Chapter 2
Considerations When Estimating Agriculture and Forestry GHG Emissions and Removals

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Acronyms, Chemical Formulae, and Units

CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalents
GHG	Greenhouse gas
GWP	Global warming potential
ha	Hectares
HWP	Harvested wood products
IPCC	Intergovernmental Panel on Climate Change
N_2O	Nitrous oxide
NH_3	Ammonia
NO	Nitric oxide
NO_x	Mono-nitrogen oxide
NO_2	Nitrite
NO_3	Nitrate
PDF	Probability density function
USDA	U.S. Department of Agriculture

2 Considerations When Estimating Agriculture and Forestry GHG Emissions and Removals

This chapter describes the linkages and cross-cutting issues relating to sector-specific and entity-scale estimation of greenhouse gas (GHG) sources and sinks. In particular, this chapter describes the common elements that must be considered both within an emissions sector or source category as well as across sectors or source categories in order for an entity to report accurate GHG inventory estimates.

Chapter 2 is organized as follows:

- Scope
- Review of Relevant Current Tools and Methods
- Selection of Most Appropriate Method and Mitigation Practices to Include
- Overview of Sectors
  - Croplands and Grazing Lands
  - Wetlands
  - Animal Production
  - Forestry
  - Uncertainty

2.1 Scope

In order for an entity to accurately inventory its direct GHG emissions to (and removals from) the atmosphere and compare emissions and removals between years, practices, or entities, it is important that estimation elements—e.g., definitions of entity and system boundaries—are common to all emission sectors and source categories. These common elements are described in more detail in the sections that follow and include:

- Definition of Entity
- Definition of System Boundaries:
  - Physical Boundaries
  - Temporal Boundaries
  - Activity Boundaries
  - Material Boundaries

2.1.1 Definition of Entity

The definition of an entity will, to a large degree, determine the (spatial) bounds of the estimation methodologies. This will primarily be driven by what data a landowner chooses to input—i.e., the definition will be user-specific and primarily depend on the user's definition.[1] However, it is anticipated that the science-based methods will be suitable to quantify GHG sources and sinks at a process or practice scale. The methods in this report provide an integrated assessment of the net

[1] It should be noted that the definition of an entity used in this report is not a policy or regulatory definition, and is only provided to help the land manager determine what practices should be included in the estimation.

GHG emissions for an entity, all lands for which the landowner has management responsibility. They also provide the basis for an integrated tool to be used by the U.S. Department of Agriculture (USDA) as well as by individual farmers, ranchers, forest owners, and other stakeholders to evaluate the net GHG emissions on parcels of land under their management. So while the entity would be defined as all of the activities occurring on all tracts of land under the management control of the landowner, the report describes practice-level methodologies that can be summed collectively to arrive at an estimate for the entity. The definition of entity applied here is intentionally broad, understanding that any policy, registry, or market will provide its own narrower definition.

2.1.2 Definition of System Boundaries

The system boundaries should include the GHG emissions and carbon sequestration occurring (or established) onsite for the source category and management practice in question. For example, this report does not address indirect land-use changes occurring offsite or biogenic GHG flux related to subsequent use of agricultural or forestry outputs (e.g., food processing, pulp and paper manufacture, biomass combustion). However, certain offsite carbon storage considerations (e.g., flow of harvested wood into harvested wood products [HWPs]) have been considered in the report to maintain consistency with national inventory efforts.

Four types of system boundaries are important for consideration:

- Physical Boundaries
- Temporal Boundaries
- Activity Boundaries
- Material Boundaries

2.1.2.1 Physical Boundaries

Physical boundaries (e.g., spatial, sectoral) address the area and the management to be considered in the reporting. Setting the boundaries for which emissions and sequestration will be estimated is more difficult than it first seems. Although there may be multiple alternatives, clarity and consistency are important. There are many facets to consider. One factor is what constitutes an entity or a farm/ranch/forest operation; another is what operations are associated with that entity. For example, does the use of fertilizer on a farm include the processes of manufacturing and delivering that fertilizer? Another consideration is how to subdivide that larger entity into the relevant sectors as presented in the individual chapters in this report. For example, is the entity entirely grazing land or is some of it in forest management? Finally, there may be questions of how to associate management practices to the most relevant categories for use of the accounting guidelines provided, including any guidance on size limits, what constitutes management, and how to address changing land uses. Definitions are an important part of setting boundaries and will be provided here as well. Examples of management practices (e.g., irrigation, tillage, or residue management for croplands) are included within the various sector descriptions below (i.e., croplands and grazing lands, wetlands, animal production, and forestry); when considering what constitutes a management practice, an entity should note that in the context of these guidelines, a management practice refers to changes in the management of agriculture, animal, or forest production that impact GHG emissions and removals.

