261979-086, California Department of Forestry and Fire Protection agreement 8CA04056 and 8CA03714. 539 p. Chapters 5 and 6. https://bof.fire.ca.gov/media/8026/4-final_1504_forest_ecosys_hwp_c_2017_13feb19_full.pdf.

of HWP C remaining in use in any given year is calculated for each end use from all prior years with the standard decay formula:

Equation 12: Decay of C from HWP in use

$$N_t = N_0 \exp(-t ln(2)/t_{1/2})$$

Where:

N_t = the amount of carbon remaining in use in inventory year t

N_0 = the amount of carbon in the end use category in the vintage year of harvest

t = the number of years since harvest

$t_{1/2}$ = the half-life of carbon in that end use

In the model calculations, the starting amount (N_0, at n=0) is adjusted downward by an 8 percent loss factor (McKeever 2004, Skog 2008) to reflect the waste when primary products (e.g., softwood lumber) enter various waste pathways, e.g., trimmed during manufacturing or discarded during construction.

The model calculates carbon stocks in product in use (PIU) pool and the SWDS pool as well as emissions associated with burning of fuelwood and waste with and without energy capture. CO_2 emissions from burning fuelwood with energy capture are typically noted for informational purposes in the energy sector, however, they are already accounted for in biomass C category in Forest lands as a loss, i.e., emission. Non-CO_2 emissions from combustion of fuelwood (CH_4 and N_2O) are reported in the Oregon SBI, under the Energy Sector. CH_4 emissions from discarded wood waste are reported in the Oregon SBI, under the Waste Sector.

The model provides multiple outputs such as cumulative carbon storage, emissions, and annual net changes in carbon storage. Annual net change in carbon storage is the value used for the land-based carbon inventory.

The model arrives at the resulting annual net change in carbon storage values by following these steps: First, carbon removed from the forest through harvest enters HWP storage pools or is burned for fuel. The HWP storage pool is allocated to PIU and SWDS. Decay and storage of carbon in the PIU and SWDS pools is modeled over time. HWP flux is calculated as the stock change in the PIU and SWDS pools from one year to the next, or the annual net change. Carbon from wood that is cut and removed from the forest ecosystem that is immediately burned for energy never enters HWP storage pools.

ODF staff produces annual harvest data and enters it into the online tool. ODF staff also publishes the state forest ecosystem carbon report including carbon emissions and removals in HWP approximately every 5 years. At that time, model parameters get reviewed and updated if new information is available. To compile the HWP estimates for the inventory, model results need to be downloaded following these steps:

1. Go to the web-based tool at https://groomanalyticsllc.shinyapps.io/HWP-C-vR/
2. On the left side panel, select Oregon under the “Select a data set” dropdown menu, then click “Upload Data”.
3. Once on the Upload Data page, click button “Download Oregon HWP Tables”. This downloads a zip folder containing 8 files with tabulated results.
4. Open file T5.0.AnnualStorageEmissionsChange.csv to retrieve the results, which are provided in:

a. Column B: SWDSchangeTgC

b. Column C: PIUchangeTgC

c. Column H: SWDSchangeTgCO_2e

d. Column I: PIUchangeTgCO_2e

NOTE: Net stock change is provided in both units of TgC and TgCO_2e, though it is just the sum of columns B&C and columns H&I, respectively. For the inventory, the emissions in units of TgCO_2e are used.

5. The results are multiplied by -1 to follow the inventory convention where emissions are positive while removals (i.e., sequestration) are negative.

6. The results in Tg are converted to million metric tons (MMT) to be consistent with Sector Based Inventory and National GHG Inventory (1Tg = 1MMT)

7. The time series results for 1990 to 2023 (or the most recent year for which data is available) should be included.

Forest Land: Uncertainty

Emissions from forests include two sources of uncertainty from activity data (NLCD derived land classification) and emission factors (FIA derived carbon density and forest group assignment) as described below.

Land Cover Classification Accuracy. NLCD land cover maps have documented classification accuracies that vary by land cover class and region. Wickham et al. (2013)[10] reported overall accuracy of 84% for NLCD 2006, with user's accuracy for the Deciduous Forest class at 82.4% and Evergreen Forest at 89.7%. However, producer's accuracy for these classes was lower (73.9% and 85.7%, respectively), indicating omission errors where forest areas may be misclassified as other cover types. The Shrub/Scrub class showed notably lower accuracy (user's accuracy 67.2%, producer's accuracy 53.8%), which is particularly relevant given its potential confusion with harvested forest areas. Wickham et al. (2021)[11] reported similar patterns for NLCD 2016, with overall accuracy of 87.0% but continued challenges in distinguishing shrub/scrub from grassland and recently disturbed forest. This classification uncertainties directly propagate into area estimates for each land cover transition category. Additionally, the temporal resolution of NLCD data used in this inventory (approximately 5-year intervals) may not capture all land cover changes occurring between mapping years, potentially missing short-duration disturbances or rapid vegetation recovery.

Forest Harvest Misclassification. As noted previously, NLCD imagery-based classification identifies harvested forest areas as grassland/herbaceous or shrub/scrub rather than forest, leading to potential overestimation of forest loss and grassland gain. Considering the documented low accuracy of the Shrub/Scrub class (53.8% producer's accuracy in NLCD 2006), harvest-related misclassification represents a substantial source of uncertainty. While a forest mask was applied to address this issue, residual uncertainty remains in distinguishing temporary harvest from permanent conversion,

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[10] Wickham, J., S. V. Stehman, D. G. Sorenson, L. Gass, and J. A. Dewitz. 2021. "Thematic Accuracy Assessment of the NLCD 2016 Land Cover for the Conterminous United States." *Remote Sensing of Environment* 257: 112357.

[11] Wickham, J. D., S. V. Stehman, L. Gass, J. Dewitz, J. A. Fry, and T. G. Wade. 2013. "Accuracy Assessment of NLCD 2006 Land Cover and Impervious Surface." *Remote Sensing of Environment* 130: 294–304.

particularly in areas with complex land use histories or where vegetation recovery occurs at rates that fall between NLCD mapping intervals.

Spatial and Temporal Sampling. FIA plot data, while comprehensive, represent a sample of forest conditions rather than a complete census. Plot locations may not fully capture the variability in carbon densities across all forest types, ages, and management histories present in Oregon. The temporal mismatch between FIA plot measurements and NLCD land cover dates introduces additional uncertainty, as carbon densities are assumed to represent conditions at NLCD mapping years.

Furthermore, FIA methodologies for data collection from FIA plots were modified in 2001 and as a result temporal variations in carbon densities could be captured only for years 2001-present. The Inventory applied mean carbon density values from 2001-2006 to estimate emissions and removals for years 1990-2000. This may have resulted in an overestimation of carbon stocks and removals between 1990-2000 because carbon density values used reflected federal restrictions on harvesting in federal lands that were put into place in the early 2000s. Forests in many FIA plots in the 1990s are likely to have been harvested and would consequently have had lower carbon stocks than they did after 2000 when harvest restrictions were in place.

Carbon Density Variability. Carbon densities extracted from FIA plots represent average conditions within forest groups. Actual carbon stocks vary significantly based on stand age, site quality, management history, disturbance regimes, and local environmental conditions. This analysis does not account for temporal changes in carbon density that may occur due to forest growth, aging, or changes in forest management practices between mapping periods.

Regional Aggregation. Grouping diverse forest types and ecoregions into broader categories may mask important local variations in carbon dynamics. Edge effects and spatial heterogeneity within classified areas are not fully captured at the resolution of this analysis.

Methodological Limitations. Formal error propagation analysis was not conducted for this inventory due to time and resource constraints. Consequently, confidence intervals for the final CO2e estimates are not provided. Such analysis would require quantifying uncertainties from each data source and modeling their combined effect through the calculation chain—from area estimation through carbon density assignment to final emissions calculations. Given the documented NLCD classification accuracies ranging from 54% to 90% depending on land cover class, uncertainty in area estimates alone could be substantial.

Data Gaps. The analysis period begins in 1990, but comprehensive statewide FIA data may not be available for all forest types in earlier years prior to 2000. Additionally, carbon density estimates for non-forest vegetation types converted to forest were not included, potentially underestimating carbon sequestration in afforestation scenarios.

Fertilizer soil emissions. Data on fertilizer application on commercial forests in Oregon are limited. Application estimates are based on reported intent to apply rather than on actual area where fertilizer was applied. Therefore, for the years where data is available, 2014-2024, the estimated emissions are likely an overestimate of emissions. While the 1990-2013 emissions are based on the average from 2014 to 2024 period, it is possible that they may underestimate the emissions because historical trends in fertilizer application in forests suggest that amount of fertilizer applied has generally decreased in the last 20 years.

Forest Land: Completeness

Emissions estimates for Forest Land include all six carbon pools: above ground, below ground, deadwood, litter, soil organic carbon and harvested wood products for Forest Land remaining Forest Land and land converted to Forest Land for inventory years between 1990 and 2021. Nitrous oxide (N_2O) are estimated using surrogate data for years 1990-2013. The current inventory does not estimate emissions and removals from Grassland converted to Forest Land due to limitations in land cover activity data.

Forest Land: Improvements

Currently, Oregon does not have a single state recognized land cover/ land use map for the forest sector. ODF uses FIA plots and statistical methods to estimate carbon emissions from the forest.[12] Emissions/removals estimated in this Inventory using NLCD and FIA plots differ slightly due to the difference in the total area of the Forest Land in Oregon. The NLCD quantification of forest (as defined in Table 3.1.1) is known to provide significantly smaller estimate of Oregon forest extent than the FIA-based estimate utilized in ODF/FIA's existing forest carbon ecosystem accounting project. The NLCD-based work in the Inventory does not supplant such forest-specific data/projects—rather, the NLCD-based methodology is preferred in the Inventory because it is able to integrate with the spatially-explicit, all-lands, backwards-looking (to 1990) needs of the current effort.

State level land cover/land use maps developed every 5 years in-line with IPCC land classes will help improve accuracy of GHG emission from forest and the entire land sector. Additionally, the data on growth rates of different forest type groups are lacking, a study to collect this data will help build state level carbon parameters for land converted to forest from other land use types.

To address uncertainty in GHG emissions from the forest due to errors in activity data and emission factors, IPCC guidelines recommend using Monte Carlo simulations in GHG estimation frameworks. We recommend adding this process in future improvements.

Future iterations of this inventory should prioritize: (1) formal uncertainty quantification through Monte Carlo simulation or comparable methods, incorporating published NLCD accuracy assessments, (2) improved forest mask development to better separate harvest from conversion, (3) temporal calibration of carbon densities to match NLCD mapping years, and (4) sensitivity analysis to identify which parameters contribute most to overall uncertainty.

Although the emissions from application of fertilizer on commercial forests are low, improvements can be made in collecting data on application amount and type of fertilizer. The inventory team may work with ODF to follow up with landowners to follow up and obtain more precise information on application area and/or rate.

The amount of carbon removed by the SWDS pool in the Harvested Wood Products category is not consistent with the estimates of long-term C stored in municipal landfills in Oregon estimated by DEQ (DEQ estimate is ~ 7x less C while including other biogenic waste constituents such as food waste and yard waste). This is typical because harvest and waste statistics are not aligned and HWP estimates are based on all the timber harvested in the state, regardless of where it is disposed of and what other sources of waste end up in Oregon. It is recommended to work with both ODF and DEQ to compare the results and identify the main factors that lead to inconsistencies in the estimates and address them. This

[12] Christensen, G.; Gray, A.; Kuegler, O.; and Yost, A. 2019. "Oregon Forest Ecosystem Carbon Inventory: 2001-2016." OR-Forest-Ecosystem-Carbon-2001-2016-Report-FINAL.pdf

may also result in improving HWP model parameterization related to the fate of harvested wood products disposed as waste in Oregon SWDS.

Category: Grassland

The Inventory includes these subcategories in the Grassland category:

- CO_2 fluxes from mineral soils
- CO_2 fluxes in biomass

Biomass carbon fluxes on grasslands reflect the balance of growth, mortality, and disturbance. In Oregon, grasslands and shrublands span a wide range of ecological regions—from semi-arid sagebrush steppe in the east to coastal prairies and valley grasslands in the west—resulting in substantial geographic variability in biomass stocks and turnover. These ecosystems typically have lower biomass than forests, but their carbon dynamics are highly responsive to drivers such as fire, grazing, invasive species encroachment, and land-use change. Biomass carbon fluxes estimates are disaggregated by ecoregions to capture variability across the state.

The methodology to estimate mineral soil carbon fluxes is based on methods outlined in the second edition of Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory (USDA Methods)[13], which was developed in response to Section 2709 of the Food, Conservation, and Energy Act of 2008. This Act directed USDA to "establish technical guidelines that outline science-based methods to measure the environmental service benefits from conservation and land management activities in order to facilitate the participation of farmers, ranchers, and forest landowners in emerging environmental services markets." The authors of the USDA Methods evaluated current science and aligned it with the methods of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for national inventories.

USDA, in collaboration with Colorado State University, has taken the methodological approach in the publication and created a web-based decision-support tool to quantify GHG emissions and removals associated with grassland. This tool, called COMET-Farm, implements a process-based, Tier 3 model, DayCENT. It is designed to estimate a complete GHG inventory of major on-farm emission sources, focusing on CO_2, N_2O, and CH_4, including CO_2 fluxes in biomass and mineral soil within the farm-gate. For this category, only mineral soil CO_2 fluxes are included. The DayCENT model is also used to estimate emissions and removals on grassland and cropland for the U.S. national GHG inventory.

COMET-Farm is able to model both the grasses and animal interactions on rangelands and grasslands. The tool has multiple crops that can be used to represent different grazing lands, such as a generic category of grass and detailed crops including rye, clover, blue grass, buffalo grass, fescue, and vetch. It models soil C fluxes based on land management information related to grazing such as the percent daily utilization of the grassland, rest days, and start and end grazing dates.

Grassland: Activity Data

Land Classification

Two NLCD land cover classes, Shrub/Scrub and Grassland/Herbaceous, were used as grassland sub-types for this analysis. Area changes for each sub-type were calculated across NLCD maps from 1996 to 2021

[13] (Ogle et al., 2024)

for both "Grassland Remaining Grassland" and "Land Converted to Grassland" categories to generate activity data.

Because NLCD data cannot distinguish between temporary forest harvest and permanent forest conversion to grassland, Forest Land conversions to Grassland were excluded from this analysis. These conversions should be incorporated when revised forest mask data becomes available. Activity data are summarized in Table 14 and should be updated accordingly when forest conversion data are included. Full activity data is available in the data library.

Table 14: Grassland area for grassland remaining grassland and land converted to grassland. Land converted to grassland values exclude forest land converted to grassland. All values in hectares.

Year	Grassland remaining grassland	Land converted to grassland
1990	12,437,138	-
1996	11,955,423	71,202
2001	11,494,734	131,380
2006	11,084,539	147,189
2011	10,844,436	172,340
2016	10,797,326	182,657
2011	10,813,677	188,915

Soils

Mineral Soils

The activity data for estimating emissions and removals in grasslands is the area of land under specific management regimes with mineral soil types. Table 15 contains the activity data parameters for grassland in COMET-Farm. Grasslands that are not managed, often called rangelands, do not require management data. If the land is actively managed, the data listed below are required to run COMET-Farm. This information is used to develop per acre CO_2 flux factors for each grassland system. Defaults are used for some of the data as indicated in the table.

Table 15: Activity Data for COMET-Farm

Category	Activity Data Element	Value Required (N = default used)
Historic Management	Pre-1980, was the land used for cropping or grazing and was the land irrigated?	Y
Historic Management	Was the land enrolled in the Conservation Reserve Program?	Y
Historic Management	1980 to 2000, was the was the land used for cropping or grazing and was the land irrigated?	Y
Historic Management	1980 to 200, why type of tillage was used?	Y
General Information	Year	Y

General Information	Geographic location (point or shapefile)	Y
Crop Information	Crop (type of grass being planted)	Y
Crop Information	Planting Date	Y
Crop Information	Continued from Previous Year (Y/N)	Y
Tillage	Date	N
Tillage	Type of tilling (conventional, reduced till, no till)	N
Organic Matter Additions	Date	N
Organic Matter Additions	Type of organic matter	N
Organic Matter Additions	Amount	N
Organic Matter Additions	Application method	N
Organic Matter Additions	N concentration	N
Organic Matter Additions	Percent wet	N
Organic Matter Additions	C/N ratio	N
Inorganic Nitrogen Fertilizer	Date	N
Inorganic Nitrogen Fertilizer	Type of fertilizer	N
Inorganic Nitrogen Fertilizer	Total amount applied (lbs/ac)	N
Inorganic Nitrogen Fertilizer	Total N applied (lbs/ac)	N
Inorganic Nitrogen Fertilizer	Percent ammonia	N
Inorganic Nitrogen Fertilizer	Application method	N
Inorganic Nitrogen Fertilizer	Enhanced efficiency fertilizer (nitrification inhibitor or controlled release)	N
Irrigation Events	Date	N
Irrigation Events	Inches	N
Liming	Date	N
Liming	Type of lime	N
Liming	Total amount applied (tons/ac)	N
Harvest	Date	N
Harvest	Yield (tons/ac)	N
Harvest	Grain/Fruit/Seed/Tuber/Root (determines what is being harvested)	N
Harvest	Stover removal	N
Grazing	Start date	Y
Grazing	End date	Y
Grazing	Daily utilization percent	Y
Grazing	Rest days	Y

There are not good independent sources of data to consistently characterize grazing activity over time. Agronomic experts were consulted to determine the parameters necessary to simulate the conditions. The data obtained from experts included:

- Typical cattle grazing practices, including start dates, end dates, and daily utilization of biomass

- Confirmation of grazing dates and rest periods
- Fertilizer rates, forms, and application dates

Biomass

For biomass carbon, NLCD classes shrubs and perennial forb and herbaceous vegetation grassland areas by vegetation class are summarized in Table 16.

Table 16: Grassland area for grassland remaining grassland and land converted to grassland, by vegetation classification. Land converted to grassland values exclude forest land converted to grassland. All values in hectares.

Year	Herb. grassland remaining grassland	Land converted to herb. grassland	Shrub/scrub grassland remaining grassland	Land converted to shrub/scrub grassland
1990	3,427,564	-	9,009,573	-
1996	2,920,572	24,806	9,034,851	46,396
2001	2,807,392	56,452	8,687,341	74,928
2006	2,845,264	64,022	8,239,275	83,167
2011	2,993,487	79,503	7,850,948	92,837
2016	3,434,266	91,057	7,363,060	91,600
2011	3,534,082	86,295	7,279,595	102,621

Furthermore, areas are disaggregated by ecoregion which are expected to have variable carbon densities.

Grassland: Emission Factors

Mineral Soils

For mineral soils grasslands, emission factors are generated using COMET-Farm tool as outlined in the cropland section.

Biomass Carbon Densities

Carbon density parameters for NLCD sub-types **shrub/scrub** and **grassland/herbaceous** are separately calculated using net primary productivity (NPP) data from Rangeland Analysis Platform (RAP). NPP is the net increase (i.e., photosynthesis minus respiration) in total plant carbon, including above and below ground carbon. Annual carbon stocks for shrub and perennial forb and herbaceous vegetation for each inventory year were generated. Carbon stock changes between consecutive inventory years were used to derive carbon density parameters or emission factors for **shrub/scrub** sub-type and **grassland/herbaceous** sub-type of the Grassland land category (Table 17).

Table 17: Average biomass carbon density for Shrub/Scrub and Grassland/herbaceous (perennial only) derived using Net Primary Productivity data from Rangeland Analysis Platform in tonne C ha^{-1}. Parentheses represent standard error.