The objective of these methods is to provide a complete estimation of GHG emissions and carbon sequestration within the boundaries of an entity. This is not intended as a life cycle analysis, as will be further explained below in the discussion of material boundaries. The methods are designed to be applied at the local scale, but need to be flexible enough to be valid for very large entities. The methods are designed to estimate fluxes for the entirety of an entity, but must also be capable of evaluating a single practice (e.g., project) implemented within a single entity or aggregated across multiple entities.

As noted in Chapter 1, the definition of an entity can be complicated. For the purposes of this report, users should simply delineate the spatial extent of its entity as the land area that is under their ownership and/or management control for the foreseeable future. This is a generalized application of the term entity, and the user should recognize that any policy, program, or contractual agreement may define the user's entity differently and result in a different boundary of the entity. Within the entity boundary, there will be a variety of land uses that will rely on methods from various chapters in this report. An entity should be subdivided if it includes different categories of land use, such as grazing land and cropland, but the entire entity should fall into some land-use category. No rigid lower bound is specified here for the areal extent of a land-use categorization, but, in general, areas of an acre or more merit identification.

Within the boundaries of the overall entity, areas of *cropland* will need to be identified. Beyond just areas producing row or close-grown crops or hay, cropland also includes land that is fallow and areas of hay and pasture that are managed in a rotation with other crops. Wetlands (including drained wetlands and hydric soils) and land under agroforestry practices where the predominant production activity is cropping should also be considered as cropland for the purposes of this report. Finally, areas of cropland that are set aside, such as lands in the Conservative Reserve Program, are included in this management type. The methods for these lands are included in Chapter 3 of this report. The cropland areas should be delineated as fields or groups of fields for which the basic rotations and management practices are all similar.

Cropland:
A land-use category that includes areas used for the production of adapted crops for harvest, including both cultivated and non-cultivated lands. Cultivated crops include row crops or close-grown crops and also hay or pasture in rotation with cultivated crops. Non-cultivated cropland includes continuous hay, perennial crops (e.g., orchards), and horticultural cropland. Cropland also includes land with alley cropping and windbreaks, as well as lands in temporary fallow or enrolled in conservation reserve programs (i.e., set-asides). Roads through cropland, including interstate highways, State highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from cropland area estimates and are, instead, classified as settlements.

The next land management type to be identified is *grazing land*. This is land that is used primarily for grazing animals and not as part of a rotation with other crops. This portion of the entity will primarily be comprised of *pastureland* (which is more intensively managed), and *rangeland* (which is typically less intensively managed and usually has a higher proportion of native species). Wetlands (including drained wetlands and hydric soils) and land managed as agroforestry should be included in this category if the primary use of the tract of land is for grazing livestock. There will be obvious overlap between grazing land and forestland methods where the land matches the definition of both uses. For example, if any active management is focused on enhancing tree growth and timber production, the user should identify these areas as forestland and the methods will need to be integrated to account for the impact of grazing management on the forestland. Grazing lands should be delineated as contiguous areas that are under a similar stocking rate and set of management practices, and the methods for grazing lands as presented in Chapter 3 should be followed. In addition, the GHG estimation methods associated with the grazing animals as presented in Chapter 5 should be followed. Development of an integrated tool that follows these methods will need to account for these management interactions.