Year	Shrub/scrub Biomass carbon density	Grassland/herb Biomass carbon density
1991-1996	0.55 (0.04)	8.79 (0.25)
1997-2001	0.48 (0.04)	8.55 (0.28)
2002-2006	0.47 (0.04)	8.26 (0.22)
2007-2011	0.47 (0.03)	8.14 (0.16)
2012-2016	0.58 (0.08)	7.53 (0.1)
2017-2021	0.63 (0.04)	7.6 (0.32)

Biomass carbon density parameters further disaggregated by ecoregion are provided in Table 18.

Table 18: Average biomass carbon density for Shrub/Scrub and Grassland/herbaceous (perennial only) derived using Net Primary Productivity data from Rangeland Analysis Platform in tonne C ha^{-1}). Parentheses represent standard error.

Class	Year	Blue Mountains	West Cascades	Coast Range	Columbia Plateau	Eastern Cascades Slopes and Foothills	Klamath Mountains/ California High North Coast Range	Northern Basin and Range	Willamette Valley
Shrub/Scrub	1991-1996	0.84 (0.05)	0.19 (0.05)	0.23 (0.08)	0.28 (0.02)	0.69 (0.05)	0.41 (0.08)	1.69 (0.08)	0.33 (0.04)
Shrub/Scrub	1997-2001	0.75 (0.06)	0.15 (0.01)	0.06 (0.02)	0.26 (0.05)	0.7 (0.04)	0.25 (0.03)	1.7 (0.23)	0.23 (0.06)
Shrub/Scrub	2002-2006	0.81 (0.06)	0.15 (0.03)	0.09 (0.01)	0.32 (0.03)	0.71 (0.04)	0.34 (0.09)	1.58 (0.13)	0.15 (0.02)
Shrub/Scrub	2007-2011	0.74 (0.07)	0.14 (0.02)	0.04 (0.01)	0.3 (0.02)	0.74 (0.04)	0.26 (0.02)	1.62 (0.14)	0.17 (0.03)
Shrub/Scrub	2012-2016	0.91 (0.14)	0.32 (0.07)	0.13 (0.03)	0.28 (0.04)	1.07 (0.18)	0.44 (0.06)	1.53 (0.19)	0.4 (0.07)
Shrub/Scrub	2017-2021	0.98 (0.08)	0.28 (0.03)	0.15 (0.03)	0.21 (0.02)	0.99 (0.08)	0.76 (0.19)	1.7 (0.09)	0.35 (0.04)
Perennial Herbaceous	1991-1996	11.56 (0.32)	3.4 (0.19)	8.07 (0.34)	8.92 (0.19)	8.66 (0.4)	9.47 (0.34)	5.21 (0.35)	13.56 (0.66)
Perennial Herbaceous	1997-2001	11.15 (0.34)	3.03 (0.12)	9.46 (0.68)	7.29 (0.44)	8.19 (0.45)	8.99 (0.54)	5.8 (0.25)	13.27 (0.77)

Perennial Herbaceous	2002-2006	10.9 (0.4)	2.98 (0.19)	9.92 (0.22)	6.82 (0.33)	8.23 (0.38)	8.2 (0.25)	5.6 (0.46)	12.72 (0.46)
Perennial Herbaceous	2007-2011	10.88 (0.11)	2.63 (0.11)	8.6 (0.35)	6.92 (0.23)	7.73 (0.26)	8.13 (0.26)	5.56 (0.22)	13.37 (0.22)
Perennial Herbaceous	2012-2016	9.7 (0.15)	2.34 (0.19)	8.73 (0.4)	6.76 (0.29)	7.07 (0.15)	8.07 (0.15)	5.58 (0.31)	11.57 (0.4)
Perennial Herbaceous	2017-2021	10 (0.47)	2.15 (0.11)	8.88 (0.19)	7.46 (0.54)	6.9 (0.38)	7.06 (0.45)	6.48 (0.55)	10.07 (0.5)

Land Conversions

Carbon fluxes for mineral soils and biomass are estimated when land is converted to Grassland for Cropland, Wetland, Other Land (biomass only), and Developed Land. Carbon fluxes associated with Forest Land to Grassland transitions are not estimated due to gap in activity data.

Mineral Soils

The estimation approach for each category of land converted to Grassland with mineral soils is listed in Table 19.

Table 19. Inventory approach for lands converted to croplands with mineral soils

Category	Inventory Approach
Cropland converted to Grassland	COMET-Farm
Wetland converted to Grassland	Utilize soil carbon stock value for Inland Wetlands (emergent)
Forest land converted to Grassland	NA
Other Land converted to Grassland	Not estimated
Developed Land converted to Grassland	Assume Cropland values pre-transition

For Cropland converted to Grassland, the cropping system is entered into COMET-Farm according to the associated processes in the sections for Mineral Soils. In the year when Cropland changes to Grassland, the cropping system in COMET-Farm is modified to represent that land use category. For example, if 100,000 acres change from Cropland to Grassland in 2001, the SOC is calculated as Cropland through 2000 and then changes to Grassland in 2001.

Biomass

Parameters are summarized in Table 20.

Table 20: Pre-conversion biomass C density

Category	Pre-conversion biomass stock
Cropland converted to Grassland	4.7 tonne C ha^{-1}
Wetland converted to Grassland	15.59 tonne C ha^{-1} (inland emergent wetlands)
Forest land converted to Grassland	NA
Other Land converted to Grassland	0
Developed Land converted to Grassland	75.4 tonne C ha^{-1} (open space)

Grassland: Methodology

Carbon Fluxes in Mineral Soils

To calculate SOC stocks for crops grown in mineral soils, the USDA Methods document adapts the model developed by IPCC[14], which is included in the COMET-Farm model. The equation is provided below in Equation 13.

Equation 13: Change in SOC stocks for mineral soils for Grassland

Tier 3 and Tier 2

$$\Delta C_{mineral} = [(SOC_0 - SOC_{0-t}) \div t] \times Area$$

Tier 2 Only

$$SOC = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_I$$

Where:

For Tier 3:

$\Delta C_{mineral}$ = annual change in mineral soil organic carbon stock, tonne C

SOC_0 = C stock at the end of the period

$SOC_{(0-T)}$ = C stock at the beginning of the period

D = 1 year

Area = area of the parcel, ha

For Tier 2:

$\Delta C_{mineral}$ = annual change in mineral soil organic carbon stock, tonne C

SOC_0 = C stock at the end of the period

$SOC_{(0-t)}$ = C stock at the beginning of the period

D = 1 year for Tier 3 and 20 years for Tier 2

Area = area of the parcel, ha

SOC_{Ref} = reference C stock

F_{LU}, F_{MG}, F_I = stock change factors for land use, management practice, and input levels of organic matter, respectively

[14] IPCC (2019). Chapter 2: Generic Methodologies Applicable to Multiple Land-Use Categories. In “2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use”. IPCC, Switzerland.
IPCC (2019). Chapter 5: Cropland. In “2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use”. IPCC, Switzerland.

Carbon Fluxes for Biomass on Grassland Remaining Grassland

Annual biomass carbon flux from Grassland Remaining Grassland is estimated for two grassland types (Shrub/Scrub and Grassland/Herbaceous) across eight EPA Level III ecoregions. The total change in biomass carbon stocks is calculated by summing the changes across both grassland types and all ecoregions. Equation 14 is used to calculate the total biomass carbon flux from Grassland Remaining Grassland.

Equation 14: **Total annual biomass carbon flux from Grassland Remaining Grassland**

$$\Delta C_{GG} = \sum_g \sum_e \Delta C_{GG,g,e} \text{ (for g = 1 to 2; e = 1 to 8)}$$

Where:

ΔC_{GG} = total annual biomass carbon stock change for Grassland Remaining Grassland, tonne C yr^{-1}

$\Delta C_{GG,g,e}$ = annual biomass carbon stock change for grassland type g in ecoregion e, tonne C yr^{-1}

g = grassland type (1 = Shrub/Scrub, 2 = Grassland/Herbaceous)

e = EPA Level III ecoregion (e = 1 to 8)

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

The annual biomass carbon stock change for each grassland type within each ecoregion is calculated using Equation 15.

Equation 15: Annual biomass carbon stock change by grassland type and ecoregion

$$\Delta C_{GG,g,e} = At_{2,g,e} \text{ x } Ct_{2,g,e} - At_{1,g,e} \text{ x } Ct_{1,g,e}$$

Where:

$\Delta C_{GG,g,e}$ = biomass carbon stock change for grassland type *g* in ecoregion *e*, tonne C yr^{-1}

$A_{t1,g,e}$ = area of grassland type *g* in ecoregion *e* at time t1, ha

$A_{t2,g,e}$ = area of grassland type *g* in ecoregion *e* at time t2, ha

$C_{t1,g,e}$ = biomass carbon stock for grassland type *g* in ecoregion *e* at time t1, tonne C ha^{-1}

$C_{t2,g,e}$ = biomass carbon stock for grassland type *g* in ecoregion *e* at time t2, tonne C ha^{-1}

g = grassland type (1 = Shrub/Scrub, 2 = Grassland/Herbaceous)

e = EPA Level III ecoregion (e = 1 to 8)

Note: Biomass carbon includes both aboveground and belowground components. To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Carbon Fluxes for Land Converted to Grassland

When land is converted to Grassland from other land use types, the change in carbon stocks is calculated as the sum of four components: (1) increase in carbon stocks due to biomass growth following conversion, (2) immediate change in carbon stocks resulting from the conversion itself (calculated as the difference between biomass stocks immediately after and before conversion), (3) decrease in carbon stocks due to biomass losses from harvesting and disturbances, and (4) change in soil carbon stocks from the conversion. Equation 16 calculates the annual change in biomass carbon stocks during the post-conversion period, while Equation 17 calculates the immediate change in biomass carbon stocks at the time of conversion to Grassland. Both equations must be applied separately for each land use type being converted to Grassland as well as carbon pool (e.g. biomass, mineral soil), with results summed across all land use types to determine the total annual carbon flux from land conversion to Grassland.

Equation 16: Annual change in biomass carbon stocks on land converted to Grassland (Eq. 2.15 in Vol. 4, Chap. 2, 2006 IPCC GL)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION}$$

Where:

ΔC_B = annual change in carbon stocks in biomass on land converted to Grassland, tonne C yr^{-1}

ΔC_G = annual increase in carbon stocks in biomass due to growth on land converted to Grassland, tonne C yr^{-1} (assumed to be zero due to lack of data)

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to Grassland (calculated once in year of conversion), tonne C yr^{-1}

Equation 17: Change in biomass carbon stocks in land converted to Grassland (adapted from Eq. 2.16 in Vol. 4, Chap. 2, 2006 IPCC GL)

$$\Delta C_{CONVERSION} = \sum_i [(C_{AFTER,i} - C_{BEFORE,i}) \times Area_{CONVERTED,i}]$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks at time of conversion, tonne C yr^{-1}

$C_{AFTER,i}$ = biomass carbon stock on land use type *i* immediately after conversion to Grassland, tonne C ha^{-1}

$C_{BEFORE,i}$ = biomass carbon stock on land use type *i* immediately before conversion to Grassland, tonne C ha^{-1}

$Area_{CONVERTED,i}$ = area of land use type *i* converted to Grassland, ha

i = land use type converted to Grassland

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Specific Methodology for Mineral Soil Carbon Modelling using COMET-Farm

The same process for using COMET-Farm on croplands is used for grasslands (see Cropland Section below). The primary difference is the grazing information required (See above for the required information). If the land is unmanaged grazing land, most of the COMET-Farm parameters are not required.

Grassland: Uncertainty

Carbon accumulation parameters in biomass (including aboveground and belowground), were based on estimates of net primary productivity (NPP) from the RAP NPP data product, for which uncertainty has not been formally assessed, but could be high. The uncertainty is related to the propagation of uncertainty arising from the cover maps used by the NPP model as well as spatial resolution of the data and ability to accurately model vegetation dynamics.

Uncertainty for mineral soils is associated with the DayCent ecosystem model used by COMET-Farm. The uncertainty is due to the process-based model structure and parameters. Uncertainty is quantified in the model with an empirically based approach, as used in the U.S. National GHG Inventory.[15] The method combines modeling and measurements to estimate SOC stock changes for entity-scale reporting.[16]

Grassland: Completeness

For mineral soils, we created scenarios based on data from the Oregon Department of State Lands and selected representative data points in each Oregon. This information was the best available, but is not believed to be comprehensive of the different land management processes throughout the state. In addition, we were unable to get COMET-Farm to provide results for a system converting from Cropland to Grassland for 19 counties (Benton, Clackamas, Clatsop, Columbia, Coos, Curry, Douglas, Hood River, Jackson, Josephine, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill). These counties represent the Western portion of the state, including the Cascades and the coastal region, where this type of conversion is less common. The current inventory does not estimate emissions and removals from Forest Land converted to Grassland due to limitations in land cover activity data.

Grassland: Improvements

The RAP Net Primary Productivity (NPP) product and associated estimates for carbon fluxes include provision of spatially explicit uncertainty estimates to support error propagation, incorporation of management-relevant inputs where feasible, and validation of the NPP model for estimating biomass or carbon stock changes.

Additional research to inform calculation methods for natural grasslands and rangelands, once they can be distinguished, would increase the accuracy of emissions/removal estimates. Information on rangeland condition such as from the SageCon Rangeland Condition Report, or information on invasive grass encroachment and burn history, could improve carbon estimates if appropriate data and methods are developed. Some of this information may be incorporated into the Rangeland Analysis Platform as

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[15] (Ogle et al., 2007; EPA. 2024. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022. Chapter 6: Land Use, Land-Use Change, and Forestry. EPA 430-R-24-004. U.S. Environmental Protection Agency, Washington, DC.).
[16] (Conant et al., 2011).

the underlying data are refined, which will help to refine the estimates for rangelands in future inventory analysis.

To improve the accuracy of the modelling results, it is recommended that additional information is collected about the starting and ending grazing dates as well as the rest period between grazing events. It is also recommended that the inventory team collaborate with the COMET-Farm team to obtain model results for omitted counties (Benton, Clackamas, Clatsop, Columbia, Coos, Curry, Douglas, Hood River, Jackson, Josephine, Lane, Lincoln, Linn, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill).

Category: Cropland

The cropland inventory includes the GHG emissions and removals on land dominated by the cultivation of annual crops, managed pasture and hay production, and perennial crops such as orchards and vineyards.

The inventory includes:

- CO_2 fluxes from mineral soils
- CO_2 fluxes in biomass from perennial woody crops
- CO_2, CH_4, and N_2O emissions from organic soils

This methodology is based on methods outlined in the second edition of Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory (USDA Methods)[17], which was developed in response to Section 2709 of the Food, Conservation, and Energy Act of 2008. This Act directed USDA to "establish technical guidelines that outline science-based methods to measure the environmental service benefits from conservation and land management activities in order to facilitate the participation of farmers, ranchers, and forest landowners in emerging environmental services markets." The authors of the USDA Methods evaluated current science and aligned it with the methods of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for national inventories.

USDA, in collaboration with Colorado State University (CSU), has taken the methodological approach in the USDA Methods and created a web-based decision-support tool to quantify GHG emissions and removals associated with grassland. This tool, called COMET-Farm, implements a process-based, Tier 3 model, DayCENT. It is designed to estimate a complete GHG inventory of major on-farm emission sources, focusing on CO_2, N_2O, and CH_4, including CO_2 fluxes in biomass and mineral soil within the farm-gate. For this category, only mineral soil CO_2 fluxes are included. The DayCENT model is also used to estimate emissions and removals on grassland and cropland for the U.S. national GHG inventory.

COMET-Farm only includes crops for which sufficient data are available to produce credible estimates as determined by the model development team. As a result, COMET-Farm does not include all the crops grown in the state of Oregon. For crops not included in COMET-Farm, Tier 2 quantification approaches from the USDA Methods document are used. COMET-Farm is also not able to quantify GHG emissions in organic soils.

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[17] (Ogle et al., 2024)

Cropland: Activity Data

Land Classification

See the beginning of this Appendix for a description of how activity data is prepared to enable classification by ecoregion and soil type. Furthermore, all cropland is disaggregated by county to identify dominant crops by county. A summary of cropland activity data is provided in Table 21. Full activity data is available in the data library.

Table 21. Cropland remaining cropland and land converted to cropland in hectares

Year	Cropland remaining cropland	Land converted to cropland
1990	2,070,375.32	-
1996	1,976,352.68	61,439.85
2001	1,916,480.09	108,171.90
2006	1,873,586.45	128,748.96
2011	1,831,705.48	153,040.68
2016	1,837,894.87	155,527.02
2011	1,834,748.92	142,853.67

Mineral Soils

The activity data for estimating emissions and removals in cropland with mineral soils is the area of land stratified by soil type and cropping system. Below is a breakdown of the specific parameters used as inputs into COMET-Farm to represent the activity data.

Modeled Crops

The following crops grown in Oregon are currently included in the COMET-Farm model:

- Alfalfa
- Barley
- Beans
- Corn
- Hay (used Grass-Legume Mix)
- Oats
- Peas
- Potato
- Rye
- Sugarbeets
- Wheat

In future years, the individual completing the inventory should review the current crops included in the COMET-Farm model to determine if new crops have been added or if there is a potentially better proxy for an Oregon-grown specific crop, and contact the COMET-Farm team to verify sufficient similarity.

Table 22 contains the activity data parameters needed to model each cropping system in COMET-Farm. This information is used to develop per acre emission factors for each cropping system. Defaults provided in the model are used for some of the data as indicated in the table.

Table 22: Activity Data for COMET-Farm

Category	Activity Data Element	Value Required (N = default used)
Historic Management	Pre-1980, was the land used for cropping or grazing and was the land irrigated?	Y
Historic Management	Was the land enrolled in the Conservation Reserve Program?	Y
Historic Management	1980 to 2000, was the was the land used for cropping or grazing and was the land irrigated?	Y
Historic Management	1980 to 200, why type of tillage was used?	Y
General Information	Cropping year	Y
General Information	Geographic location (point or shapefile)	Y
Crop Information	Crop	Y
Crop Information	Planting Date	Y
Crop Information	Prune Date	N
Crop Information	Continued from Previous Year (Y/N)	Y
Tillage	Date	N
Tillage	Type of tilling (conventional, reduced till, no till)	N
Organic Matter Additions	Date	N
Organic Matter Additions	Type of organic matter	N
Organic Matter Additions	Amount	N
Organic Matter Additions	Application method	N
Organic Matter Additions	N concentration	N
Organic Matter Additions	Percent wet	N
Organic Matter Additions	C/N ratio	N
Inorganic Nitrogen Fertilizer	Date	N
Inorganic Nitrogen Fertilizer	Type of fertilizer	N
Inorganic Nitrogen Fertilizer	Total amount applied (lbs/ac)	N

Inorganic Nitrogen Fertilizer	Total N applied (lbs/ac)	N
Inorganic Nitrogen Fertilizer	Percent ammonia	N
Inorganic Nitrogen Fertilizer	Application method	N
Inorganic Nitrogen Fertilizer	Enhanced efficiency fertilizer (nitrification inhibitor or controlled release)	N
Irrigation Events	Date	N
Irrigation Events	Inches	N
Liming	Date	N
Liming	Type of lime	N
Liming	Total amount applied (tons/ac)	N
Harvest	Date	N
Harvest	Yield (tons/ac)	N
Harvest	Grain/Fruit/Seed/Tuber/Root (determines what is being harvested)	N
Harvest	Stover removal	N

Nitrogen use

County-level nitrogen and phosphorus from fertilizer and manure are provided by (Falcone, 2020). The Oregon Department of Agriculture (ODA) also provides data on fertilizer type by year (Oregon Tonnage Summary for the Fertilizer Program).

Cropping systems

USDA conducts two different data collection efforts – Census and Survey (USDA National Agricultural Statistics Service (NASS)). For the Census, data is gathered from every known and potential agricultural operation and producer in the United States. It is conducted every five years. The NASS Survey is a selection of respondents who best represent the population of an agricultural crop. It is conducted annually. Each of these data collection efforts have benefits and drawbacks. For the state of Oregon, the dataset with the highest quality activity data is used in developing the state's GHG inventory. Each data source is listed below.