Grazing Land:
A land-use category on which the plant cover is composed principally of grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing, and includes both pastures and native rangelands. This includes areas where practices such as clearing, burning, chaining, and/or chemicals are applied to maintain the grass vegetation. Savannas, some wetlands and deserts, and tundra are considered grazing land. Woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also classified as grazing land if they do not meet the criteria for forest land. Grazing land includes land managed with agroforestry practices such as silvopasture and windbreaks, assuming the stand or woodlot does not meet the criteria for forest land. Roads through grazing land, including interstate highways, State highways, other paved roads, gravel roads, dirt roads, and railroads are excluded from grazing land area estimates and are, instead, classified as settlements.

Forestland should be delineated as land that is used primarily for woody biomass production, whether for saw wood, pulp, biofuels, or other forest or woodland related industry, or land that is tree covered and managed for recreational or conservation purposes. This will include areas of agroforestry and silvopasture where the primary management objective on the landscape is forest-related production. An integrated tool would need to be flexible enough to also capture the impact of the additional cropping or grazing activities occurring on the parcel. Similarly, wetland areas that are wooded or forested and managed primarily as forests and woodlands will be considered in this category. Also, because harvesting is one of the major management practices in forestland and because harvested wood moves to several long-term carbon pools that undergo differing rates of decay, it is important that the methods account for emissions from HWPs, even though they may be moved outside of the boundary of the farm/ranch/forest operation.

The forestland methods are presented in Chapter 6 of this report. Tracts of forest should be delineated such that any given tract is made up of trees of a similar stand age and species mix, and that the entire tract is under one uniform set of management practices. On a given entity, there may be trees that exist outside of clearly defined forests, such as orchards and vineyards, farmstead shelterbelts and field windbreaks, and agroforestry practices. Even though these lands may not meet the definition of a forest, the carbon storage in the trees is likely significant. In some cases it may be useful to evaluate individual trees or small stands of trees (using methods presented in Chapter 6). In other cases, the estimation may require a blending of methods such as cropland methods from Chapter 3 with forest methods from Chapter 6.

Forestland:
A land-use category that includes areas at least 120 ft (36.6 m) wide and 1 acre (0.4 ha) in size with at least 10 percent cover (or equivalent stocking) by live trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 ft (36.6 m) and continuous length of at least 363 ft (110.6 m) to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 ft (36.6 m) wide or 1 acre (0.4 ha) in size; otherwise they are excluded from forest land and classified as settlements. Tree-covered areas in agricultural production settings, such as fruit orchards, or tree-covered areas in urban settings, such as city parks, are not considered forest land (Smith et al., 2009).

Wetland areas will fall into one of two categories: managed wetlands or natural, unmanaged wetlands. Many wetland areas may have already been delineated in one of the above categories, and their management will be captured through estimation for that category. If, however, there are wetland areas that have not already been included in the cropland, grazing land, or forestland delineations above, those should be identified here. A naturally occurring wetland that does not have active management being applied in order to increase productivity or provide other environmental services will not be included in the estimation of GHG fluxes. These natural, unmanaged wetlands should simply be included in the category of "other land" as defined below. Any wetland areas that are outside the boundaries of the defined areas mentioned above and where the land manager is actively applying management decisions in order to enhance productivity or provide environmental services should be delineated as a managed wetland and included. This report provides estimation methods in Chapter 4 for emissions from palustrine wetlands,[2] influenced by a variety of management options such as water table management, timber or other plant biomass harvest, and wetlands that are managed with fertilizer applications. Currently, there are insufficient data and therefore, the GHG fluxes will likely not be included in an entity's GHG estimation until adequate data exist to provide that estimation with a reasonable and measurable level of uncertainty.

Wetland:
A land-use category that includes land with hydric soils, native or adapted hydrophytic vegetation, and a hydrologic regime were the soil is saturated during the growing season in most years. Wetland vegetation types may include marshes, grasslands or forests. Wetlands may have water levels that are artificially changed, or where the vegetation composition or productivity is manipulated. These lands include undrained forested wetlands, grazed woodlands and grasslands, impoundments managed for wildlife, and lands that are being restored following conversion to a non-wetland condition (typically as a result of agricultural drainage). Provisions for engineered wetlands including storm water detention ponds, constructed wetlands for water treatment, and farm ponds or reservoirs are not included. Natural lakes and streams are also not included.

Settlements will fall into two broad categories: (1) land where the entity manager imposes management decisions; and (2) land where the manager does not regularly impose management decisions that impact carbon balances. Examples of settlement land that may be significant from a carbon management perspective would be developed livestock feed yards, dairy barns, poultry houses, manure piles, and manure or runoff lagoons. Examples of developed land where management is not of concern to carbon balances is homes, yards, driveways, workshops, roads, and parking areas. For purposes of the GHG flux estimation, only the areas with carbon management implications (e.g., animal housing, manure waste treatment areas) need to be identified within the spatial boundary delineation. These livestock and manure management methods are presented in Chapter 5 of this report. The remaining settlement lands without carbon management implications (e.g., roads and railroads) can simply be excluded from the spatial boundaries an entity chooses to account for within the settlement land-use category.

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[2] Palustrine wetlands are nontidal wetlands that are primarily composed of trees, shrubs, persistent emergent, emergent mosses or lichens, and all wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent. Palustrine wetlands must have an area less than 20 acres, not have active wave-formed or bedrock shoreline, have a maximum water depth of less than 2 m [6.6 ft], and have a salinity less than 0.5 percent (USGS, 2006).

Settlements:
A land-use category representing developed areas consisting of units of 0.25 acres (0.1 ha) or more that includes residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; parks within urban and built-up areas; and highways, railroads, and other transportation facilities. Also included are tracts of less than 10 acres (4.05 ha) that may meet the definitions for forest land, cropland, grassland, or other land but are completely surrounded by urban or built-up land, and so are included in the settlement category. Rural transportation corridors located within other land uses (e.g., forest land, cropland, and grassland) are also included in settlements.

Any land that is actively managed in such a way as to impact biomass growth or otherwise impact production-related GHG emissions should have been captured within the spatial boundaries defined for the land-use categories listed above. Any remaining land should be categorized as *other lands* or *unmanaged land* and will not be considered in the estimation of GHG fluxes. This includes the wetland and developed areas that were previously noted as not having active management—i.e., unmanaged wetlands and unmanaged settlements. It also includes any other areas within the entity boundary that represent barren, mined, abandoned, or otherwise unmanaged land—i.e., other land.

Land-cover change is simply a variation from year to year in what is growing on a parcel of land, such as rotating corn and soybean crops, and is not considered land-use change. In contrast, *land-use change* is a fundamental shift in purpose or production of a parcel, such as a shift from cropping to forest production or vice versa. Land-use change needs to be accounted for in the annual GHG flux, as the impact (either positive or negative) on biomass and soil carbon can be significant. These land-use change methods are presented in Chapter 7 of this report.

Other Land:
A land-use category that includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories, which allows the total of identified land areas to match the identified land base.

Animal production is not necessarily a spatially defined activity within the entity, but has to be considered as part of the physical boundary of the manager's operation. There are three main areas that need to be considered as important to estimating GHG emissions from an animal production system: methane emissions from the animals, methane and nitrous oxide emissions from management of manure, and any emissions impacts related to animal housing. Animal production in the chapter is discussed by animal system type, including beef, dairy, sheep, swine, and poultry. The collective noun for a group of animals typically varies by species, but for the purposes of this report, we will refer to any group of animals of the same animal type that are kept together under a common set of production management practices as a *herd*. Following this definition, the entity's manager may have several distinctly different herds that make up the entity. GHG emissions from animal production will vary greatly depending upon species (digestive processes), growth stage, diet, and manure storage and management. Timing is also a challenge in estimating emissions from the animal production sector, as emissions per animal change dramatically as a young animal grows and matures, as feedlot cattle are finished, or as dairy cows cycle between gestating and lactating. In some cases, it will likely be necessary for the user to estimate emissions for a herd using average weight, average age, and other representative characteristics to represent the herd population. In other cases, it will be necessary to generalize by seasons—manure management may be different in winter than summer, animal feed mixture may vary by season or by animal growth stage. Averaging and generalizing in this way should be adequate in capturing the information needed to provide a reasonable estimate of GHG emissions as long as the manager applies assumptions consistently across the herds and throughout the time under consideration. For example, assuming an average finish weight for feeder animals in the herd should provide a reasonable GHG estimate as long as the assumed weight does not change from year to year, unless a specific management decision (such as a change in animal diet) results in an actual change in finishing weight, in which case the change in averages would be appropriate. Specific methods for animal production systems are presented in Chapter 5 of the report. In some cases, such as manure applied to cropland, methods from Chapter 3 will be utilized as well.