Survey data is applied to the year collected by USDA. Because the Census data is only collected every five years, it is interpolated between Census intervals. Both the Census and Survey data were obtained using USDA's Quick Stats tool (https://quickstats.nass.usda.gov/).

- Average acres harvested by crop totaled by county for each year of the inventory (USDA NASS Survey)
- Data describing, among other parameters, the planting and harvest dates for: the given year, the previous year, and the averages from the past five years, for key crops (barley, corn, oats, spring wheat, sugar beets, and winter wheat) (NASS Crop Progress and Condition Graphical Products, https://www.nass.usda.gov/Charts_and_Maps/Crop_Progress_&_Condition/index.php)
- Crop yield by commodity totaled by county (Survey)

- Tillage data by commodity totaled by county (USDA NASS Census)
- Cover crop types (USDA NRCS)
- Irrigated acres (USDA NASS Census)
- Burned acres (USDA NASS Census)

Once the data is collected using the data sources above, expert opinion of agronomic experts is used to confirm the accuracy of the data. The minimum data that is confirmed by the agronomic experts includes:

- Crop rotations
- Fertilizer rates, forms, and application dates
- Tillage dates and practices

Tier 2 Specialty Crops

CO_2 flux in mineral soils and biomass for crops that are not included or do not have a good proxy in COMET-Farm are quantified using the activity data listed below for a Tier 2 method and are quantified using Equation 3-12 in USDA Methods. More detail on the quantification process is found in the sections below. The activity data required for these crops are:

- Biomass type (woody, shrub, other/annual)
- County
- Soil type
- Climate Zone

The biomass type was determined using USDA's Plant List of Attributes, Names, Taxonomy, and Symbols (PLANTS) Database.

Crops Unavailable in COMET-Farm:

- Apples
- Blackberries
- Blueberries
- Boysenberries
- Broccoli
- Carrots
- Cauliflower
- Cherries
- Christmas trees
- Cranberries
- Cucumbers
- Garlic
- Grapes
- Hazelnuts
- Hops
- Mint
- Onions

- Peaches
- Pears
- Plums
- Pumpkins
- Raspberries
- Squash
- Strawberries
- Watermelon

Organic Soils

To quantify emissions from organic soils, such as Histosols, the activity data required are acres of organic soils, obtained through the USDA SSURGO dataset as described in the soils characteristics section at the beginning of this Appendix.

Woody Biomass

To quantify emissions from woody and shrub biomass, such as orchards, the activity data required are the annual hectare by type of fruit or nut tree. The acres were obtained through the USDA NASS Census dataset and converted to hectares. The trees included in the inventory are:

- Apples
- Cherries
- Chestnuts
- Christmas Trees
- Grapes
- Hazelnuts
- Peaches
- Pears
- Plums

The USDA NASS Census totals Christmas Trees by number of trees rather than acres. According to Patrick White in the Winter 2012 edition of Northern Woodlands: “Spacing trees at 5-by-5 feet will allow for more than 1,700 trees per acre, while 6-by-6 spacing yields about 1,200. It’s hard to imagine when the young transplants are first put in the ground, but even 6-by-6 spacing will be pretty tight by the time the trees are fully grown.” To convert from trees to hectares, an average number of 1,450 trees per acre was assumed and the acre value was converted to hectares.

Cropland: Emission Factors

Mineral Soils

Modeled Crops

COMET-Farm is used to derive emissions factors for crops in Oregon either directly or using proxy crops. COMET-Farm can be used through a web-based or application program interface (API). Generating the inventory using the API involves a four-step process. The first step is to identify representative locations for each cropping system. The next two steps produce an estimate of initial soil organic carbon (SOC) stocks prior to the reporting period. The final step is to parameterize and run the model for the time series of the inventory. The specific steps are as follows:

1. For each cropping system included in the inventory, representative locations must be selected throughout the state where that cropping system is the most common. This can be designated as a single point with a latitude and longitude and an overall size in acres or as a shapefile for a location. Each cropping system requires the Activity Data collected and entered into the Cropping Systems Excel workbook detailed below.
2. Run the COMET-Farm model to create a steady-state condition (i.e., equilibrium) with native vegetation, historical climate data, and the soil physical attributes for the land parcel. This is performed by the model without any user intervention based on the locations selected above.
3. Simulate a period from the mid-1800s to the year prior to the first year of the inventory time series selecting practices that best match the cropping system of the location. This step is run with minimal activity data. The user provides information about management for the location between 1980 and 2000. The resulting SOC stock (kg C per meter squared) at the end of the simulation provides the SOC value for the year 2000. To obtain the stock value for 1990, the data from 2000 onward are interpolated back to 1990.
4. Develop SOC fluxes values for each year of the inventory time series based on the management activity for the land parcel. The python script calculates the SOC flux values for each cropping system and scales them up to the state level based on the acres of each crop produced in the state (more detail below).

Specialty Crops using Tier 2 Methods

The quantification of SOC for 25 crops grown in Oregon that are not included in COMET-Farm, a Tier 2 approach based on the USDA Methods document is used to determine above and belowground carbon stocks. This is detailed in the following section. The stock change factors to be used in these calculations are provided in Table 23.

Table 23: Stock change factors for Equation 19 (unitless). Reference: Quantifying GHG Fluxes in Agriculture and Forestry USDA, Chap 3, Table 3-10. Values in parentheses represent 95 percent confidence interval.

Variable	Parameter	Cool Moist Climate	Cool Dry Climate	Warm Moist Climate	Warm Dry Climate
F_{lu}	Cultivated	1	1	1	1
F_{lu}	General Uncultivated	1.37 (±0.15)	1.37 (±0.15)	1.58 (±0.13)	1.58 (±0.13)
F_{lu}	Set-asides	1.05 (±0.24)	1.05 (±0.24)	1.18 (±0.19)	1.18 (±0.19)
F_{mg}	Full intensive till	1	1	1	1
F_{mg}	Reduced till	1.05 (±0.08)	1	1.05 (±0.08)	1
F_{mg}	No-till	1.14 (±0.06)	1.09 (±0.07)	1.14 (±0.06)	1.09 (±0.07)
F_i	Low	0.94 (±0.02)	0.94 (±0.02)	0.94 (±0.02)	0.94 (±0.02)
F_i	Medium	1	1	1	1
F_i	High	1.07 (±0.04)	1.07 (±0.04)	1.07 (±0.04)	1.07 (±0.04)

F_i	High with amendment	1.44 (±0.19)	1.37 (±0.16)	1.44 (±0.19)	1.37 (±0.16)

Organic Soils

CO_2, N_2O, and CH_4 emissions and removals for organic soils are calculated according to IPCC Guidelines. The emissions factors are provided in the Table below. To estimate emissions from drained organic soils, Tier 1 approach was used because the IPCC Wetland Supplement published in 2014 provides the most recent set of emission factors to estimate emissions from drained organic soils across climate zones, land use categories, and GHGs. Although these are not US specific, enabling Tier 2 approach, they reflect the latest research and ensure completeness and consistency.

Table 24: Emission factors for drained organic soils on cropland. Ranges in parentheses represent 95 percent confidence interval.

Parameter	Gas	Value	Unit	Reference
EF, on-site	CO_2	7.9 (6.5 – 9.4)	tonne CO_2-C ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.1*
EF_{DOC}, off-site	CO_2	0.31 (0.19–0.46)	tonne C ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.2*
EF, direct emissions	N_2O	13 (8.2 – 18)	kg N_2O-N ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.5*
EF, land	CH_4	0 (-2.8 – 2.8)	kg CH_4 ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.3*
EF, ditch	CH_4	1165 (335-1995)	kg CH_4 ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.4*
Frac_ditch	CH_4	0.05	unitless	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.4*

Woody Biomass

GHG emissions and removals for biomass are calculated according to Equation 2.7 in Chapter 2 of the 2006 IPCC Guidelines for National GHG Inventories. The default emissions factors used are found in Table 5.3 of Chapter 5 of the 2019 Refinement to the 2006 IPCC Guidelines and included Table 24 below. Since the exact acres of harvest and immature areas are unknown, the IPCC assumption is used, which states that "the annual harvest area is equal to total area divided by rotation length in years."

Table 25: IPCC Above-Ground Biomass Emission Factor

Cropping System	Harvest/ Maturity Cycle (yr)	Mean biomass carbon stock (tonnes C ha^{-1})
Orchard	20 ± 42%	6.4 ±25%
Coppice (Shrubs)	4	6.35 ± 40%
Vine	20 ± 18%	2.8 ± 25%

Reference: 2019 Refinement to 2006 IPCC Guidelines Volume 4, Chapter 5, Table 5.3

Land Converted to Cropland

The inventory approach for each category of land converted to Cropland with mineral soils is listed in Table 26.

Table 26: Inventory approach for lands converted to croplands with mineral soils

Category	Inventory Approach
Forest land converted to Cropland	COMET-Farm
Grassland converted to Cropland	COMET-Farm
Other Land converted to Cropland	Not estimated
Developed Land converted to Cropland	Assume no change

For each category using COMET-Farm, the cropping system is entered according to the associated processes in the sections for Mineral Soils. In the year when the land changes from one usage to another, the data for COMET-Farm is modified to represent that land use category. For example, if 100,000 acres change from Grassland to Cropland in 2001, the SOC is calculated as Grassland through 2000 and then changes to Cropland in 2001.

To determine the SOC associated with Forest Land converting to Cropland, we modeled the SOC for Grassland as representative for those land categories. Developed Land converted to Cropland assumes no change. Flux due to conversion from Other Land is not estimated due to lack of data.

Cropland: Methodology

Cropland Remaining Cropland

Carbon Fluxes on Mineral Soils for Modeled Crops

To calculate SOC stocks for crops grown on mineral soils, the USDA Methods adapts IPCC equation (Equation 18) for mineral soils (Ogle et al., 2019a). The COMET-Farm model outputs provide values for SOC_0 and $SOC_{(0-t)}$.

Equation 18: Change in SOC stocks for mineral soils for Cropland

Tier 3 and Tier 2

$$\Delta C_{mineral} = [(SOC_0 - SOC_{0-t}) \div t] \times Area$$

Tier 2 Only

$$SOC = SOC_{Ref,crop} \times F_{LU} \times F_{MG} \times F_I$$

Where:

For Tier 3:

$\Delta C_{mineral}$ = annual change in mineral soil organic carbon stock, tonne C

SOC_0 = C stock at the end of the period

$SOC_{(0-T)}$ = C stock at the beginning of the period

D = 1 year

Area = area of the parcel, ha

For Tier 2:

$\Delta C_{mineral}$ = annual change in mineral soil organic carbon stock, tonne C

SOC_0 = C stock at the end of the period

$SOC_{(0-t)}$ = C stock at the beginning of the period

D = 1 year for Tier 3 and 20 years for Tier 2

Area = area of the parcel, ha

$SOC_{Ref,crop}$ = reference C stock (see Equation 19)

F_{LU}, F_{MG}, F_I = stock change factors for land use, management practice, and input levels of organic matter, respectively

The output file from COMET-Farm contains location-specific SOC estimates for a representative cropping system from 2000 through ten years beyond the current year (i.e., in 2025, COMET-Farm provides estimates through 2035). The $\Delta C_{mineral}$ value is the average annual change in kg per square meter for each representative location within a given county and associated representative cropping system. Using a python script developed to extract data from COMET outputs, the factor is converted to units of tonnes CO_2e/acre and multiplied by the area of each cropping system in the county and then the total $\Delta C_{mineral}$ for each county is summed for each year and cropping system to yield state-level soil carbon change over time.

Carbon Fluxes on Mineral Soils for Specialty Crops using Tier 2 Methods

For crops not included in COMET-Farm (see list above), CO_2 emissions and removals in above and belowground biomass and mineral soils are calculated according to the process in this section of the methodology.

For crops not included in COMET-Farm, D is used to determine SOC stock for mineral soils, based on reference carbon stocks and land use, management, and input factors from Table 26. Then total SOC is calculated according to Equation 19.

The SOC_{ref} value is based on soil type and IPCC climate zones. For each crop, it is calculated according to Equation 19. Equation 19 assumes a county only has one climate zone.

Equation 19: $SOC_{ref,crop}$ for mineral soils

$$SOC_{ref,crop} = \sum(SOC_{ref,crop} \times \text{Crop Area Percent}_{county})$$

Where $SOC_{ref,county}$ is calculated by:

$$SOC_{ref} = \sum(\text{Soil type area\%}_{soil} \times SOC_{ref,soil})$$

Where:

$SOC_{ref,crop}$ = Derived SOC_{ref} value for a given crop type, tonne C ha^{-1}

$SOC_{ref,county}$ = Derived SOC_{ref} value for a given county, tonne C ha^{-1}

Crop Area% = Proportion of crop area grown in county out of total crop area in the state

Soil type area% = Proportion of mineral soil type for a given county

SOC_{ref} = SOC value for the county-specific climate zone, tonne C ha^{-1}

Biomass Carbon Fluxes for Perennial Crops

For trees and shrubs not included in COMET-Farm, the Inventory uses the Tier 1 IPCC equation for perennial woody cropland, which is detailed in Equation 20.

Equation 20: Biomass carbon stock for perennial woody crops

$$C_{biomass} = (Area_b \times EF_b)$$

Where:

$C_{biomass}$ = woody biomass stock for perennial woody cropland, tonne C

$Area_b$ = area of croplands in the entire land parcel being estimated, ha

EF_b = emission factor for biomass carbon stock, tonne C ha^{-1}

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Land Converted to Cropland

The inventory approach for land converted to cropland is to quantify biomass C flux, mineral soil organic carbon (SOC) as C flux.

Biomass

When land is converted from other land categories to Cropland, the change in biomass carbon stocks is assumed to occur in the year of transition. The carbon flux is calculated using Equation 21.

Equation 21. Carbon stock change in biomass carbon stocks in land converted to Cropland (adapted from Eq. 2.16 in Vol. 4, Chap. 2, 2006 IPCC GL)

$$\Delta C_{CONVERSION} = \sum_i[(C_{AFTER,i} - C_{BEFORE,i}) \times Area_{CONVERTED,i}]$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks at time of conversion, tonne C yr^{-1}

$C_{AFTER,i}$ = biomass carbon stock on land use type *i* immediately after conversion to Cropland, tonne C ha^{-1}

$C_{BEFORE,i}$ = biomass carbon stock on land use type *i* immediately before conversion to Cropland, tonne C ha^{-1}

$Area_{CONVERTED,i}$ = area of land use type *i* converted to Cropland, ha

i = land use type converted to Cropland

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Mineral Soil

Soil carbon flux for Forest Land converted to Cropland and Grassland converted to Cropland is calculated using COMET-Farm. For Wetland converted to Cropland, see Equation 18 (Tier 2).

Drained Organic Soils

For drained organic soils, the 2013 IPCC Guidelines for Wetlands[18] methodology is used. CO_2 emissions are calculated for both on-site and off-site sources according to Equation 22, Equation 23, and Equation 24. CH_4 emissions are calculated according to Equation 25. Emissions are calculated the same way for cropland remaining cropland and land converted to cropland.

Equation 22: On-site CO_2-C emissions from drained organic soils

$$CO_2\text{-}C_{on\text{-}site} = (Area \times EF)$$

Where:

$CO_2\text{-}C_{on\text{-}site}$ = annual on-site CO_2-C emissions/removals from drained organic soils in a land-use category, tonne C yr^{-1}

Area = area of drained organic soils in temperate Cropland, ha

EF = emission factor for drained organic soils, tonne C ha^{-1} yr^{-1} (7.9 for temperate climates)

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Equation 23: Off-site CO_2 emissions due to dissolved organic carbon (DOC) loss from drained organic soils

$$CO_2\text{-}C_{off\text{-}site} = Area \times EF_{DOC}$$

Where:

$CO_2\text{-}C_{off\text{-}site}$ = annual off-site CO_2-C emissions due to DOC loss from drained organic soils in a land-use category, tonne C yr^{-1}

[18] (IPCC, 2014)

Area = area of drained organic soils in temperate croplands, ha

EF_{DOC} = emission factor for CO_2 emissions due to DOC loc from drained organic soils, tonne C ha^{-1} yr^{-1}

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Equation 24: N_2O emissions from drained organic soils

N_2O emissions from drained soils [(tonne N_2O-N year^(-1)) = (Drained cropland area (acres)× EF])/1000

Where:

N_2O emissions = annual N_2O emissions from drained soils, tonne N_2O-N yr^{-1}

Area = drained cropland area, ha

EF = emission factor for drained organic soils, kg N_2O-N $hectare^{-1}$ $year^{-1}$

Note: convert N_2O-N to N_2O by applying conversion rate 44/28.

Methane Emissions

Equation 25: CH_4 Emissions from Drained Organic Soils

$$CH_{4\ organic} = \sum(c,n,p)\ (A(c,n,p) \times ((1\text{-}Frac\_ditch) \times EF(CH4\ land(c,n)) + Fracditch \times EF(CH4\ ditch(c,p)\ )\ ))/1000$$

Where:

$CH_{4\ organic}$ = CH_4 loss from drained organic soils, tonne CH_4 yr^{-1}

Area = land area of drained organic soils in a land-use category, ha

$EF_{CH4\ land}$ = emission factors for direct CH_4 emissions from drained organic soils, kg CH_4 ha^{-1} yr^{-1}

$EF_{CH4\ ditch}$ = emission factors for CH_4 emissions from drainage ditches, kg CH_4 $ha^{-1}yr^{-1}$

$Frac_{ditch}$ = fraction of the total area of drained organic soil which is occupied by ditches (where “ditches” are considered to be any area of manmade channel cut into the peatland). The ditch area may be calculated as the width of ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width should be calculated as the average width of open water plus any saturated fringing vegetation.

Detailed Methodology for Modeled Crops

COMET-Farm has an API that allows for uploading detailed information about different cropping systems and associated management, such as crop rotations, type and timing of agronomic practices (fertilizing, planting, harvesting, etc.), and management regimes (tillage, residue management, fertilization rates) by geographic regions throughout the State. That feature is used to prepare the Oregon mineral soil carbon flux estimates. This section explains the approach.

Cropping Systems Excel Workbook

The first step to running the COMET-Farm API, is registering for a COMET-Farm account. To register for an account, go to https://comet-farm.com/login/ and click “Create an Account.” Each account requires a first name, last name, email address, and the selection and confirmation of a password.

The second step is to complete the Crop System Excel workbook, which is used to compile the activity data necessary to run the model. The workbook contains six tabs. The purpose of each tab is detailed below.

1. **COMET Inputs:** This tab includes the geographic location and cropping systems that will be analyzed. For each geographic location where the model is being run provide:
    a. County name
    b. Number of field (if more than one field is run in a count)
    c. Longitude
    d. Latitude
    e. Acres of the geographic area being modeled. The default in the workbook is 10 acres and should not exceed 30 acres to minimize model runs, cost, and computing time
    f. Pre-2000 Cropping System (described below)
    g. Cropping System name (described below)
2. **Cropping System Blank**: This tab provides a template to develop each cropping system that will be run.
3. **Pre-2000 Blank**: This tab includes information to develop the initial carbon stock of the region. It is broken down into two components – one for Pre-1980 and one for 1980 to 2000.
4. **Units:** This tab included the units that are allowed in COMET-Farm. It is a reference in developing the inventory.
5. **Valid Inputs**: Like the Units tab, this tab includes all the valid inputs that are allowed in COMET-Farm.
6. **Cropping Systems**: A separate tab is created for each cropping system using the Activity Data that was collected.

COMET-Farm has 37 data elements for each cropping year. While not all data elements are critical to running the model, the more data elements that are included, the more COMET-Farm can model the cropping system.