Occasionally, physical boundaries will change over time. Whether a portion of a cropland field is converted to an animal feedlot, shelterbelt or riparian trees are planted onto former cropland, or abandoned land reverts to grazing land or forestland, these changes could result in the need for a new delineation of parcel boundaries or a dissection of one parcel into several parcels with more than one management strategy. For the portion of the parcel where this change has occurred, the land-use change methods (Chapter 7) will be used to estimate GHG fluxes.

Figure 2-1 can be used to help landowners determine the land use category for their land area, according to the definitions above.

2.1.2.2 Temporal Boundaries

Temporal issues include such considerations as the frequency of the reported estimates, the treatment of activities that occur within an accounting period but have long-term implications for carbon balances (e.g., changes in soil carbon following a change in tillage practices), and how to account for short-term management or short-term adjustments to long-term management decisions. Also significant is how to address movement of spatial boundaries over time and with land-use change. This section will attempt to resolve some of these temporal issues around GHG emission estimation and reporting.

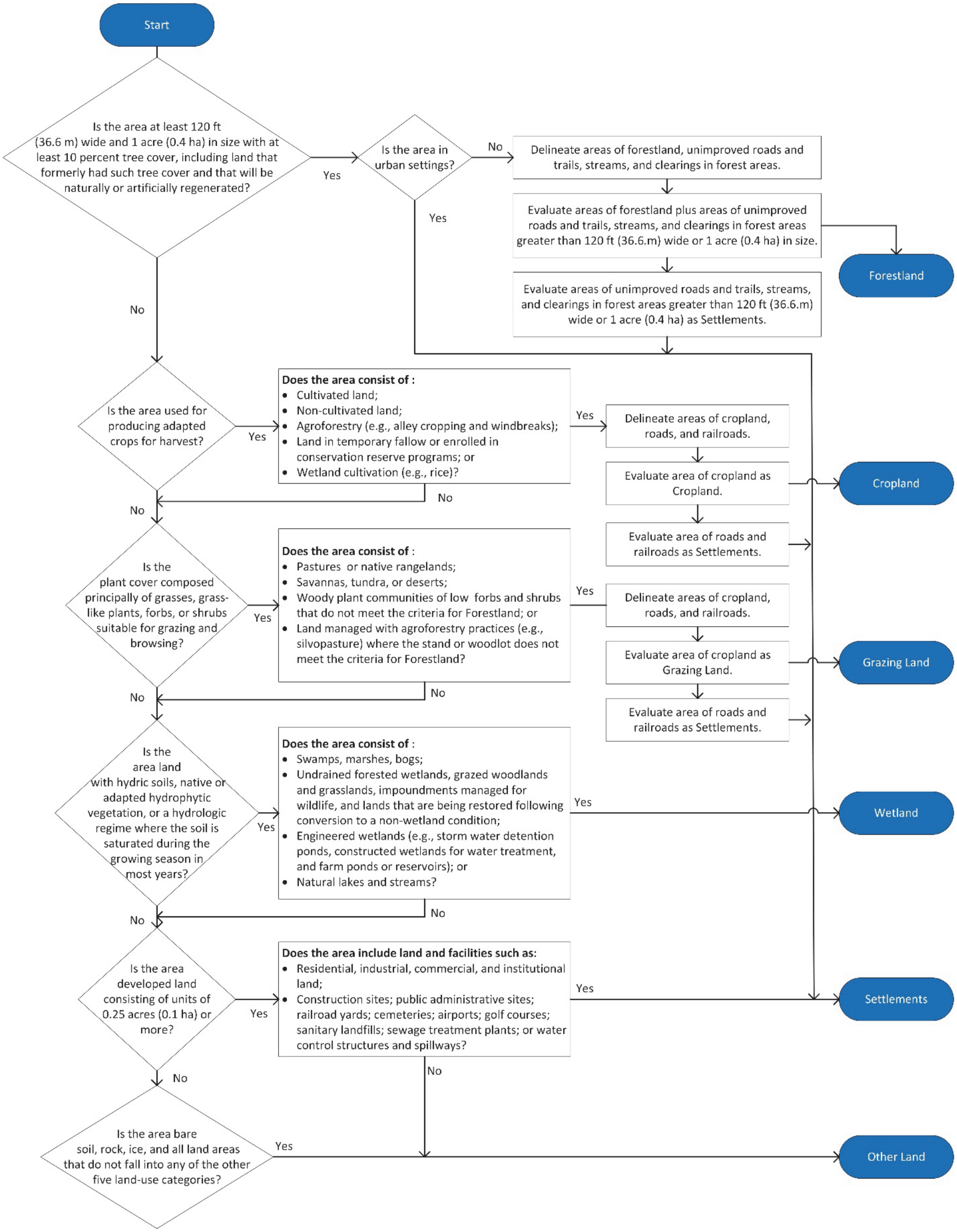
The methods reported here are intended to provide a means of annual accounting and reporting of GHG fluxes. Annual changes in some emissions are easily quantified, but for others it is much more difficult. Carbon stored in trees, for example, may need to be estimated over a longer period, with the change then converted to an annualized estimate.

The report methodologies assume an accounting period of one calendar year (e.g., 365 days) when estimating annualized emissions in a particular sector or source category.

Management decisions also are significant to the accounting time horizon. For example, a forest management plan might call for timber harvest or thinning. In the year of harvest, the annual accounting will reflect a loss of standing live and/or standing dead carbon stocks, yet in the longer term management strategy, the net result could be an increase in total carbon stocks. If a land manager has a management plan that prescribes forest thinning, but then harvests more aggressively than the plan, consideration should be given as to whether this constitutes a change in forest management, which would be discussed in the forest management methods (see Chapter 6).

There are also times when management has to take corrective action or temporarily deviate from a long-term management plan. This could be the case where a cropland manager has adopted a no-till management strategy, but after several years has to use tillage one year because of weather, pests, or other extenuating circumstances. In this case, the methods will ideally be sensitive enough to capture the GHG impact of the deviation from the management plan.

Figure 2-1: Decision Tree for Determining Land-Use Category for Land Areas



2.1.2.3 Activity Boundaries

It is important to distinguish which activities within an entity are subject to accounting. This accounting system is focused on land-based activities such as tillage and harvesting, and not on emissions of GHGs that are related to fossil fuel use. Thus, emissions from tractor fuel or fuel used for crop drying are not counted, nor are the energy inputs required to manufacture fertilizer or farm tools, or to heat farm buildings—i.e., indirect GHG emissions (see Chapter 1). However, as mentioned in Chapter 1, where there are obvious changes in the level of combustion due to a change in practices, that change is qualitatively discussed. For example, a shift from conventional tillage to no till can result in a large reduction in fuel consumption because of fewer trips across the field. These relationships are noted qualitatively in the report, but quantitative methods are not proposed. Methods for quantifying emissions from stationary or mobile combustions are available from other Federal agencies.

As previously mentioned, the methods in this report do not constitute a life-cycle assessment for two primary reasons. First the activity boundaries do not include emissions from fossil-fuel use. Second, the temporal boundaries are focused on annual reporting and do not encompass the range of activities such as capital investment, material supplies, and disposal.

2.1.2.4 Material Boundaries

Material boundaries include the GHGs that are to be considered in the estimation and should also delineate what sources of those gases are included and what are excluded. Also included in this section is a discussion of the global warming potentials (GWPs) used throughout the report. It is important to determine up front which gases are included and which are not. It is also important to determine how much freedom the user has in what is estimated and where these boundaries lie in order to ensure that a change in management that reduces emissions in one sector does not inadvertently cause emissions to rise outside of the boundaries being reported.