Input xml Generator

A python script has been developed to take the data from the Cropping Systems Excel workbook and convert it into an xml file that can be uploaded to COMET-Farm. After running the python script, go to https://comet-farm.com/api-access to upload the file. Enter a valid COMET-Farm account email as the Return Email Address and upload the desired input file. Results files will be emailed to the COMET-Farm account and will be compressed in .lzma format. Software such as 7zip is needed to extract the results file. After extraction, rename the file and write ".xml" at the end of it. This will save the file as an xml file, so the file structure can be interpreted by python. Move this file into the COMET_Result_xml_files folder under the correct region you are combining the runs within.

Note: Several files may be sent from COMET. If COMET breaks the file into numerous parts, a macro can be used to download the files quickly.

For ease of conversion, a LZMA Extractor tool that will convert the LZMA files to xml format is available as part of the toolset. Run the tool and select which file the downloaded LZMAs have been stored in.

Errors in the Input File

If any errors occur in the upload to COMET-Farm, an email will be sent with a compressed file detailing the errors. Open this file with 7zip and extract the file. To easily read this extracted file, save it as an xml and open it using a web browser. For assistance with these errors, contact the COMET-Farm team at appnrel@colostate.edu.

Output xml File Interpreter

This python script reads COMET output xml files and transcribes necessary data into a separate Excel workbook, which can be given a custom name by the user. This script then inserts formulas into the Excel workbook. If multiple files are interpreted, the script creates a merged xml file. The output file will be saved into the Results folder. The python script scales up the results to the county and regional level using data from NASS.

Cropland: Uncertainty

Uncertainty for mineral soils is associated with the DayCent ecosystem model used by COMET-Farm. The uncertainty is due to the process-based model structure and parameters. Uncertainty is quantified in the model with an empirically based approach, as used in the U.S. National GHG Inventory. The method combines modeling and measurements to estimate SOC stock changes for entity-scale reporting.[19]

For organic soils, uncertainty is driven by the uncertainty of acres of organic soils combined with the uncertainty of the emissions factors.

Cropland: Completeness

In addition, COMET-Farm calculates the nitrous oxide (N_2O) associated with nitrogen management. The cropland inventory could include N_2O using this information. Currently N_2O emissions are covered in the SBI inventory.

Only 36 of Oregon's 220 crops were calculated as part of this effort. While that represents approximately 96% of all cropland acres in the state, the inventory is not comprehensive.

There is a difference in the total number of acres in NLCD compared to those from the USDA Census. While the NLCD total is higher and believed to represent all cropland acres in the state, a detailed analysis of the acres was not conducted.

[19] (Conant et al., 2011)

Cropland: Improvements

As research on the GHG fluxes of crops continues to be published, COMET-Farm will be updated to include those crops. When future inventories are calculated, those new crops can be added to the Modeled Crops section of the inventory.

Additional inputting more management data in COMET-Farm, such as planting of cover crops, use of enhanced efficiency fertilizers, and use of reduced tillage can improve the accuracy of COMET-Farm estimates.

Category: Wetlands

This section outlines the technical approach for quantifying greenhouse gas (GHG) emissions and removals from Oregon's coastal (tidal and non-tidal) and inland wetlands from 1990 to 2024. The work adheres to best-practice inventory protocols recognized by the Intergovernmental Panel on Climate Change (IPCC), the U.S. National Greenhouse Gas Inventory (NGHGI), and recent region-specific research—it is designed to meet both state and national greenhouse gas reporting standards. The methodology estimates emissions and removals from wetlands by: (1) disaggregating the coastal wetland from inland wetland, (2) mapping spatial extent of wetland, (3) tracking land cover or land use change over time, (4) applying carbon stocks, accumulation rates, and methane and nitrous oxide emission factors to wetland classes to estimate GHG emissions and removals, and (5) summing emissions and removals for wetlands that remain or land that is converted to a wetland from another land type. [20]

Following this approach, emissions and removals of carbon dioxide and methane are estimated from soils, above and below ground biomass across land use categories: **Wetland Remaining Wetland,** which includes **Wetland to Open Water** and **Open Water to Wetland,** and **Land Converted to Wetland.**

Table 27: Greenhouse gases tracked in inventory according to the carbon pool and land use category

Land Use Category	Carbon Pool	Gas Type
Wetland Remaining Wetland	Biomass	CO_2
Wetland Remaining Wetland	Soil	CO_2, CH_4
Wetland Remaining Wetland	Dead Organic Matter (forested wetland only)	CO_2
Wetland Remaining Wetland - Wetland to Open Water	Biomass	CO_2
Wetland Remaining Wetland - Wetland to Open Water	Soil	CO_2, CH_4
Wetland Remaining Wetland - Wetland to Open Water	Dead Organic Matter (forested wetland only)	CO_2
Wetland Remaining Wetland - Open Water to Wetland	Biomass	CO_2

[20] (Crooks et al., 2018).

Wetland Remaining Wetland - Open Water to Wetland	Soil	CO_2, CH_4
Wetland Remaining Wetland - Open Water to Wetland	Dead Organic Matter (forested wetland only)	CO_2
Land Converted to Wetland	Biomass	CO_2
Land Converted to Wetland	Soil	CO_2, CH_4
Land Converted to Wetland	Dead Organic Matter (forested wetland only)	CO_2

The Inventory separates coastal wetland into estuarine (wetlands with salinities greater than 0.5 ppt) and palustrine (wetlands with salinities less than 0.5 ppt) based on C-CAP classification, while inland wetland is all palustrine. Additionally, emissions of nitrous oxide from fish hatcheries are estimated across all wetlands.

A large proportion of Oregon's coastal wetlands have been lost due to conversion to agricultural or developed land.[21] Since before the 1990s, restoration projects have worked to reintroduce tidal flows and recover wetland ecosystem functions.[22] To account for alternative land use in wetlands, the Inventory includes two additional categories of wetland: pasture wetland and cropland wetland.

Although eelgrass meadows and kelp forests are key blue carbon ecosystems along Oregon's coast and within its estuaries, limitations in the availability and completeness of activity data prohibit their inclusion within the Inventory. However, emission factors are provided and summarized in the tables that follow for future use.

Additionally, due to limitations in data availability flooded lands are not included in this Inventory version but we provide an approach for its inclusion in future analysis.

Wetlands: Activity Data

Wetland remaining Wetland

Table 28: Area of Wetland remaining Wetland according to wetland type in hectares

Wetland Type	1990	1996	2001	2006	2011	2016	2021
Cropland Wetland (Coastal)	813	771	736	698	672	697	693
Emergent Herbaceous Wetlands (Coastal)	6,644	6,566	6,501	6,598	6,433	6,548	6,651
Estuarine Emergent Wetland (Coastal)	4,301	4,294	4,287	4,282	4,263	4,270	4,118
Estuarine Forested Wetland (Coastal)	0	0	0	0	0	0	0
Estuarine Scrub Shrub Wetland (Coastal)	2	2	2	2	2	2	2
Palustrine Emergent Wetland (Coastal)	20,247	20,125	20,024	18,995	19,023	19,747	19,644
Palustrine Forested Wetland (Coastal)	8,761	8,706	8,661	8,394	8,085	8,153	8,120
Palustrine Scrub Shrub Wetland (Coastal)	6,046	6,024	6,006	5,849	6,324	6,483	6,488

[21] (Brophy et al. 2019).
[22] (Janousek et al. 2021).

Pasture Wetland (Coastal)	3,683	3,595	3,522	3,503	3,485	3,496	3,535
Woody Wetlands (Coastal)	984	1,216	1,436	1,413	1,348	1,415	1,347
Emergent Herbaceous Wetlands (Inland)	332,469	328,691	325,542	320,949	311,649	309,213	317,694
Woody Wetlands (Inland)	97,987	103,656	108,382	110,313	110,127	112,835	117,104

Wetland to and from Open Water

Table 29: Area of Wetland converted to Open Water and Open Water converted to Wetland in hectares

Converted from Wetland Type	Land Converted to Open Water	1990	1996	2001	2006	2011	2016	2021
Open Water	Coastal Wetland	156	218	463	183	284	392	466
Coastal Wetland	Open Water	558	407	282	411	193	201	215
Open Water	Inland Wetland	5,180	4,520	10,353	2,109	5,974	16,088	4,052
Inland Wetland	Open Water	24,354	12,638	3,159	10,295	7,487	998	623

Land Converted to Wetland

Table 30: Area of land converted to Wetland in hectares

Converted From	Converted To	1990	1996	2001	2006	2011	2016	2021
Cropland	Wetland (Coastal)	247	274	300	426	444	335	348
Forest Land	Wetland (Coastal))	18	17	16	18	19	18	17
Grassland	Wetland (Coastal))	11	10	10	13	15	14	14
Other Land	Wetland (Coastal))	32	42	62	80	85	73	61
Developed Land	Wetland (Coastal))	25	28	30	34	40	31	31
Cropland	Wetland (Inland)	1,498	5,577	12,735	11,885	15,557	11,754	17,347
Forest Land	Wetland (Inland)	452	836	1,239	1,563	1,806	1,644	1,573
Grassland	Wetland (Inland)	4,871	3,859	3,045	3,767	4,109	2,859	3,337
Other Land	Wetland (Inland)	217	225	247	288	295	263	265
Developed Land	Wetland (Inland)	76	106	133	159	210	182	212

Nitrous Oxide Emissions on All Wetlands

Pounds of Fish Produced

Oregon Department of Fish and Wildlife Hatchery Management Plans and Fish Propagation Reports for years 1999 through 2024 provide data on the amount of fish released from hatcheries each year in terms of total weight (lbs).

Table 31: Amount of liberated fish used to calculate emissions of nitrous oxide (N_2O) as emissions of CO_2 from wetlands.

Year	Liberated Fish (pounds)	Liberated Fish (kg)
1999	5,068,495	2,299,029
2000	4,838,900	2,194,887
2001	4,598,528	2,085,855
2002	4,858,590	2,203,818
2003	4,811,931	2,182,654
2004	4,700,918	2,132,299
2005	4,609,927	2,091,026
2006	4,440,506	2,014,178
2007	4,471,969	2,028,449
2008	4,530,462	2,054,981
2009	4,617,405	2,094,418
2010	4,715,452	2,138,891
2011	4,459,460	2,022,775
2012	4,556,364	2,066,730
2013	4,640,633	2,104,954
2014	4,732,051	2,146,420
2015	4,724,237	2,142,876
2016	4,643,358	2,106,190
2017	4,388,353	1,990,522
2018	4,450,552	2,018,735
2019	4,251,984	1,928,666
2020	4,572,223	2,073,924
2021	4,356,897	1,976,254
2022	4,437,586	2,012,854
2023	4,464,287	2,024,965
2024	4,702,208	2,132,884
2025	4,702,209	2,132,884

Wetlands: Emission Factors

Wetland Remaining Wetland

Carbon dioxide emissions and removals across coastal and inland wetlands
Carbon dioxide emissions and removals for each wetland type are estimated from wetland area using appropriate emission factors for each carbon pool, with removals for forested/woody and non-forested/woody wetland dead organic matter, and soil, and emissions for methane. For biomass, we assume net fluxes are zero for Wetland Remaining Wetland; that is, once a pixel reaches a stable wetland state, no additional biomass gain is credited. The specific equations and units are provided in the table below, but are derived from equations expressed in General Methodology section of this Appendix.

Table 32: Equations used to calculate the emissions and removals from Wetlands Remaining Wetlands according to Carbon Pool

Carbon Pool	Equation	Type	Unit
Biomass (Forested/Woody)	Area * ($EF_{RateWetland}$) *44/12	Removal	$MMTCO_2e$
Dead Organic Matter (Forested/Woody)	Area * ($EF_{RateWetland}$) *44/12	Removal	$MMTCO_2e$
Soil	Area * ($EF_{RateWetland}$) *44/12	Emissions/Removal	$MMTCO_2e$
Methane	Area *($EF_{RateWetland}$)*GWP	Emission	$MMTCO_2e$

Area = Annualized area in hectares, EF = Emission Factor (StockWetland=tonne C ha^{-1}, RateWetland=tonne C ha^{-1} yr^{-1}), GWP = Global Warming Potential (for methane it is 28).

Coastal Wetland Remaining Coastal Wetland

Soil carbon stocks and accumulation rates
Soil carbon stocks (t C ha^{-1}) and accumulation (t C ha^{-1} yr^{-1}) for each coastal wetland type is determined via the Blue Carbon Calculator. Funded through the Oregon Watershed Enhancement Board (OWEB) the Pacific Northwest Blue Regional Blue Carbon Calculator (PNWBCC) allows users to quantify greenhouse gas emissions and removals from coastal wetlands. The “Lookup Table” page in the PNWBCC provides emission factors aggregated from the Coastal Carbon Research Coordination Network’s Carbon Atlas and data from the Pacific Northwest Blue Carbon Working Group (Tier 2). Soil organic carbon stocks at 1 meter depth and accumulation rates are calculated as an average across wetland type. While Woody and Herbaceous wetland (see the table below) are not included in the PNWBCC these wetland classes were assigned forest and emergent emission factors from the PNWBCC.

Table 33: Emission factors used to calculate emissions and removals of CO_2 from coastal wetland soils within Wetland remaining Wetland

Wetland Type	Soil C Stock (tonne C ha^{-1}, 1m depth)	Soil C Accumulation (tonne C ha^{-1}yr^{-1})	Reference
Estuarine Forested	382.26	0.92	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Scrub-Shrub	531.41	1.37	*PNWBCC (Schile-Beers et al. 2025)*

Estuarine Emergent	287.38	0.98	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Forested	382.26	0.92	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Scrub/Shrub	531.41	1.37	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Emergent	287.38	0.98	*PNWBCC (Schile-Beers et al. 2025)*
Woody Wetland	382.26	0.92	*PNWBCC (Schile-Beers et al. 2025)*
Herbaceous Wetland	287.38	0.98	*PNWBCC (Schile-Beers et al. 2025)*

Total Biomass Carbon Stocks

Total perennial biomass stocks (t C ha^{-1}) for coastal estuarine and palustrine non-forested wetland are determined via the PNWBCC which incorporates data from Kauffman et al. 2020 (Tier 2) but only presents data as total biomass stocks. No biomass accumulation rates are established for non-forested coastal wetland.

Total biomass carbon stocks (t C ha^{-1}) and biomass accumulation rates (t C ha^{-1} yr^{-1}) of forested coastal wetland are accounted for using the PNWBCC which incorporates data from Smith et al. 2006 and Kauffman et al. 2020 (Tier 2).

Dead Organic Matter

Data on dead organic matter carbon stocks are not available for palustrine or estuarine wetland. Dead organic matter carbon stocks and accumulation rates for forested wetland are provided by the PNWBCC and are derived from Smith et al. 2006.

Table 34: Emission factors used to calculate emissions and removals of CO_2 from coastal wetland biomass within Wetland remaining Wetland.

Wetland Type	Total Biomass C Stock (tonne C ha^{-1})	Total Biomass Growth Rate (tonne C $ha^{-1}yr^{-1}$)	Dead Organic Matter Stock (tonne C ha^{-1})	Dead Organic Matter Accumulation (tonne C ha^{-1} yr^{-1})	Reference
Estuarine Forested	302.44	2.00	78.81	0.40	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*
Estuarine Scrub-Shrub	19.42	N/A	N/A	N/A	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*

Estuarine Emergent	19.42	N/A	N/A	N/A	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*
Palustrine Forested	302.44	2.00	78.81	0.40	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*
Palustrine Scrub/Shrub	13.42	N/A	N/A	N/A	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*
Palustrine Emergent	13.42	N/A	N/A	N/A	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025))*
Woody Wetland	302.44	2.00	78.81	0.40	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*
Emergent Herbaceous Wetland	19.42	N/A	N/A	N/A	IPCC Wetlands Supplement, 2013; *PNWBCC (Schile-Beers et al. 2025)*

Methane

Methane (CH_4) fluxes from coastal wetlands are partially controlled by salinity (concentration of dissolved ions) as higher sulfate (the third most abundant ion in sea water) concentrations can suppress methanogenesis. Accordingly, emission factors for CH_4 are typically assigned based on both wetland habitat type and available salinity classification data. According to the 2013 IPCC Wetlands Supplement, Chapter 4: Coastal Wetlands, estuarine wetland classes are assigned a CH_4 emission factor of zero while areas classified as palustrine are assigned a default factor for CH_4 (Tier 1: 0.1937 t CH_4 ha^{-1} yr^{-1}). Instead, in an effort to more accurately represent methane emissions within coastal estuarine and palustrine wetlands defined in C-CAP, regionally specific methane emission factors derived from the PNWBCC are applied (i.e., Tier 2). Because the estuarine C-CAP classification does not differentiate estuarine coastal wetlands by their salinity (no differentiation between brackish and saline water), a CH_4 emission factor of zero is applied across all estuarine wetland classes, which potentially leads to underestimation of emissions, while palustrine wetland classes are assigned an emission factor.

Table 35: Emission factors used to calculate emissions of CH_4 from coastal wetland within Wetland remaining Wetland

Wetland Type	Salinity Range	Aggregated Methane (tonne $CH_4 ha^{-1} yr^{-1}$)	Above MHHW Methane (tonne $CH_4 ha^{-1} yr^{-1}$)	Below MHHW Methane (tonne $CH_4 ha^{-1} yr^{-1}$)	Reference
Palustrine Emergent	<5.0 PSU	0.41	0.798	0.018	PNWBCC (*Schile-Beers et al. 2025)*
Palustrine Scrub-Shrub	<5.0 PSU	0.41	0.798	0.018	PNWBCC (*Schile-Beers et al. 2025)*
Palustrine Forested or Woody	<5.0 PSU	0.006	0.006	0.006	PNWBCC (*Schile-Beers et al. 2025)*
Estuarine Emergent or Emergent Herbaceous	>5.0 PSU	0.029	0.033	0.024	PNWBCC (*Schile-Beers et al. 2025)*
Estuarine Scrub-Shrub	>5.0 PSU	0.029	0.033	0.024	PNWBCC (*Schile-Beers et al. 2025)*
Estuarine Forested or Woody	>5.0 PSU	0.006	0.006	0.006	PNWBCC (*Schile-Beers et al. 2025)*

Aggregated methane is the average of the above and below mean higher high water (MHHW) values for the given Wetland Type and Salinity Range.

Wetlands with Agricultural Land Use

Soil organic carbon stocks, soil carbon fluxes, biomass stocks, and methane fluxes for agricultural and farmed wetlands are determined from the Ogle et al. 2024 and the PNWBCC.

Table 36: Emission factors used to calculate emissions and removals of CO_2 and CH_4 from pasture or cropland coastal wetlands (soil, biomass, methane) within Wetland remaining Wetland.

Wetland type	Soil C (tonne C ha^{-1}, 1m)	Soil C flux# (tonne C ha^{-1} yr)	Total Biomass (tonne C ha^{-1})	Methane (tonne CH_4 $ha^{-1} yr^{-1}$)	Reference
Pasture	246.98	3.50#	5.39	0.45	Janousek 2022; Table 3-13 Ogle et al. 2024; PNWBCC (*Schile-Beers et al. 2025)*

Cropland	246.98	14.00#	0.00	0.06	Janousek 2022*;* Table 3-13, Ogle et al. 2024; PNWBCC (*Schile-Beers et al. 2025)*

# indicates emissions

Inland Wetlands Remaining Inland Wetlands

Inland wetlands in Oregon are exceedingly diverse in biota, substrate and biogeochemical characteristics such as hydroperiod and soil chemistry, with at least 16 different types of wetland communities (Christy 2017) across eight ecoregions. Oregon also has steep climatic gradients from east to west, falling into three IPCC climate zones: Warm Temperate Moist climate (WTM), Warm Temperate Dry (WTD) or Cool Temperate Dry climate (CTD). NLCD landcover distinguished forested and herbaceous inland wetlands, which were intersected with the datasets mentioned above to categorize inland wetlands by soil type, climate zone and ecoregion. However, adequate carbon stock and flow data were not available to parameterize wetlands across these strata. For example, no studies were found providing methane emissions or soil carbon accumulation rates for wetlands within the CTD climate region. Therefore, data from similar environments in other regions or national averages (Tier 2 emissions factors) are used for the wetland type and soil type. However, maintaining these categories (strata) is of utility for future inventories should data become more widely available or additional wetland areas be inventoried in state-level efforts.