The report includes estimation methodologies covering the GHG emissions from the croplands and grazing lands, wetlands, animal production, forestry, and land-use change sectors. Within these sectors and source categories, emissions and removals of the main GHGs—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)—are accounted for. It should be noted that carbon sequestration (i.e., increases in carbon stocks) is estimated in terms of carbon dioxide equivalents (CO_2-eq). It should also be noted that the animal production chapter includes discussion of ammonia (NH_3), as this is an important precursor to N_2O emissions from manure management. Estimating NH_3 emissions is beyond the scope of this report—NH_3 is not considered a GHG—but since NH_3 is significant as a precursor to N_2O, understanding changes in NH_3 emissions resulting from changes in management is important.

Emissions and sequestration values are presented in this report in terms of the mass (not volume) of each gas, using metric units (e.g., metric tons of methane). In the integrated tool, the masses of each gas will be converted into CO_2 equivalent units using the GWPs for each gas in the International Panel on Climate Change (IPCC) Second Assessment Report.

A GWP is an index used to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric conditions. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a GHG to that from the emissions of one kilogram of CO_2 over a defined period of time, such as 100 years. Emissions in terms of CO_2 equivalents (CO_2-eq) are estimated by multiplying the mass of a particular GHG (e.g., CH_4, N_2O) by the respective GWP for that particular GHG. The GWPs used in this report are shown in Table 2-1 below.

The methods in this report focus primarily on the direct emissions resulting from management decisions made within the boundaries of the entity—e.g., within the farm and forest gate. The indirect emissions related to inputs into the entity are not considered. The reason for this is that those emissions would likely be reported by the manufacturer producing the inputs. If one were conducting a full life-cycle assessment, these emissions would need to be included, but for purposes of the emissions being estimated here we focus primarily on the emissions resulting within the spatial boundary of the entity. The one notable exception that is accounted for is when management decisions on the operation have a specific related influence on emissions leaving the entity's boundary. An example of this is indirect emissions such as nitrogen that is applied within the operation but then carried offsite via erosion or leaching and contributes to N_2O emissions offsite. Another example to consider is harvested commodities. In the case of grains or other agricultural commodities, the product is assumed to be consumed within a relatively short amount of time, resulting in no net gain or loss related to GHG accounting. HWPs are somewhat different, as much of that harvest will end up in long-term carbon pools either as structures, furniture, or other wood products, or in landfills. This report does provide a discussion of N_2O losses that result from erosion and leaching of fertilizer nitrogen and the carbon pools related to the fate of HWPs.

Table 2-1: Global Warming Potentials Used in the Report

Species	Chemical Formula	Lifetime (years)	GWP[a]
Carbon dioxide	CO_2	Variable	1
Methane	CH_4	12±3	21
Nitrous oxide	N_2O	120	310

[a] GWPs used are 100-year time horizon, in accordance with the IPCC Second Assessment Report (IPCC, 2007).

2.2 Review of Relevant Current Tools and Methods

This section provides an overview of the current estimation methods or approaches an entity could use to estimate GHG emissions and sinks on their property. This overview is followed by a summary of each sector's proposed methodologies for entity GHG estimations.

There are several approaches that a farmer or landowner can use to estimate GHG emissions at an entity scale, and each approach gives varying accuracy and precision. The most accurate way of estimating emissions is through direct measurement, which often requires expensive equipment or techniques that are not feasible for a single landowner or manager. On the other hand, lookup tables and estimation equations alone often do not adequately represent local variability or local conditions. This report attempts to delineate methods that balance user-friendliness, data requirements, and scientific rigor in a way that is transparent and justified.

The following approaches were considered for these guidelines:

- Basic estimation equations – Involve combinations of activity data[3] with parameters and default emission factors.[4] Any default parameters or default emission factors (e.g., lookup tables) are provided in the text, or if substantial in length, in an accompanying compendium of data.

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[3] Activity data are data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time (IPCC, 1997).

[4] Emission factor is defined as a coefficient that quantifies the emissions or removals of a gas per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions (IPCC, 2006).