Soil Organic Carbon Stocks

Average soil carbon stocks were estimated using a spatially explicit and modelled 1 meter depth soil carbon raster derived from SSURGO and NWCA data (Uhran et al. 2022). Briefly, the modelled soil raster was joined with our 2011-basemap described in the Methodology section to obtain tidal status, soil type, wetland type, and ecoregion specific 1 m soil carbon stocks. Following this method, organic carbon stocks were not directly calculated for Woody and Herbaceous organic wetlands in the Klamath Mountains and Columbia Plateau ecoregions. For these wetland types, we applied the mean organic carbon stocks derived from the other ecoregions (values are bolded in the table below).

Table 37: Soil carbon stocks for inland wetland soil sat 1 m depth

Wetland Type	Soil Type	Climate Zone	Ecoregion	Soil Carbon (tonne C ha^{-1})
Emergent Herbaceous	Mineral	CTD	Blue Mountains	497
Emergent Herbaceous	Mineral	WTM	Coast Range	253
Emergent Herbaceous	Mineral	CTD	Eastern Cascades Slopes and Foothills	344
Emergent Herbaceous	Mineral	WTM	Klamath Mountains	381
Emergent Herbaceous	Mineral	WTM	West Cascades	330
Emergent Herbaceous	Mineral	WTM	Willamette Valley	279
Emergent Herbaceous	Mineral	WTD	Columbia Plateau	205
Emergent Herbaceous	Mineral	CTD	Northern Basin and Range	315
Emergent Herbaceous	Organic	CTD	Blue Mountains	600
Emergent Herbaceous	Organic	WTM	Coast Range	448
Emergent Herbaceous	Organic	CTD	Eastern Cascades Slopes and Foothills	587

Emergent Herbaceous	Organic	WTM	Klamath Mountains	570
Emergent Herbaceous	Organic	WTM	West Cascades	596
Emergent Herbaceous	Organic	WTM	Willamette Valley	588
Emergent Herbaceous	Organic	WTD	Columbia Plateau	570
Emergent Herbaceous	Organic	CTD	Northern Basin and Range	600
Woody	Mineral	CTD	Blue Mountains	448
Woody	Mineral	WTM	Coast Range	282
Woody	Mineral	CTD	Eastern Cascades Slopes and Foothills	290
Woody	Mineral	WTM	Klamath Mountains	239
Woody	Mineral	WTM	West Cascades	455
Woody	Mineral	WTM	Willamette Valley	248
Woody	Mineral	WTD	Columbia Plateau	111
Woody	Mineral	CTD	Northern Basin and Range	147
Woody	Organic	CTD	Blue Mountains	600
Woody	Organic	WTM	Coast Range	479
Woody	Organic	CTD	Eastern Cascades Slopes and Foothills	349
Woody	Organic	WTM	Klamath Mountains	529
Woody	Organic	WTM	West Cascades	556
Woody	Organic	WTM	Willamette Valley	592
Woody	Organic	WTD	Columbia Plateau	529
Woody	Organic	CTD	Northern Basin and Range	600

As other land use types only track soil C to 30 cm, for conversions to other land uses, a reference SOC value of 97tonne C ha^{-1} for soil C to this depth was calculated from an area-weighted average across ecoregions for mineral soil inland wetlands, as 30 percent of the carbon stock to 1 m depth. This is within the range of default values (for the climate zones of OR) in the IPCC Tier 1 default values (Table 5.2 in IPCC 2013 Wetland Supplement).

Soil Accumulation Rates

Soil accumulation rates are acquired from literature from CONUS wide values in the SOCCR1 (Bridgham et al. 2007) and SOCCR2 (Kolka et al. 2018) reports. For herbaceous wetlands, this accumulation represents the primary CO_2 sink as biomass stocks are assumed consistent from year to year in Wetland remaining Wetland. SOCCR2 did not provide estimates for biomass and soil accumulation separately, but the assumption of constant biomass means that ecosystem level carbon sequestration can be attributed to the soil for herbaceous wetlands. For woody wetlands, we use separate soil accumulation rates provided in the older SOCCR1 report.

Table 38: Emission factors used to calculate emissions and removals of inland wetland soils within Wetland remaining Wetland.

Wetland Type	Soil Type	Soil C Accumulation (tonne C ha^{-1} yr^{-1})	Reference
Emergent Herbaceous	Mineral	1.02	Kolka et al. 2018
Woody	Mineral	0.72	Bridgham et al. 2007
Emergent Herbaceous	Organic	1.35	Kolka et al. 2018
Woody	Organic	0.17	Bridgham et al. 2007

Biomass Carbon Stocks

Above ground stocks of inland herbaceous wetlands are estimated based on literature from similar settings and climates. Below ground biomass stocks of herbaceous wetlands are assumed to be 1.15 times that of above ground stocks based on the ratio for coastal palustrine wetlands from the 2013 IPCC wetlands supplement. We use an aboveground biomass (7.25 tonne C ha^{-1}) here from a study of an intact marsh in the Upper Klamath Basin (Ray et al. 2012). This is within the range of CONUS values used in the SOCCR1 Report (20.2 tonne C ha^{-1}; Bridgham et al. 2007) and SOCCR2 Report (5.13 tonne C ha^{-1}). Given the very limited data available from inland wetlands in the state, it was determined that different values by ecoregion could not be supported.

Biomass carbon stocks (tonne C ha^{-1}) and growth rates (tonne C ha^{-1} yr^{-1}) of forested inland wetland are accounted for using FIA data using the EVALIDator tool, pooling all data for hydric soil physiographic classes (n=36 plots, Swamps, Small Drains, Other Hydric; citation). Each pool is queried individually using EVALIDator, but we calculate the effective Root-Shoot ratio for scaling biomass accumulation. Given the small sample size, it was determined that different values by ecoregion could not be supported.

Table 39: Emission factors used to calculate emissions and removals of inland wetland biomass within Wetland remaining Wetland

Wetland Type	Above Ground Biomass C (tonne C ha^{-1})	Root-Shoot Ratio	Below Ground Biomass C (tonne C ha^{-1})	Total Biomass C (tonne C ha^{-1})	Reference
Woody	87.0	0.20	17.3	104.3	FIA 2024
Emergent Herbaceous	7.25	1.15	8.34	15.59	Ray et al. 2012

Data in the table are converted from tonne C $acres^{-1}$ yr^{-1} to tonne C ha^{-1} yr^{-1} using a multiplication conversion factor of 2.471 acres for every 1 hectare.

Biomass Accumulation

It is assumed that inland herbaceous wetlands, after initial establishment, do not accumulate biomass across years, but rather accumulate soil carbon. Biomass is assumed to accumulate in inland woody wetlands based on aboveground growth rates estimated using FIA data in the EVALIDator tool, pooling all data for hydric soil physiographic classes (n=36 plots, Swamps, Small Drains, Other Hydric; USDA Forest Service, Forest Inventory and Analysis Program), assuming 50 percent carbon content of biomass. Given the small sample size, it was determined that different values by ecoregion could not be supported.

Table 40: Emission factors used to calculate emissions and removals of inlandwetland biomass within Wetland remaining Wetland

Wetland Type	AGB Accumulation C (tonne C ha^{-1} yr^{-1})	Root-Shoot Ratio	BGB Accumulation C (tonne C ha^{-1} yr^{-1})	Total Biomass Accumulation C (tonne C ha^{-1} yr^{-1})	Reference
Woody	0.19	0.20	0.04	0.23	FIA 2024

Data in the table are converted from tonne C $acres^{-1}$ yr^{-1} to tonne C ha^{-1} yr^{-1} using a multiplication conversion factor of 2.471 acres for every 1 hectare.

Dead Organic Matter

Data on dead organic matter carbon stocks in inland herbaceous wetlands is dynamic on a sub-annual basis but relatively stable from year to year. This leads to confounding with living biomass and soil carbon, especially in organic soils. Thus, no litter or dead organic matter stock is quantified for herbaceous wetlands.

Dead organic matter stocks (tonne C ha^{-1}) of forested inland wetland are accounted using FIA data using the EVALIDator tool for litter and deadwood, pooling all data for hydric soil physiographic classes (n=36 plots, Swamps, Small Drains, Other Hydric). Given the small sample size, it was determined that different values by ecoregion could not be supported. For woody inland wetlands, we use DOM accumulation rates for Western and Eastern Pacific Northwest zones (PWW and PWE) from Smith et al. (2006), averaged across forest types for stand ages 25-125 years.

Table 41: Emission factors used to calculate emissions and removals of inland wetland dead organic matter within Wetland remaining Wetland

Wetland Type	Litter C (tonne C ha^{-1})	Deadwood C (tonne C ha^{-1})	Total DOM (tonne C ha^{-1})	Key Source	Total DOM accumulation (tonne C ha^{-1} yr^{-1})	Reference
Woody	10.3	33.2	43.5	FIA 2024	0.65	Smith et al. 2006

Data in the table are converted from tonne C $acres^{-1}$ yr^{-1} to tonne C ha^{-1} yr^{-1} using a multiplication conversion factor of 2.471 acres for every 1 hectare. DOM = litter + deadwood

Methane

Methane emissions rates were acquired from literature for similar climate zones. There are some indications in the literature that wetlands with extended seasonal dry periods, such as wet prairies in the Willamette Valley (Pfeifer-Meister et al. 2018) have low or no methane emissions, due to low soil carbon availability and/or alternative electron acceptors. Notably, there are also non-tidal saline inland wetlands in eastern Oregon in the form of intermittently flooded alkaline marshes, lakes and playas. While no data are available from saline wetlands in the CTD climate zone of Oregon, similar semiarid saline wetlands from the Central Spanish Plateau have low emission of CH_4, less than 0.002 t CH_4 ha^{-1} y^{-1} (Camacho et al. 2017). However, as we do not have sufficient data at this time to distinguish such cases, we have applied CONUS level estimated mean emission rates from Kolka et al. (2018) based on vegetation and soil classes.

Table 42: Emission factors used to calculate emissions of CH_4 from inland wetlands within Wetland remaining Wetland

Wetland Type	Soil Type	Methane (tonne CH_4 ha^{-1} yr^{-1})
Emergent Herbaceous	Mineral	0.348
Emergent Herbaceous	Organic	0.315
Woody	Mineral	0.359
Woody	Organic	0.119

Open Water to Wetland

Carbon dioxide emissions and removals across coastal and inland wetlands

For areas where Open Water is converted to Wetland, carbon dioxide emissions and removals are estimated from the wetland area using appropriate emission factors for each carbon pool. Removals are calculated for forested/woody biomass, non-forested/woody biomass, dead organic matter, and soil carbon pools, while methane is calculated as an emission. Biomass removals are estimated using a biomass accumulation rate that is calculated by dividing the biomass standing stock by the 20-year holding period. This annualized rate (tonne C ha^{-1} yr^{-1}) is then applied to the area in the transition class each year. For dead organic matter, soil and methane, we use Wetland remaining Wetland rates. The specific equations and units are provided in the table below.

Table 43: Equations used to calculate the emissions and removals from Open Water to Wetland according to Carbon Pool

Carbon pool	Equation	Type	Unit
Forested/Woody Biomass	Area * ($EF_{RateWetland}$) *44/12	Removal	MMTCO2e
Non-Forested/ Woody Biomass	Area * ($EF_{RateWetland}$) *44/12	Removal	MMTCO2e
Dead Organic Matter (Forested/Woody Wetland)	Area * ($EF_{RateWetland}$)*44/12	Removal	MMTCO2e
Soil	Area * ($EF_{RateWetland}$) *44/12	Emission/Removal	MMTCO2e
Methane	Area *($EF_{RateWetland}$)*GWP	Emission	MMTCO2e

Area = Annualized area in hectares, EF = Emission Factor (StockWetland=tonne C ha^{-1}, RateWetland=tonne C ha^{-1} yr^{-1}), GWP = Global Warming Potential (for methane it is 28).

Open Water to Coastal Wetland

A table of emission factors used in the equations above for Coastal wetlands is below. These emission factors are the same as Wetland remaining Wetland and land converted to Wetland.

Table 44: Emission factors used to calculate emissions of CO_2 and CH_4 from coastal wetlands within Open Water to Wetland.

Wetland Type	Soil C Accumulation# (tonne C ha^{-1} yr^{-1})	Total Biomass C (tonne C ha^{-1})	Dead Organic Matter (tonne C ha^{-1})	Methane (tonne CH_4 ha^{-1} yr^{-1})	Reference
Estuarine Forested	0.92	302.44	78.81(Accumulation Rate, 0.40 tonne C ha^{-1} yr^{-1})	0	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Scrub-Shrub	1.37	19.42	N/A	0	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Emergent	0.98	19.42	N/A	0	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Forested	0.92	302.44	78.81(Accumulation Rate, 0.40 tonne C ha^{-1} yr^{-1})	0.006	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Scrub/Shrub	1.37	13.42	N/A	0.41	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Emergent	0.98	13.42	N/A	0.41	*PNWBCC (Schile-Beers et al. 2025)*
Woody	0.92	302.44	78.81(Accumulation Rate, 0.40 tonne C ha^{-1} yr^{-1})	0.006	*PNWBCC (Schile-Beers et al. 2025)*
Herbaceous	0.98	13.42	N/A	0	*PNWBCC (Schile-Beers et al. 2025)*
Pasture	3.50#	5.39	NA	0.45	Ogle et al. 2024; PNWBCC (*Schile-Beers et al. 2025)*
Cropland	14.00#	0.00	NA	0.06	Ogle et al. 2024; PNWBCC (*Schile-Beers et al. 2025)*

# indicates emissions

Open Water to Inland Wetlands

For both woody and herbaceous inland wetlands, we follow the same methane emission factors as Wetland remaining Wetland, as consistent with IPCC standards for flooded lands and rewetted organic soils. Likewise, we follow the same soil accumulation and DOM accumulation factors as Wetland remaining Wetland and land converted to Wetland. Biomass emissions and removals are specific to ecoregion and previous land use, as for coastal wetlands.

Table 45: Emission factors used to calculate emissions of CO_2 and CH_4 from inland wetlands within Open Water to Wetland

Wetland Type	Soil Type	Total Biomass (tonne C ha^{-1})	Dead Organic Matter Accumulation (tonne C ha^{-1} yr^{-1})	Soil Organic Matter Accumulation (tonne C ha^{-1} yr^{-1})	Methane (tonne CH_4 ha^{-1} yr^{-1})
Woody	Mineral	104.3	1.21	0.65	0.359
Woody	Organic	104.3	1.21	0.65	0.119
Emergent Herbaceous	Mineral	15.59	0	1.02	0.348
Emergent Herbaceous	Organic	15.59	0	1.35	0.315

Wetlands to Open Water

Carbon dioxide emissions and removals

For areas of coastal wetland where Wetland is converted to Open Water, all carbon stored in biomass, dead organic matter and soil (1 m carbon stock) is assumed to be released as carbon dioxide. We do not include methane emissions for these land conversions in tidal wetlands, as we assume a change in salinity condition does not occur and therefore methane fluxes are not impacted (Crooks et al. 2018).

However, in inland wetlands we assume that conversion of wetland to open water results in methane and carbon dioxide emissions (Tier 1 IPCC for Land Converted to Flooded Lands, IPCC 2019).

Table 46: Equations used to calculate the emissions and removals from Wetland to Open Water according to Carbon Pool

Carbon pool	Equation	Type	Unit
Forested/Woody Biomass	Area * ($EF_{StockWetland}$) *44/12	Emission	MMTCO2e
Non-Forested/Woody Biomass	Area * ($EF_{StockWetland}$) *44/12	Emission	MMTCO2e
Dead Organic Matter (Forested/Woody)	Area * ($EF_{StockWetland}$) *44/12	Emission	MMTCO2e
Soil	Area * ($EF_{StockWetland}$) *44/12	Emission	MMTCO2e
Carbon Dioxide (Inland Only)	Area * ($EF_{RateWetland}$) *44/12	Emission	MMTCO2e
Methane (, Inland Only)	Area * ($EF_{RateWetland}$) *44/12	Emission	MMTCO2e

Area = Annualized area in hectares, EF = Emission Factor (StockWetland=tonne C ha^{-1}, RateWetland=tonne C ha^{-1} yr^{-1}), GWP = Global Warming Potential (for methane it is 28).

Coastal Wetland to Open Water

For Wetland to Open Water conversions the same emission factors as Wetlands Remaining Wetlands are used.

Table 47: Emission factors used to calculate emissions of CO_2 from tidal wetlands within Wetland to Open Water

Wetland Type	Soil C Stock (tonne Cha^{-1}, 1m depth)	Total Biomass C (tonne C ha^{-1})	Dead Organic Matter (tonne C ha^{-1})	Reference
Estuarine Forested	382.26	302.44	78.81	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Scrub-Shrub	531.41	19.42	N/A	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Emergent	287.38	19.42	N/A	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Forested	382.26	302.44	78.81	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Scrub/Shrub	531.41	13.42	N/A	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Emergent	287.38	13.42	N/A	*PNWBCC (Schile-Beers et al. 2025)*
Woody	382.26	302.44	78.81	*PNWBCC (Schile-Beers et al. 2025)*
Emergent Herbaceous	287.38	13.42	N/A	*PNWBCC (Schile-Beers et al. 2025)*
Pasture	246.98	5.39	NA	Janousek, 2022Ogle et al. 2024; *PNWBCC (Schile-Beers et al. 2025)*
Cropland	246.98	0.00	NA	Janousek, 2022Ogle et al. 2024; *PNWBCC (Schile-Beers et al. 2025)*

Inland Wetlands to Open Water

Following IPCC guidance, inland Wetland converted to Open Water do not immediately release biomass, dead organic matter, and soil stocks, but rather release CO_2 and CH_4 over the transition period (20 years) according to the following emissions factors, depending on climate zone (Tier 1 IPCC for Land Converted to Flooded Lands, IPCC 2019). Climate zones for each ecoregion can be found in Table 37 above.

Table 48: Emission factors used to calculate emissions of CO_2 and CH_4 from inland wetlands within Wetland to Open Water

Climate Zone	Carbon Dioxide (tonne C ha^{-1} yr^{-1})	Methane (tonne CH_4 ha^{-1} yr^{-1})
Warm Temperate Moist	1.46	0.1275
Warm Temperate Dry	1.70	0.1956
Cold Temperate Dry	1.02	0.0847

Land Converted to Wetland

Carbon dioxide emissions and removals

For land converted to Wetland, biomass carbon dioxide removal rates are calculated by dividing the difference in biomass standing stocks between the wetland and the previous land-use class by the 20-year hold period. Previous land biomass carbon stock which are derived from emission factors aggregated by other land categories and are specific to the region. For dead organic matter, soil and methane we use Wetland remaining Wetland rates. We assume biomass, dead organic matter, and soil begins accumulating carbon while methane is emitted at the same rate as mature wetlands. The equations and units for each carbon pool are provided in the corresponding table below.

Table 49: Equations used to calculate the emissions and removals from Land Converted to Wetland according to Carbon Pool.

Carbon pool	Equation	Type	Unit
Biomass	Area * ($EF_{RateWetlandOtherLand}$) *44/12	Removal or Emission (depends on the change in stock)	MMTCO2e
Dead Organic Matter (Forested/ Woody Wetland)	Area * ($EF_{RateWetland}$) *44/12	Removal	MMTCO2e
Soil	Area * ($EF_{RateWetland}$) *44/12	Emission/Removal	MMTCO2e
Methane	Area *($EF_{RateWetland}$)*GWP	Emission	MMTCO2e

Area = Annualized area in hectares, EF = Emission Factor (StockWetland=tonne C ha^{-1}, RateWetland=tonne C ha^{-1} yr^{-1}), GWP = Global Warming Potential (for methane it is 28).

Land Converted to Coastal Wetland

A table of emission factors used in the equations above for coastal wetlands is below. These emission factors are the same as Wetland remaining Wetland.

Table 50: Emission factors used to calculate emissions of CO_2 and CH_4 from coastal wetlands within Open Water to Wetland and Land Converted to Wetland.

Wetland Type	Soil C Accumulation# (tonne C ha^{-1} yr^{-1})	Total Biomass C (tonne C ha^{-1})	Dead Organic Matter (tonne C ha^{-1})	Methane (tonne CH_4 ha^{-1} yr^{-1})	Reference
Estuarine Forested	0.92	302.44	78.81(*Accumulation Rate, 0.40 tonne C ha^{-1} yr^{-1}*)	0	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Scrub-Shrub Wetland	1.37	19.42	N/A	0	*PNWBCC (Schile-Beers et al. 2025)*
Estuarine Emergent	0.98	19.42	N/A	0	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Forested	0.92	302.44	78.81(*Accumulation Rate, 0.40 tonne C ha^{-1} yr^{-1}*)	0.006	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Scrub/Shrub	1.37	13.42	N/A	0.41	*PNWBCC (Schile-Beers et al. 2025)*
Palustrine Emergent	0.98	13.42	N/A	0.41	*PNWBCC (Schile-Beers et al. 2025)*
Woody	0.92	302.44	78.81(*Accumulation Rate, 0.40 tonne C ha^{-1} yr^{-1}*)	0.006	*PNWBCC (Schile-Beers et al. 2025)*
Emergent Herbaceous	0.98	13.42	N/A	0	*PNWBCC (Schile-Beers et al. 2025)*
Pasture	3.50#	5.39	NA	0.45	Ogle et al. 2024; PNWBCC (*Schile-Beers et al. 2025)*
Cropland	14.00#	0.00	NA	0.06	Ogle et al. 2024; PNWBCC (*Schile-Beers et al. 2025)*

# indicates emission

Land Converted to Inland Wetland

For both woody and herbaceous inland wetlands, we follow the same methane emission factors as Wetlands Remaining Wetlands, as consistent with IPCC standards for flooded lands and rewetted organic soils. Likewise, we follow the same soil accumulation and DOM accumulation factors as Wetland remaining Wetland. Biomass emissions and removals are specific to ecoregion and previous land use, as for coastal wetlands.

Table 51: Emission factors used to calculate emissions of CO_2 and CH_4 from inland wetlands within Open Water to Wetland and Land Converted to Wetland.

Wetland Type	Soil Type	Total Biomass (tonne C ha^{-1})	Dead Organic Matter Accumulation (tonne C ha^{-1} yr^{-1})	Soil Organic Matter Accumulation (tpnne C ha^{-1} yr^{-1})	Methane (tonne CH_4 ha^{-1} yr^{-1})
Woody	Mineral	104.3	1.21	0.65	0.359
Woody	Organic	104.3	1.21	0.65	0.119
Emergent Herbaceous	Mineral	15.59	0	1.02	0.348
Emergent Herbaceous	Organic	15.59	0	1.35	0.315

Nitrous Oxide Emissions from Hatcheries on all Wetlands

Emissions of nitrous oxide from hatcheries activity are determined using Tier 1 IPCC methodology (Equation 4.10) which uses a default emission factor of 0.00169 kg N_2O-N per kg (2013 IPCC Wetlands Supplement, Table 4.15) fish produced which is then applied to the annual production of fish.

For nitrous oxide emissions on all wetlands Equation 4.10 in the 2013 IPCC Wetlands Supplement is used to derive the amount of nitrogen emitted from hatcheries by using the annual amount of liberated fish statewide. The table above shows the annual pounds of liberated fish converted to kgs and was provided by Hatchery Operations Biologist, Sarah J. Bjork, at the Oregon Department of Fish and Wildlife. Data are unavailable prior to 1999. Therefore, we assume that liberated fish production before 1999 was equivalent to 1999 levels, and that production in 2025 will remain consistent with 2024 levels.

Equation 26: Used to calculate emissions of nitrous oxide (N_2O) from hatcheries as emissions of CO_2 from wetlands

$$N_2O\text{-}N_{AQ} = F_F \times EF_F$$

Where:

$N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from aquaculture use, kg N_2O-N yr^{-1}

F_F = annual fish production, kg fish yr^{-1}

EF_F = emission factor for N_2O emissions from fish produced, kg N_2O-N per kg fish produced

Wetlands: Methodology

Wetlands Classification

To determine change in land cover for coastal and inland wetlands NLCD datasets are used as the primary land cover with C-CAP coastal land cover datasets providing wetland specific information. As C-CAP is only available for image dates: 1996, 2001, 2006, 2011, 2016 and 2021 in Oregon the 1996 C-CAP data was copied over to 1990 NLCD data to create a time series data using NLCD basemaps for 1990, 1996, 2001, 2006, 2011, 2016, 2021. All rasters are clipped using the Oregon Boundary Geopackage which is reprojected into EPSG: 5070 Conus Albers. As NLCD only provides classification of woody wetland, herbaceous wetland, and open water, NLCD data is harmonized and intersected with several layers to better assign emission factors.

NLCD data is reprojected to EPSG: 5070 Conus Albers. For all years of analysis NLCD is spatially joined with:

1. C-CAP to reclassify wetland into the following C-CAP land classes: Palustrine Forested Wetland=13, Palustrine Scrub/Shrub Wetland=14, Palustrine Emergent Wetland=15, Estuarine Forested Wetland=16, Estuarine Scrub/Shrub Wetland=17, Estuarine Emergent Wetland=18,
2. C-CAP to reclassify wetland into agricultural wetland subclasses using C-CAP land classes Cultivated Crop=6, Pasture Hay=7,
3. a composite polygon uniting the PMEP Current and Historical Tidal Extent layer (which uses a 50% flood scenario) intersected with a Mean Higher High Water Spring boundary to set the coastal area of interest boundary defining coastal and inland wetland,
4. the EPA Level 3 Ecoregions,
5. IPCC Climate Zone,
6. a SSURGO-derived organic versus mineral soils layer,
7. the Aquatic Setting layer of the Coastal and Marine Ecological Classification Standard (CMECS) for the Columbia River estuary, a wetland loss layer (Brophy, 2025) for wetland along the outer coast, and an updated data product developed by the Nature Conservancy using these two layers is then used to identify areas that are tidally "Connected" or "Disconnected." As these data layers represent a single time point it is assumed that tidal connectivity has not changed from 1990 to the present.

Within the Wetlands section land conversions between Wetland remaining Wetland, Wetland converted to Open Water, Open Water converted to Wetland, lands converted to Wetland are tracked.

To generate annual estimates, linear interpolation was applied between the end years of each interval. For each combination of wetland type and land conversion category, the difference in area between consecutive end years was evenly distributed across the intervening years. This produced estimated areas for all years within the observed intervals.

For years outside the range of known C-CAP/NLCD end years, linear extrapolation was applied. Backward extrapolation (1990–2996) used the annual rate of change calculated from the first fully known interval (1996–2001), while forward extrapolation (from 2021 to 2024) used the area of the last known year of available data (2021). Any negative values resulting from extrapolation were set to zero.

This approach yielded a continuous, annual time series (OR_annualized_activitydata.xlsx) of wetland areas from 1990 through 2024, preserving distinctions by soil type and land conversion category, which facilitates temporal analysis of greenhouse gas emissions and removals. All analyses of output data from ArcGIS Pro data were conducted in R version 4.4.3 (R Core Team, 2025) using RStudio version 2024.09.1+394 (Posit Software, 2024).

Wetlands Emissions Estimates

Data preparation and calculations for wetlands emissions estimates were carried out in R version 4.4.3 (R Core Team, 2025) using RStudio version 2024.09.1+394 (Posit Software, 2024).

The spreadsheet titled OR_annualized_activitydata.xlsx provides activity data (area in hectares for each year from 1990-2024) for four land use categories: Wetland Remaining Wetland, Open Water to Wetland, Wetland to Open Water, and Land Converted to Wetland. Each record is classified by From_Class (starting land type), To_Class (ending land type) and Land Category (one of the 4 land use categories), and includes associated attributes such as Soil Type (Organic or Mineral), Tidal status (Coastal or Inland), Tidal Connection (Connected or Disconnected), EPA Ecoregion (8 different ecoregions) and IPCC Climate Zone. The spreadsheets titled OR_coastal_EFs_combined.xlsx and OR_inland_EFs_combined.xlsx contain expanded emission factor data for the corresponding land transitions organized by soil type, EPA ecoregion and IPCC Climate Zone using data from tables in the Wetland section of this Appendix. All processing steps are documented and explained in the Rmd file, 2025_Step 3_OR_GHGI_model.Rmd, which outlines steps for merging activity data with emission factors tables, calculations annual emissions and removals, and summarizing results by land category and carbon pool. Custom R functions were developed for each of the four land transition categories.

The outputs from all transition categories are combined into a single results spreadsheet OR_wetlands_emissions.xlsx in wide format and are summarized by land use transition and carbon pool with emissions data available in MMTCO2e from 1990-2024. A ReadMe file lists all parameters in the spreadsheets and describes their meaning.

Wetlands: Uncertainty

Uncertainty in carbon dioxide emissions and removals was assessed using IPCC Tier 1 (Approach 1) guidelines. This approach propagates the uncertainties associated with activity data (wetland area) and emission factors to estimate overall uncertainty for each carbon pool. It provides a transparent, conservative estimate that is consistent with IPCC recommendations for greenhouse gas inventories. Reported removals and emissions are presented with their corresponding uncertainties to reflect confidence in the estimates.

Wetlands: Completeness

Coastal ecosystems such as eelgrass, mudflats, and kelp forests are not yet included due to insufficiently validated spatial datasets and emission factors, limiting representation of nearshore carbon dynamics. Methane emissions from coastal wetlands are estimated using coarse land-cover classes rather than hydrologically explicit salinity gradients, which may omit spatial variability in CH_4 fluxes. Additionally, the inventory does not incorporate lateral carbon exports—such as dissolved and particulate carbon transport from wetlands to adjacent aquatic systems—or potential sequestration in downstream waters, omissions that reflect current IPCC guidance but understate total carbon cycling. Emissions reductions associated with completed or ongoing restoration projects are also not included because a comprehensive, statewide restoration geodatabase is not yet available. Collectively, these gaps bias the wetlands assessment toward under-reporting and will be reduced as new spatial datasets and restoration tracking tools become available.

All wetlands are included in the inventory, including tidally connected, disconnected, and areas of unknown tidal connectivity. Wetlands under agricultural use (cultivated crops and pasture/hay) are treated separately using land use specific emission factors to reflect managed conditions. For natural wetlands, tidal connectivity is only partially resolved: connected wetlands make up 22% of all coastal wetlands, disconnected wetlands make up 37% of coastal wetlands, and wetlands of unknown connectivity make up 41% coastal wetlands. Since emissions and removals of GHG are calculated uniformly across all wetlands, GHG emissions from diked, impounded, or otherwise modified wetlands may be underestimated in our inventory or are not accurately represented.

Wetlands: Improvements

Improving wetland emissions estimates in future inventories require better spatial data and more refined biogeochemical inputs. Several new datasets are expected to help clarify the geographic distribution of wetlands within Oregon and will be made publicly available over the next year. One dataset, the Wetland Intrinsic Potential tool, will help clarify the geographic distribution of inland wetlands and drained organic soils across multiple land-use categories. Planned improvements to this tool include development of a CONUS-wide dataset, wetland classification and soil and biomass carbon stocks. Additionally, the newly developed restored land project maps from the Nature Conservancy would allow Oregon to explicitly account for emissions reductions associated with completed or on-going restoration projects. The statewide salinity map expected in Q1 of 2026 will allow methane emissions from coastal wetlands to be modelled on hydrologic and salinity gradients rather than coarse classifications provided through C-CAP. Beyond coastal wetlands, Oregon's current inventory excludes eelgrass, mudflats and kelp forests. Although preliminary datasets exist to map these habitat types and assign them appropriate emission factors see Table 52 below, substantial harmonization and validation is required prior to inclusion within the wetlands inventory. Oregon could build on methodological approaches currently being carried out by the Department of Natural Resources in Washington and academic partners to improve habitat mapping and generate defensible greenhouse gas flux estimates for the next inventory cycle.

Oregon's current wetland inventory relies on C-CAP and NLCD land cover products, the former of which are only released every five years. This creates a mismatch with the statutory requirement to update the inventory every two years. Interim updates could extend the most recent C-CAP/NLCD time series data 2021 for the next inventory cycle. Additionally, a similar approach could extend the linear trend in C-CAP/NLCD from the most recent period (2016-2021) using NLCD datasets for 2021 onwards as a baseline for area estimates. In the longer term, developing a spatially explicit, state-led mapping framework that leverages publicly available tools (e.g., Wetland Intrinsic Potential Tool, University of Washington), regional datasets (e.g., CMECS biotic layer), and Landsat/Sentinel data directly would reduce the dependence on national products that are irregularly updated or at risk of discontinuation.

There is a notable lack of carbon cycle data for inland wetlands in Oregon, especially on CO2 and CH4 emissions from different wetland types and climate zones. As noted in the methodology above, there may be classes of wetlands (such as inland saline wetlands) that may have lower emissions than suggested by a Tier 1 or 2 approach. Given the diversity of wetland types in OR, a spatially explicit modeling framework may be more precise if certain wetland types were targeted for monitoring that could support a separate set of emission factors and remotely sensed extents for those wetland types.

Without data on emissions of different wetland types, however, there is limited utility in the inventory for refinement of the extent of different wetland types.

Oregon has likely lost more than one third of its historical wetlands, meaning a substantial portion of former wetland area is absent from the current inventory. Drained organic soil emissions serve as a proxy for this legacy loss, so we identified potential former wetlands by mapping histosols (organic soils) which require persistent anoxic (i.e., waterlogged) conditions to form. Since wetland drainage in Oregon was predominantly undertaken to convert land to rangeland, cropland, or developed land we only apply drained-organic-soil emission factors to histosols under those lands (see 3.6.4.3 and 3.7.3.1). This reduces the risk of overestimating emissions but excludes histosols currently mapped under grassland or forest land, which may also represent historical wetlands, resulting in a conservative estimate. Future products such as the Wetland Intrinsic Potential Tool being developed at the University of Washington are expected to improve historical wetland delineation and enhance detection of areas likely to contain drained organic soils. These advances will allow more accurate attribution of wetland loss and more precise estimation of associated emissions.

Improving the treatment of Wetland to Open Water conversions is also a priority, as these losses directly offset removals from Wetlands Remaining Wetlands and strongly influence net emissions. In coastal wetlands, current methods assume immediate oxidation of soil carbon stocks following conversion, which may overestimate emissions because soil carbon loss occurs over both fast and slow pathways. Incorporating more realistic oxidation timelines and refining soil carbon loss factors would better represent post-conversion dynamics. These conversions are tracked using NLCD, and both NLCD and C-CAP saw notable classification and change-detection improvements during the 2000s and 2010s, meaning some of the observed conversion area may reflect mapping artifacts rather than ecological change and should be addressed in subsequent inventories. At the same time, conversions may also signal increasing system stability associated with hydrologic restoration, which has reduced coastal wetland loss in Oregon. Work by the Nature Conservancy on providing restoration and tidal connectivity polygons may help improve uncertainty.

In the longer term, Oregon may benefit from transitioning toward a Tier 3, spatially explicit modeling framework. The current method applies tabular Tier 2 emission factors to land-cover classes rather than representing processes in space or time. While this approach is standard for Tier 1–2 and yields uncertainty ranges of approximately 30–40%, a spatially explicit system that accounts for hydrology, geomorphology, biogeochemistry, and ecology, could reduce uncertainty and improve representation of Oregon’s diverse wetland types. Developing a Tier 3 scoping report would provide an understanding of the feasibility of integrating land-use change models or biogeochemical, and spatially explicit flux datasets into future inventory cycles.

Table 52: Emission factors that can be used to calculate emissions and removals of CO_2 from eelgrass meadows, adjacent to eelgrass mudflats, and macroalgae (Bull kelp) within Wetland remaining Wetland.

Submerged Aquatic Vegetation	Soil C Stock (tonne C ha^{-1}, 1m depth)	Soil C Accumulation (tonne C ha^{-1} yr^{-1})	Above Ground Biomass C (tonne C ha^{-1})	Below Ground Biomass C (tonne C ha^{-1})	Total Biomass C (tonne C ha^{-1})	Lateral Export (tonne C $ha^{-1}yr^{-1}$)	Reference
Eelgrass (Adjacent Mudflat, "Unvegetated)	79.24	0.27	0.73	0.95	1.67	NA	Kauffman et al. 2020; Prentice et al. 2020
Eelgrass	120.49	0.27	NA	NA	1.85	NA	PNWBCC (*Schile-Beers et al. 2025)*
Kelp forest	NA	NA	0.26	NA	0.26 (Biomass Production Rate, 1.41 tonne C ha^{-1} yr^{-1})	0.31	McHenry et al. 2025

Category: Developed Land

The Developed Land include the following categories:

- CO_2, CH_4, and N_2O emissions from drained organic soils on Developed Land remaining Developed Land
- CO_2 emissions and removals in biomass (urban trees)
- CO_2, CH_4, and N_2O emissions from drained organics soils on land converted to Developed Land
- CO_2 emissions and removals in mineral soils and biomass on land converted to Developed Land

The IPCC Tier 1 assumption that CO2 emissions and removals from mineral soils are '0' in Developed Land remaining Developed Land is applied, and thus this category is not estimated.

The area of land in Developed Land remaining Developed Land and land converted to Developed Land is processed according to the approach described in the cross-cutting section. Carbon emissions and removals in mineral soil are accounted for separately in Developed Land remaining Developed Land and land converted to Developed Land. For all other categories, emissions and removals are calculated at the level of Developed Land. Therefore, information in the following sections is organized by GHG source categories at the highest level, rather than by Developed Land remaining Developed Land and land converted to Developed Land.

Developed Land: Activity Data

Land Area

As described in the cross-cutting section, the following NLCD classes are included in the Developed Land category:

- Open space
- Low intensity development
- Medium intensity development
- High intensity development

The area of Developed Land remaining Developed Land and land converted to Developed Land was determined for 1990, 1996, 2001, 2006, 2011, 2016, and 2021 as summarized in Tables 53 and 54. Full activity data is available in the data library.

Table 53: Developed Land remaining Developed Land area in hectares

Land Type	1990	1996	2001	2006	2011	2016	2021
Developed, High Intensity	17,929	19,919	20,801	21,821	22,583	24,298	26,065
Developed, Low Intensity	267,798	268,609	269,989	277,486	282,380	293,940	299,927
Developed, Medium Intensity	77,981	87,251	91,425	97,395	99,692	105,053	109,008
Developed, Open Space	389,334	374,646	367,343	349,020	333,083	345,115	351,985
Grand Total	753,043	750,424	749,557	745,722	737,738	768,406	786,984

Table 54: Land converted to Developed Land area in hectares

Land Type	1990	1996	2001	2006	2011	2016	2021
Cropland converted to Developed Land	-	19,264	30,384	44,253	56,651	47,985	49,024
Forest land Converted to Developed Land	-	17,102	28,369	38,823	45,159	34,517	30,201
Grassland Converted to Developed Land	-	11,153	18,612	28,471	38,335	37,914	40,915
Wetlands Converted to Developed Land	-	869	1,510	1,830	2,085	1,652	1,475
Other Land Converted to Developed Land	-	327	492	568	630	373	267

Stratification by Soil Type

Area by Soil Taxonomy

Developed Land is further disaggregated by soil taxonomic order into mineral or organic soils. Data on taxonomic order are taken from the USDA SSURGO dataset (retrieved Oct 2025). State-wide data preparation and processing by land class and soil type are covered in the cross-cutting section. The area (Table 55) of land with drained organic soils is the activity data used to estimate emissions from drained organic soil.

Table 55: Area of drained organic soils in Developed Land in hectares

Land Type	1990	1996	2001	2006	2011	2016	2021
Developed land remaining Developed Land	62,219	66,567	69,190	71,882	73,752	75,162	76,670
Cropland converted to Developed Land	-	2,558	4,053	5,759	7,227	5,946	5,766
Forest land Converted to Developed Land	-	1,487	2,400	3,187	3,640	2,602	2,203
Grassland Converted to Developed Land	-	453	739	1,115	1,499	1,456	1,621
Wetlands Converted to Developed Land	-	35	51	76	86	59	53
Other Land Converted to Developed Land	-	4	4	5	5	2	2

Urban Trees and Tree Cover

Following the NGHGI methodology, total area and percent tree cover (%TC) in Developed Land is used to derive per unit area of tree cover (specifically: area of settlement (ha) x tree cover (%) = area of tree cover in Developed Land). The National Land Cover Dataset (NLCD) Tree Cover data product was utilized to determine the percent tree cover for each Developed Land sub-class (open space, low, medium, and high-intensity development) classification by overlaying NLCD land use data with NLCD % Tree cover data and computing the average tree cover values for each of the 4 subclasses. NLCD percent tree cover values are provided in Table 56.

Table 56: NLCD tree cover % for Oregon

Land Type	1990	1996	2001	2006	2011	2016	2021
Developed, High Intensity	0%	0%	1%	1%	1%	1%	1%
Developed, Low Intensity	15%	16%	17%	17%	18%	18%	17%
Developed, Medium Intensity	11%	12%	12%	12%	12%	13%	12%
Developed, Open Space	29%	32%	33%	35%	36%	36%	33%

The NLCD tree cover data set underestimates % tree cover. Average underestimation of tree canopy cover estimated for 2001 NLCD for developed land is 13.7% (Nowak and Greenfield 2010). All NLCD % tree cover values were adjusted by this amount. It should be noted that the degree of differences varies, however state level analysis across the time series is not available to enable application of different adjustment factors for different developed land NLCD sub-classes and years.

Carbon Fluxes from Land Converted to Developed Land

Total area of land converted to Developed Land as well as land converted to Developed Land on mineral soils is generated as described above. Land converted to Developed Land is further disaggregated by which land category it came from to assign appropriate emission parameters. Total area of land converted to Developed Land is shown in Table 57. This area provides the total area in-transition; however, to estimate the changes in C biomass during conversion, the data was further processed to estimate the area that was converted in the most recent cycle to estimate the biomass lost during conversion (Table 58). The area values were linearly extrapolated to simulate gradual transition over the 5-year period. The area for Other Land converted to Developed Land is provided for information, however, biomass carbons fluxes are not estimated because 0 carbon stock is assumed on Other Land.

Table 57: Land converted to Developed Land area in hectares

Land Type	1990	1996	2001	2006	2011	2016	2021
Forest land Converted to Developed Land	-	17,102	28,369	38,823	45,159	34,517	30,201
Grassland Converted to Developed Land	-	11,153	18,612	28,471	38,335	37,914	40,915
Cropland Converted to Developed Land	-	19,264	30,384	44,253	56,651	47,985	49,024
Wetlands Converted to Developed Land	-	869	1,510	1,830	2,085	1,652	1,475
Other Land Converted to Developed Land	-	327	492	568	630	374	267

Table 58: Land converted to Developed Land area in the most recent data cycle in hectares

Land Type	1990	1996	2001	2006	2011	2016	2021
Forest land Converted to Developed Land	-	17,102	11,329	10,521	6,809	7,224	7,177
Grassland Converted to Developed Land	-	11,153	7,530	9,931	10,129	10,962	10,735
Cropland Converted to Developed Land	-	19,264	11,310	14,134	12,786	10,596	12,619
Wetlands Converted to Developed Land	-	869	692	474	377	436	448
Other Land Converted to Developed Land	-	327	173	93	72	60	64

Area of land converted to Developed Land on mineral soils is shown in Table 59. This area is used to estimate the changes in SOC during conversion.

Table 59: Land converted to Developed Land area on mineral soils in hectares

Land Type	1990	1996	2001	2006	2011	2016	2021
Cropland converted to Developed Land	-	16,706	26,331	38,494	49,424	42,039	43,258
Forest land Converted to Developed Land	-	15,614	25,969	35,637	41,519	31,915	27,998
Grassland Converted to Developed Land	-	10,700	17,873	27,357	36,836	36,457	39,294
Wetlands Converted to Developed Land	-	834	1,459	1,753	1,999	1,593	1,422
Other Land Converted to Developed Land	-	324	488	563	625	372	265

Developed Land: Emission Factors

Drained Organic Soil

Developed Land occurring on organic soils (histosols taxonomic order) are assumed to be drained and would continue to emit CO_2, CH_4, and N_2O. Under the Tier 1 approach applied, there is no differentiation between emissions from soils that have been recently drained and those that were drained longer ago, therefore, the same parameters are used to estimate emissions for Developed Land remaining Developed Land and land converted to Developed Land. There are no default parameters for this land category. The same emission factors are applied as for cropland. The IPCC guidelines recommend selecting parameters of the land category that is closest to developed land in terms of drainage level, vegetation, or management conditions. Organic soils in Developed Land remaining Developed Land and land converted to Developed Land are assumed to be losing C at a rate similar to croplands due to deep drainage (Ogle et al. 2003). Therefore, emission factors for croplands are used. CO_2 emissions are estimated for both on-site emissions, resulting from losses of carbon due to oxidation at the site of drainage as well as off-site emissions, resulting from losses due to waterborne carbon export. The emission factors are provided in Table 60.

Table 60: Emission factors for drained organic soil. Values in parentheses represent 95 percent confidence interval.

Parameter	Gas	Value	Unit	Reference
EF, on-site	CO_2	7.9 (6.5 – 9.4)	tonne CO_2-C ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.1*
EF_{DOC}, off-site	CO_2	0.31 (0.19–0.46)	tonne C ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.2*
EF, direct emissions	N_2O	13 (8.2 – 18)	kg N_2O-N ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.5*
EF, land	CH_4	0 (-2.8 – 2.8)	kg CH_4 ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.3*
EF, ditch	CH_4	1165 (335-1995)	kg CH_4 ha^{-1} yr^{-1}	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.4*
Frac_ditch	CH_4	0.05	unitless	*IPCC 2013 Wetland Supplement, Chap 2, Table 2.4*

Urban Trees- Carbon dioxide Emissions/Removals in Biomass for Land Remaining in Developed Land

To estimate annual C sequestration by urban trees, statewide gross and net sequestration rates are determined by Novak (2013), which is based on data from Corvallis, OR. The parameters for calculating carbon flux from urban trees in Oregon are in Table 61.

Table 61. Parameters for estimating urban tree C sequestration.

Parameter	Value	Unit	Value	Unit
Gross Annual Sequestration per Area of Tree Cover	0.265	Kg Cm^{-2} yr^{-1}	2.65	tonne C ha yr^{-1}
Net Annual Sequestration per Area of Tree Cover	0.193	Kg C m^{-2} yr^{-1}	1.93	tonne C ha yr^{-1}
Net:Gross Annual Sequestration Ratio	0.73	Unitless	0.73	Unitless

Reference: NGHGI

For estimating C biomass loss in other land categories when Developed Land is converted to other land uses, biomass carbon stock values are needed. Carbon stock biomass values are derived from FIA urban tree inventory data for Portland, OR, by averaging biomass carbon stocks for 2018-2022. FIA data is queried using the USFS Urban tree platform (https://texasforestinfo.tamu.edu/urbanforeststats/) to obtain data on C density for the two relevant carbon pools: 1) live and dead aboveground and 2) live and dead belowground using parameters listed in Table 62.

Table 62: Carbon density query parameters for the USFS Urban tree inventory.

Selection Parameters	User Selection
Geography	Portland, OR
Year	2018, 2019, 2020, 2021, 2022
Estimate	Ratio
Numerator	Aboveground carbon, live and dead trees (short tons) Belowground carbon, live and dead trees (short tons)
Denominator	Area of tree cover, in acres
Summary categories, columns	Land use (FIA)
Press RUN	*Press RUN*
Urban statistics table	Click "show sampling errors"
Output format	Download statistics in CSV
Unit conversion	Convert short tons to tonnes, acres to hectares

The total C biomass density values for live and dead trees are summarized in Table 63 and converted to tonne C per hectare. An average value is derived based on measurements from the 5 inventories conducted. While the carbon stock values are provided in this section, they are used in methodologies for other land categories. The C biomass values that aligned with the NLCD classes were selected: open space – recreation/cemetery land use, low intensity development – residential land use, medium intensity development – multi-family residential land use, and high intensity development – commercial/industrial land use.

Table 63: Developed Land C biomass density. ***Reference: USFS Urban tree inventory for Portland, OR***

Parameter	NLCD Class	FIA Land Use	Unit	Value
Total C biomass density	High intensity	Commercial/Industrial	tonnes C ha^{-1}	73.8
Total C biomass density	Low intensity	Residential	tonnes C ha^{-1}	105.2
Total C biomass density	Medium intensity	Multi-family Residential	tonnes C ha^{-1}	47.9
Total C biomass density	Open space	Recreation/Cemetery	tonnes C ha^{-1}	75.4

Carbon dioxide emissions/removals in Biomass and Soils in Land Converted to Developed Land (Including Urban Trees)

Biomass Carbon Density

When land is converted to Developed Land from another land category, average biomass carbon density of the land pre-transition should be subtracted from average carbon density of land post-transition to calculate carbon fluxes due to conversion. The parameters are summarized below in Table 64.

Table 64: C biomass density parameters for land converted to Developed Land

Converted from	Pre-transition C density (tonne C $hectare^{-1}$)	Reference
Cropland	4.7 tonnes C ha^{-1}	2019 IPCC Guidelines, Vol. 4, Ch 5, Table 5.3, Table 5.11
Forest	118 tonnes C ha^{-1}	Mean biomass C stock based on 2021 FIA data
Grassland	2.86 tonnes C ha^{-1}	Weighted average of grassland biomass C stock based on NPP models (RAP)
Wetlands	15.59 tonnes C ha^{-1}	Inland emergent wetlands biomass C stock
Other Land	0	NA

Soil Organic Carbon in Mineral Soils

Fluxes in SOC in mineral soils (not inclusive of histosols taxonomic order) are expected to occur when land is converted to Developed Land. For mineral soils, the IPCC default assumption is it takes 20 years for the system to reach a new equilibrium from the time land use changes. IPCC Tier 1 parameters are used to estimate SOC selected from the parameters listed in Table 65. For all land categories except wetlands, SOCref values disaggregated by climate zone and soil type were used (Table 3). For wetlands converted to developed land, SOCref of 97 tonne C ha^{-1} at 30cm depth was used. This value is based on a weighted average across ecoregions of soil carbon stock for mineral soils for inland wetlands. This value is indicative of 30% of carbon stock at 1m depth.

All grasslands converted are assumed to be nominally managed. Stock change parameters for cropland were disaggregated by climate zone assuming long term cultivated land with conventional tillage and medium inputs is converted. The wetland supplement provides stock change factor, Flu, for inland mineral soils for conversion to cropland. The same value was assumed for developed land. For developed land stock change factors are based on the following assumptions recommended by the IPCC guidelines: for paved areas - high and medium intensity development classes, product of stock change factors is 0.8. For turfgrass - open spaces, assume the same values as improved grassland. For low intensity development, product of stock change factors was assumed to be 0.9 (a mix of paved and vegetated areas).

Table 65: Soil Carbon stock change factors for land converted to Developed Land (unitless). Values in parentheses represent two standard deviations, expressed as a percent of the mean.

Converted from/to	Climate	F_{LU}	F_{MG}	F_{I}	Reference
Forest	All	1	-	-	Section 4.2.3.2 (2019 IPCC Refinement, Vol. 4, Chap 4)
Grassland	All	1	1	-	Table 6.2 (2019 IPCC Refinement, Vol 4, Chap 6)
Cropland	Cool Temperate Dry	0.77 (±14%)	1	1	Table 5.5 (2019 IPCC Refinement, Vol 4, Chap 5)
Cropland	Warm Temperate Dry	0.76 (±12%)	1	1	Table 5.5 (2019 IPCC Refinement, Vol 4, Chap 5)

Cropland	Warm Temperate Moist	0.69 (±16%)	1	1	Table 5.5 (2019 IPCC Refinement, Vol 4, Chap 5)
Wetlands	All	1	-	-	Table 5.3, (2013 Wetland Supplement)
Developed, High Intensity	All	0.8	-	-	Section 8.3.3.2 (2006 IPCC GL, Vol 4, Chap 8)
Developed, Low Intensity	All	0.9	-	-	Expert judgement
Developed, Medium Intensity	All	0.8	-	-	Section 8.3.3.2 (2006 IPCC GL, Vol 4, Chap 8)
Developed, Open Space	All	1.14 (±11%)	1	-	Table 6.2 (2019 IPCC Refinement, Vol 4, Chap 6)
All developed when converted from wetlands	All	0.71	-	-	Table 5.3 (2013 Wetland Supplement)

Developed Land: Methodology

Drained Organic Soil Emissions

An IPCC Tier 1 method is used to estimate soil organic C stock changes for organic soils in Developed Land (IPCC 2013 Wetland Supplement, Chap. 2). Methane and nitrous oxide emissions also occur from drained organic soils. All organic soils occurring in Developed Land (combining Developed Land remaining Developed Land and land converted to Developed Land) are assumed to be drained, which is generally necessary for development. CO_2 emissions occur onsite where drainage occurred, due to oxidation, and offsite, due to waterborne export; all three are estimated separately. CH_4 and N_2O emissions occur on-site only. To estimate annual emissions, area of land with drained organic soil is multiplied by the emission factor according to the equations below.

Equation 27: On-site CO_2 emissions from drained organic soils

$$CO_2\text{-}C_{on\text{-}site} = A \times EF_{on\text{-}site}$$

Where:

$CO_2\text{-}C_{on\text{-}site}$ = annual on-site CO_2-C emissions from drained organic soils in a land-use category, tonne C yr^{-1}

Area = area of drained organic soils in Developed Lands, ha

$EF_{on\text{-}site}$ = emission factor for drained organic soils, tonne C ha^{-1} $year^{-1}$

NOTE: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Equation 28: Off-site CO_2 emissions from drained organic soils

$$CO_2\text{-}C_{off\text{-}site} = Area \times EF_{DOC}$$

Where:

$CO_2\text{-}C_{off\text{-}site}$ = annual on-site CO_2-C emissions from drained organic soils in a land-use category (tonnes C/yr)

Area = land area of drained organic soils in Developed Lands (ha)

EF_{DOC} = emission factors for drained organic soils (tonnes C/ha/year)

Note: convert CO_2-C to CO_2 by multiplying by 44/12

Equation 29: CH_4 emissions from drained organic soils

$$CH_{4\ organic} = A \times (((1-Frac_{ditch}) \times EF_{CH4\ land}) + Frac_{ditch} \times EF_{CH4\ ditch})/1000$$

Where:

$CH_{4\ organic}$ = CH_4 loss from drained organic soils, tonne CH_4 yr^{-1}

Area = area of drained organic soils in a land-use category

$EF_{CH4\ land}$ = emission factors for direct CH_4 emissions from drained organic soils, kg CH_4 ha^{-1} yr^{-1}

$EF_{CH4\ ditch}$ = emission factor for CH_4 emissions from drainage ditches, kg CH_4 ha^{-1} yr^{-1}

$Frac_{ditch}$ = fraction of the total area of drained organic soil which is occupied by ditches (where "ditches" are considered to be any area of manmade channel). The ditch area may be calculated as the width of ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width should be calculated as the average width of open water plus any saturated fringing vegetation.

Equation 30: N_2O emissions from drained organic soils

$$N_2O\text{-}N = (Area \times EF)/1000$$

Where:

N_2O-N = annual N_2O-N emissions from drained organic soils in a land-use category, tonnes C yr^{-1}

Area = area of drained organic soils in Developed Lands, ha

EF = emission factor for drained organic soils, kg N_2O-N $hectare^{-1}$ yr^{-1}

Note: convert N_2O-N to N_2O by multiplying by 44/28

Urban Trees- Carbon dioxide Emissions/Removals in Biomass for Land Remaining in Developed Land

Dominant factors affecting carbon flux in Developed Land are due to urban trees. Carbon flux in trees changes in relation to the amount of area (increasing sequestration due to more land and trees) and net changes in tree cover (e.g., tree losses versus tree gains through planting and natural regeneration). To quantify the carbon stored in urban trees, the methodology used by NGHGI requires analysis per unit area of tree cover, rather than per unit of total land area (as is done for Forest Land). The same approach is utilized to estimate CO_2 fluxes from urban trees in land remaining as Developed Land and land converted to Developed Land, i.e., estimates are not disaggregated by land remaining and land converted.

Equation 31: Biomass C Flux from Urban Trees

$$C_{sequestration} = \text{Net rate} \times \text{Area} \times \%\ \text{tree cover}$$

Where:

$C_{sequestration}$ = Net state annual C sequestration, tonne C yr^{-1}

Net rate = Net Annual sequestration per area of tree cover, tonne C ha^{-1} yr^{-1}

Area = Developed Land area, ha

% tree cover = % tree cover in Developed Land, by developed land class

NOTE: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Land converted to Developed Land

When land is converted to Developed Land, it can lead to losses of carbon to the atmosphere, particularly from loss of biomass during conversions and soil disturbance. For land converted to Developed Land, the carbon loss in biomass is calculated following the methodology outlined in the other land category methodology sections and assumed to be lost in the year when the land conversion occurred. Only losses associated with conversion are estimated here since accumulation of carbon in urban trees is estimated for all Developed Land area together. The equation 32 is used to calculate C biomass flux from conversion.

Equation 32: Biomass C flux from land converted to Developed Land (Eq. 2.15 in Vol. 4, Chap 2 2006 IPCC GL)

$$\Delta C_b = \Delta C_g + \Delta C_{conversion} - \Delta C_l$$

Where:

ΔC_b = annual change in carbon stocks on land converted to Developed Land

ΔC_g = annual increase in carbon stocks due to growth in Developed Land

$\Delta C_{conversion}$ = initial change in carbons stocks in biomass on land converted to Developed Land

ΔC_l = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering, other disturbances

NOTE: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

ΔC_g is estimated using Equation 31, same approach is applied for both, area of Developed Land remaining Developed Land and area of land converted to Developed Land. ΔC conversion is estimated using Equation 33.

Equation 33: Biomass C Change Due to Conversion (adapted from Eq. 2.16 in Vol. 4, Chap 2 2006 IPCC GL)

$$\Delta Cconversion = i(Cafter\_i = Cbefore\_i)*\Delta Area\_converted$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks at time of conversion, tonne C yr^{-1}

C_{AFTER},i = biomass carbon stock on land use type i immediately after conversion to Developed Land, tonne C ha^{-1}

C_{BEFORE},i = biomass carbon stock on land use type i immediately before conversion to Developed Land, tonne C ha^{-1}

$Area_{CONVERTED}$ = area of land use type i converted to Developed Land, ha

NOTE: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

ΔCl is included in the sequestration rate for urban trees and therefore can be assumed to be 0.

Carbon Dioxide Flux from Mineral Soils

Mineral soil C fluxes are calculated using a Tier 1 approach using carbon factors from the 2019 Refinement to the 2006 IPCC Guidelines.

Equation 34: Soil organic carbon flux on mineral soils in land converted to Developed Land (i.e., equation 2.25 in Volume 4, Chap 2 of 2006 IPCC GL)

$$\Delta C_{MINERAL} = (SOC_0 - SOC_{(0-T)})/D$$

$$SOC = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_I$$

Where:

$\Delta C_{MINERAL}$ = annual change in mineral soil organic carbon stock, tonne C

SOC_0 = C stock at the end of the period

$SOC_{(0-T)}$ = C stock at the beginning of the period

D = the default time period for the transition between equilibrium SOC values, 20 years

SOC_{Ref} = reference C stock

F_{LU}, F_{MG}, F_I = stock change factors for land use, management practice, and input levels of organic matter, respectively

Note: To report emissions in CO_2 equivalents, multiply carbon values by 44/12 (the molecular weight ratio of CO_2 to C).

Developed Land: Uncertainty

Tree canopy cover: While NLCD land cover products provide a fairly robust identification of developed land classes (91% land cover accuracy) (Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 3.0, February 2024): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54.), the NLCD tree cover product has been reported to underestimate % tree cover (Nowak and Greenfield 2010). The greatest underestimation tended to be in the zones with the greatest tree cover, especially in developed land (13.7%). Even though NLCD tree cover values were adjusted by that amount, it is likely that tree canopy remains underestimated to varying degree resulting in underestimation of carbon sequestration by urban trees.

Urban tree sequestration rate: A state-wide sequestration rate was used in estimating removal of carbon by urban trees, which could mask some regional variations.

Drained organic soil emissions: There is no systematic data on drainage practices at the state level, therefore estimates are based on key assumptions that all organic soils are drained and that they are most like cropland in terms of their properties and management. Furthermore, default emission factors are used for estimates.

Developed Land: Completeness

Soil emissions from application of fertilizer on Developed Land are not included in this category to avoid double counting. Currently they are reported by the SBI prepared by Oregon DEQ. This is not consistent with the IPCC guidelines, however, and it is recommended that in the future accounting for this emission source occurs in the LCI.

Developed Land: Improvements

Current estimates of carbon sequestration utilizes national GHG inventory methodology which utilizes state level parameters. In order to improve the estimates, it recommended that those parameters are updated and/or disaggregated further by other relevant attributes that better capture urban tree characteristics across Oregon. Building on the state's TreePlotter inventory, the state could further develop its urban tree inventory to be used for analysis and development of necessary emission parameters.

Refinement of activity data and emission factors for drained organic soils is also recommended to improve the accuracy of the estimates. Currently it is assumed that drained organic soils behave similar to drained organic soils on croplands.

It is recommended that there is harmonization of activity data and methodology across the land based and sector-based inventories related to estimating nitrous oxide emissions from soils on developed land due to application of fertilizer. The current inventory excludes this emission source because it is already captured in the SBI. Regardless of where it is reported, refinement of fertilizer data would improve accuracy. In addition reporting it under the Inventory would bring it into alignment with the National GHG Inventory.

Category: Biomass Burning

The following two categories are included in this section:

- Non-CO_2 emissions from wildfires
- Non-CO_2 emissions from prescribed burns

Wildfires and prescribed burning occurring in Oregon result in emissions of CO_2, CH_4 and N_2O. CO_2 emissions are accounted for as changes in biomass C stocks. This section describes the methods for estimating non-CO_2 emissions (i.e., CH_4 and N_2O) from biomass burning occurring on all lands other than croplands. Non-CO_2 emissions from agricultural residue burning are reported in the Oregon Sector Based GHG Inventory. The methodology for estimating non-CO_2emissions from wildfires is based on the Wildland Fire Emissions Inventory System calculator (WFEIS, https://wfeis.mtri.org/calculator), the same tool used by the US EPA to estimate forest fire emissions for the National GHG Inventory. This tool estimates emissions from the wildfire and enables disaggregation of emissions by land category based on fuel type. Emissions from prescribed burns are also estimated. The methodology is applied at the land category level (not disaggregated by land remaining and land converted).

Biomass Burning: Activity Data

Activity data needed to estimate emissions from biomass burning are:

- Total burn area
- Fuel available for combustion

The Oregon Department of Forestry (ODF) is the agency that manages fire response for wildfires. ODF also oversees prescribed burn activities in the state. ODF collects data on wildfires and maintains a spatial database of wildfires going back to 1933, including fire date, area, name, country, cause, and numerous other identifying attributes. Typically ODF annual data was produced by compiling data from the national fire service responders as well as local districts that manage smaller fires and/or fires that are not on federal lands. Starting in 2021, the state has adopted the National Incident Feature Service (NIFS) data standard, which results in a more consistent and comprehensive documentation of fires. These events are documented and provided for download by the National Interagency Fire Center (NIFC, https://data-nifc.opendata.arcgis.com/). There are additional data products available that document wildfire occurrences, including MODIS, Monitoring Trends in Burn Severity (MTBS) perimeters, National Interagency Fire Center (NIFC)/GeoMAC perimeters, and Wildland Fire Interagency Geospatial Services (WFIGS) perimeters. Each has trade-offs in terms of data temporal coverage and spatial resolution as summarized in Table 66. Because these datasets capture slightly different subsets of fires, they will all be used to estimate GHG emissions and the results averaged to obtain a statewide estimate. This is analogous to the approach taken by the NGHGI (Smith et al. Carbon Balance and Management https://doi.org/10.1186/s13021-024-00274-0). All the burn perimeter datasets are available through the Wildlands Fire Emissions Inventory System (WFEIS) tool, which is used for estimating emissions and described in detail below. The tool also allows upload of custom data, such as the ODF historic burn perimeters to be used as an input.

Table 66: Summary of the Wildfire Data Sources

Source	Coverage	Data Type	Time Span / Update Frequency
MTBS (Monitoring Trends in Burn Severity)	Nationwide (fires ≥1,000 ac West; ≥500 ac East)	Fire perimeters, burn severity (dNBR)	1984–present, updated periodically
Wildland Fire Interagency Geospatial Services (WFIGS) / NIFC Fire Perimeters[23]	Nationwide	Historical and current fire perimeters	1950–present, Integrates NIFS/Geomac data
NASA FIRMS (MODIS/VIIRS)	Global	Satellite hotspot detections	Near real-time (daily, 375m–1km) 2000- present
Oregon Dept. of Forestry (ODF)[24]	Oregon statewide	Fire perimeters based on reports and suppression data	Annual reports, 1933 - present

For prescribed burns, the inventory utilizes ODF Fire Program/Burning and smoke management program data. The database of burns can be queried to obtain a summary of fire occurrence by type (e.g., broadcast, landing, pile, right of way, and underburn), location (lat/long) representing burn center, acres (but not the exact perimeter), tons of material burned (short tons), ownership, date, county, and management unit.

The following burn type definitions are used:

- **Broadcast Activity (B):** Ignition across an area, active fuel distribution
- **Underburn Activity (U):** Low intensity burning mostly in the understory layer.
- **Broadcast Natural (F):** Naturally occurring fuel (not logging slash) burned via broadcast
- **Underburn Natural (N):** Low-intensity burn in natural (not harvest-slash) fuels in the understory
- **Handpile (H):** Piled woody debris created manually (by hand) and burned
- **Grapple Pile (G):** Piled woody debris created by a grapple machine and burned
- **Tractor Pile (T):** Piled woody debris created by a tractor and burned
- **Landing Only (L):** Burn restricted to logging landing area only (no broadcast/underburn)
- **Right-of-way (R):** Burning along rights-of-way (e.g., access roads, utility corridors)
- **Rangeland (S):** Burning on rangeland fuels (grass, sagebrush, etc.)

Data was provided by request by ODF staff in tabular format for each year starting in 2010. Total tonnage of fuel burned is summed for each burn type that occurred that year and converted from short tons to metric units - tonnes. For years prior to 2010, an average tonnage for each burn type for years 2012-2024 was used as a representative value. Note that years 2010 and 2011, although have data

[23] OSU's Oregon Explorer package and distribute these datasets for public and research use.
[24] ODF's internal historic fire perimeter dataset available upon request from Erik Larsen. Includes fires >10 acres in size on ODF-protected lands.

records, appear to have much lower levels of prescribed burn activities, suggesting a data collection gap. Therefore these years were excluded from the average used to fill in data gaps for years 1990 to 2009.

Biomass Burning: Emission Factors

Emission parameters for estimating burning emissions include combustion factors for particular fuel types and emission factors for particular gases. The emission factors are taken from the Smoke Emission Reference Application (SERA, https://depts.washington.edu/nwfire/sera/index.php). It is good practice to periodically download and document the emission factors. Specific emission factors are selected by the wildfires emissions modeling tool used to estimate emissions (described in detail below). Emission factors are based on fuel type determined by the location of the fire and fuel type. The emission factors are also determined within the model based on fuel bed type.

For prescribed burns, emission factors for different burn types are summarized in Table 67 from the SERA. Attributes guiding emission parameters selection are provided.

Table 67: Combustion factor and emission factors for prescribed burns. Values in parentheses represent standard deviations.

Burn Type	C_f	IPCC attributes#	CH_4 (g kg^{-1})	N_2O* (g kg^{-1})	SERA attributes
Broadcast Activity	0.62 (±0.12)	Other temperate forests; Post logging slash burn	5.387 (±3.508)	0.195 (±0.105)	West, Broadcast Rx, include slash
Underburn Activity	0.62 (±0.12)	Other temperate forests; Post logging slash burn	5.387 (±3.508)	0.195 (±0.105)	West, Broadcast Rx, include slash
Broadcast Natural	0.45 (±0.16)	All other temperate forests	4.677 (±2.61)	0.247 (±0.063)	West, Broadcast Rx, exclude slash
Underburn Natural	0.45 (±0.16)	All other temperate forests	4.677 (±2.61)	0.247 (±0.063)	West, Broadcast Rx, exclude slash
Hand pile	0.62 (±0.12)	Other temperate forests; Post logging slash burn	4.673 (±4.021)	-	West, Pile, include slash
Grapple Pile	0.62 (±0.12)	Other temperate forests; Post logging slash burn	4.673 (±4.021)	-	West, Pile, include slash
Tractor Pile	0.62 (±0.12)	Other temperate forests; Post logging slash burn	4.673 (±4.021)	-	West, Pile, include slash
Landing Only	0.62 (±0.12)	Other temperate forests; Post logging slash burn	4.673 (±4.021)	-	West, Pile, include slash
Right-of-way	0.51	Other temperate forests; Felled and burned (land-clearing fire)	4.677 (±2.61)	0.247±0.063	West, Broadcast Rx, exclude slash
Rangeland	0.77 (±0.26)	All savanna grasslands (mid/late dry season burns)	2.749 (±1.583)	0.247±0.063	West, Broadcast, Shrubland, exclude slash

*# Reference: Table 2.6, 2019 Ref, Vol 4, Chap2; *For pile burns, N_2O EF factor is not available. CO_2 emissions will be calculated (EF_{CO2} - 1,688.98±99.53, Reference: SERA) and converted to N_2O (based on the N_2O to CO_2 ratio of 0.000166, Reference: 2024 US GHG Inventory, US EPA).*

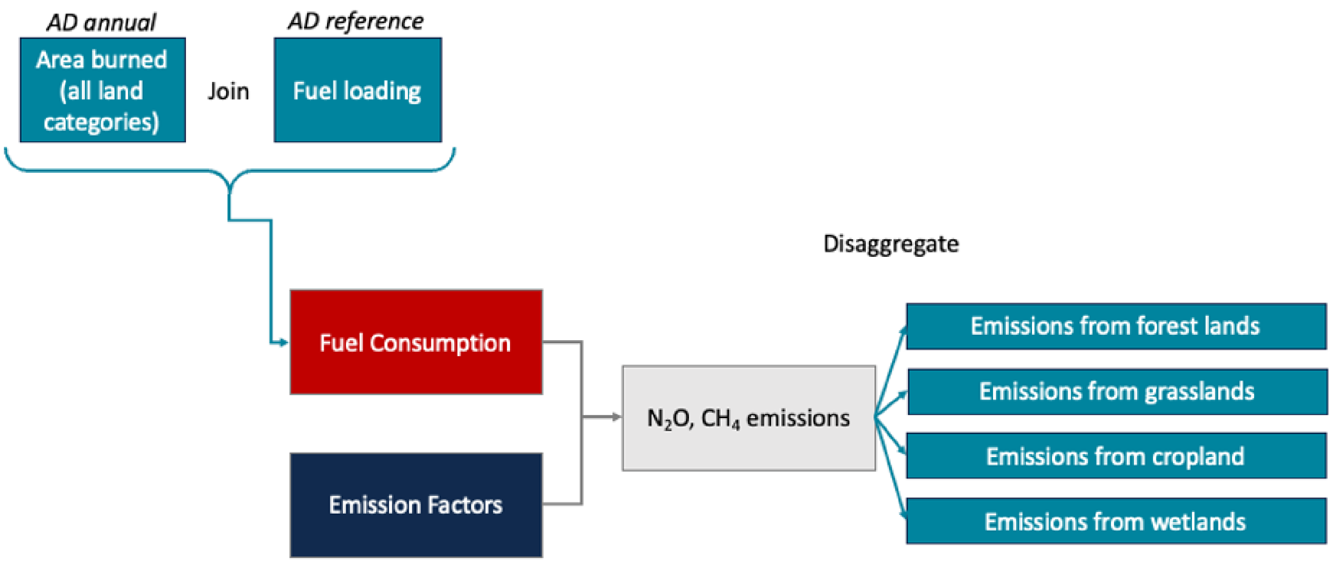
Biomass Burning: Methodology

Wildfires

For wildfire emissions, the Wildlands Fire Emissions Inventory System (WFEIS) tool is used. WFEIS estimates emissions with the *Consume* model (see Figure 4) utilizing spatially explicit data on burn areas, fuelbed types, and weather conditions. Fuelbeds representing the type of vegetation consumed during the fire are determined according to the Fuel Characteristic Classification System (FCCS) [25] and is based on the Landfire Vegetation Type (EVT) data product.[26] This information is used to estimate fuel consumption and further disaggregate emissions by land category. WFEIS also uses meteorological data to simulate conditions at the time of the fire to simulate burning conditions. The tool applies emission factors from SERA to estimate a suite of emissions including CO_2 and CH_4. The model does not calculate N_2O emissions, which are derived by scaling estimated CO_2 emissions based on the average N_2O to CO_2 ratio of 0.000166. [27]

The 4 datasets identified in the activity data section will be used as inputs. MTBS, MODIS, and WFIGS datasets are provided as part of the WFEIS tool. In addition, the tool allows the user to upload an input data file (GeoJSON or Shapefile) with burn perimeters, which would allow application of state level activity data. ODF fire perimeter layers are uploaded through this feature to obtain emission estimates.

Figure 4: Conceptual Model of the WFEIS Tool.



Note: cropland emissions will be provided for information only

Emission calculations are performed by the WFEIS Calculator tool,[28] with selected activity data, other relevant input data and emission factors applied by the tool. The output (emissions by gas in units of mg)

[25] Prichard, Susan J.; Sandberg, David V.; Ottmar, Roger D.; Eberhardt, Ellen; Andreu, Anne; Eagle, Paige; Swedin, Kjell. 2013. Fuel Characteristic Classification System version 3.0: technical documentation. Gen. Tech. Rep. PNW-GTR-887. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 79 p.
[26] USDA & US Dept of Interior, https://www.landfire.gov/vegetation/evt
[27] (Larkin et al. 2014; IPCC 2019).
[28] The calculator development and detailed methodology is documented by French et al (2014) (Earth Interactions, Volume 18 (2014), Paper No. 16).

is exported for each year by fuelbed type (code represents vegetation type, e.g., 8 = Western hemlock-Douglas-fir-western redcedar/vine maple forest) as shown in Table 68. Once disaggregated by land category, the annual emission estimates from the four datasets are averaged to obtain final emission estimates by land category.

Table 68: Example File Export from WFEIS tool.

year	fuelbed_aggregate	area_km2	consume_output__carbon_mg	consume_output__ch4_mg	consume_output__co2_mg
2020	0	112.457	0.0	0.0	0.0
2020	2	0.118	532.9	5.9	1,727.3
2020	6	0.377	647.4	3.0	2,161.6
2020	7	0.0	0.0	0.0	0.1
2020	8	6.579	43,868.9	517.6	141,536.7
2020	10	0.04	275.0	3.2	887.6
2020	12	0.015	45.6	0.5	147.5
2020	13	0.039	129.3	1.6	416.1
2020	14	0.001	1.0	0.0	3.4
2020	15	0.0	1.9	0.0	6.0

Prescribed Burns

For estimating emissions from prescribed burns, the IPCC methodology is used. The calculation follows Equation 37.

Equation 35: Estimation of greenhouse gas emissions from fire (Equation 2.27, 2019 IPCC, Vol. 4, Chap 2)

$$L_{FIRE} = Area \times M_b \times C_f \times G_{ef} \times 10^{-3}$$

Where:

L_{FIRE} = amount of GHG emission from fire, tonnes

Area = area burned, ha

M_b = mass of fuel available, tonnes ha^{-1}

C_f = combustion factor, dimensionless

G_{ef} = emission factor, g GHG kg^{-1} dry matter burned (i.e., g CH_4 or g N_2O)

10^{-3} = conversion of kg to tonne

Since the ODF dataset on prescribed burns provides tonnage of material burned, this is used directly in the equation for the $A \times M_b$ terms. Emissions are calculated for each burn type annually and summed.

Biomass Burning: Uncertainty

Key contributors to estimating emissions from biomass burning, specifically for wildfires, include incomplete or inconsistent fuel data, simplified consumption assumptions, and inadequate burn-area mapping. Because true emissions cannot be measured directly and due to lack of validation against realworld fuel consumption measurements, there remains a need for systematic uncertainty quantification and improved datasets. Several sources of uncertainty are related to the following factors:

Fuel loading assumptions - WFEIS uses FCCS fuelbeds, which may have higher canopy fuel loadings than satellite-derived estimates (e.g., MODIS) potentially biasing WFEIS estimates upward; Shrub consumption within WFEIS is based on a simplified assumption (50% of shrub biomass burns), which is not empirically validated due to lack of data, potentially inflating consumption estimates, especially in shrub dominated landscapes;

Fuel type and moisture variability - Fuel loads and moisture conditions vary across landscapes, but input datasets may not fully capture this variability, affecting consumption estimates.

Burned-area mapping discrepancies - MODIS and Landsat burned-area products may differ from validated fire records, introducing another important data uncertainty in emission estimation. These discrepancies directly affect the amount of area burned, a major driver of total emissions. Furthermore, ODF historic fire data reports lower burn perimeter areas then national datasets due to potentially incomplete databases, bringing the overall average estimate of emissions down. However, starting in 2021, changes in state level data collection led to improved consistency in data across sources.

Lack of systematic validation - None of the models (WFEIS, GFED, FINN, BlueSky) have undergone comprehensive accuracy assessments, making inter-model differences difficult to interpret. As a result, higher or lower estimates cannot be confidently classified as bias or improved representation.

For prescribed burn emission estimates, the main sources of uncertainty are also related to estimates of fuel loading as well as emission factors used in the calculations.

Biomass Burning: Completeness

Emission estimates cover main sources of emissions – wildfires and prescribed burns. Emissions from agricultural residue burning are reported elsewhere. WFEIS model also estimates emissions occurring on other land categories such as wetlands. These estimates were not included in the inventory during this cycle, however, maybe considered for inclusion after validation of methodology with state land management experts.

Biomass Burning: Improvements

For wildfires, improved data collection at the state level would enhance the completeness of the burn area mapping and reduced discrepancies. For future data, ODF data should contain fire date to tag representative fuel moisture information to each perimeter.

For prescribed burns, the dataset currently only contains the center point location of the fire activity rather than the burn perimeter. Collecting spatial data on fire perimeters could be helpful in improving estimates of the fuel load using the WFEIS tool rather than the approach currently used by ODF to estimate fuel loading. This type of data collection could be done for one year and results compared to assess if there are major differences. ODF data should disaggregate by broadcast and understory burns with and without slash if possible to improve estimates of fuel loading and assignment of emission factors corresponding to relevant conditions.

More broadly, it is recommended that the inventory team utilize the support of the WFEIS team to conduct analysis, understand tool improvements and refine the modeling parameters.