- Models – Use combinations of activity data with parameters and default emission factors. The inputs for these models can be ancillary data[5] (e.g., temperature, precipitation, elevation, and soil nutrient levels that may be pulled from an underlying source), biological variables (e.g., plant diversity), or site-specific data (e.g., number of acres, number of animals). The accuracy of the models is dependent on the robustness of the model and the accuracy of the inputs.
- Field measurements – Actual measurements that a farmer or landowner would need to take to more accurately estimate the properties of the soil, forest, or farm to estimate actual emissions. Measuring actual emissions on the land requires special equipment that monitors the flow of gases from the source into the atmosphere. This equipment is not readily available to most entities, so more often field measurements are incorporated into other methods described in this section to create a hybrid approach. A field measurement such as a sample mean tree diameter could be incorporated into other models or equations to give a more accurate input.
- Inference – Uses State, regional, or national emissions/sequestration factors that approximate emissions/sequestration per unit of the input. The input data is then multiplied by this factor to determine the total onsite emissions. This factor can have varying degrees of accuracy and often does not capture the mitigation practices on the farm or the unique soil conditions, climate, livestock diet, livestock genetics, or any farm-specific characteristics, although they can be developed with specific soil types, livestock categories, or climactic regions.
- Hybrid estimation approaches – An approach that uses a combination of the approaches described above. The approach often uses field measurements or models to generate inputs used for an inference-based approach to improve the accuracy of the estimate.

2.3 Selection of Most Appropriate Method and Mitigation Practices to Include

In drafting the report, a number of selection criteria were considered (e.g., transparency, consistency, comparability, completeness, accuracy, cost effectiveness, ease of use). A description of each appears below:

- Transparency – The assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The transparency of inventories is fundamental to the success of the process for the communication and consideration of information.
- Consistency – The methods used to generate inventory estimates should be internally consistent in all its elements and the estimates should be consistent with other years. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. Consistency is an important consideration in merging differing estimation techniques from diverse technologies and management practices.
- Comparability – For the guidelines to be comparable, the estimates of emissions and sequestration being reported by one entity are comparable to the estimates being reported by others. For this purpose, entities should use common methodologies and formats for

[5] Ancillary data are additional data necessary to support the selection of *activity data* and *emission factors* for the estimation and characterization of emissions. Data on soil, crop or animal types, tree species, operating conditions, and geographical location are examples of ancillary data.

estimating and reporting inventories. Consequently, in general, the methods specify one method for any technology or management practice (i.e., methods suggested in this report do not allow users to select from a menu of methods).

- Completeness – The methods must account for all sources and sinks, as well as all GHGs to the greatest extent possible. Completeness also means full coverage of sources and sinks under the control of the entity. Completeness is an important consideration to be balanced with ease of use in reporting appropriately for an entity that may have a minor activity or an activity with severely limited data availability.
- Accuracy – A relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable.
- Cost effectiveness – A measure of the relative costs and benefits of additional efforts to improve inventory estimates or reduce uncertainty. For example there is a balance between the relative costs and benefits of additional efforts to reduce uncertainty.
- Ease of use – A measure of the complexity of the user interface and underlying data requirements.

The working groups developed the following selection criteria for the mitigation practices that could be included in the methods:

1. The science reflects a mechanistic understanding of the practice's influence on an emission source.
2. Published research supports a reasonable level of repeatability/consistency (can use international studies if similar management, climate, and soils as U.S. conditions).
3. There is general agreement that at least the sign and range of responses are reasonably well understood.
4. There is consensus of the authors that the practice can be adequately included. To reach consensus, the authors discussed issues such as: Would leaving a mitigation practice out make the report incomplete? Is there strong enough evidence that the method will hold up for this practice for at least the next five years?

There were mitigation practices that did not fulfill these criteria, and those practices were cited as areas that require more research in order to fully understand the effect of changes in the practice to GHG emissions. These research gaps are intended to become areas that USDA, non-governmental organizations, universities, and other research institutions will consider as important areas to focus agriculture and forestry climate-change research priorities. Other topics, such as albedo effects, were not considered. Currently, with the exception of urban areas, albedo effects are highly variable and are difficult to reliably quantify.

2.4 Overview of Sectors

This report covers emissions sources and sinks from croplands/grazing lands, managed wetlands, animal production systems, and forestry, along with changes in land use. Figure 2-2 can be used to help landowners determine which chapter can be used to estimate their GHG sources and sinks from their land.

Figure 2-2: Decision Tree for Determining Which Methods to Follow in This Report

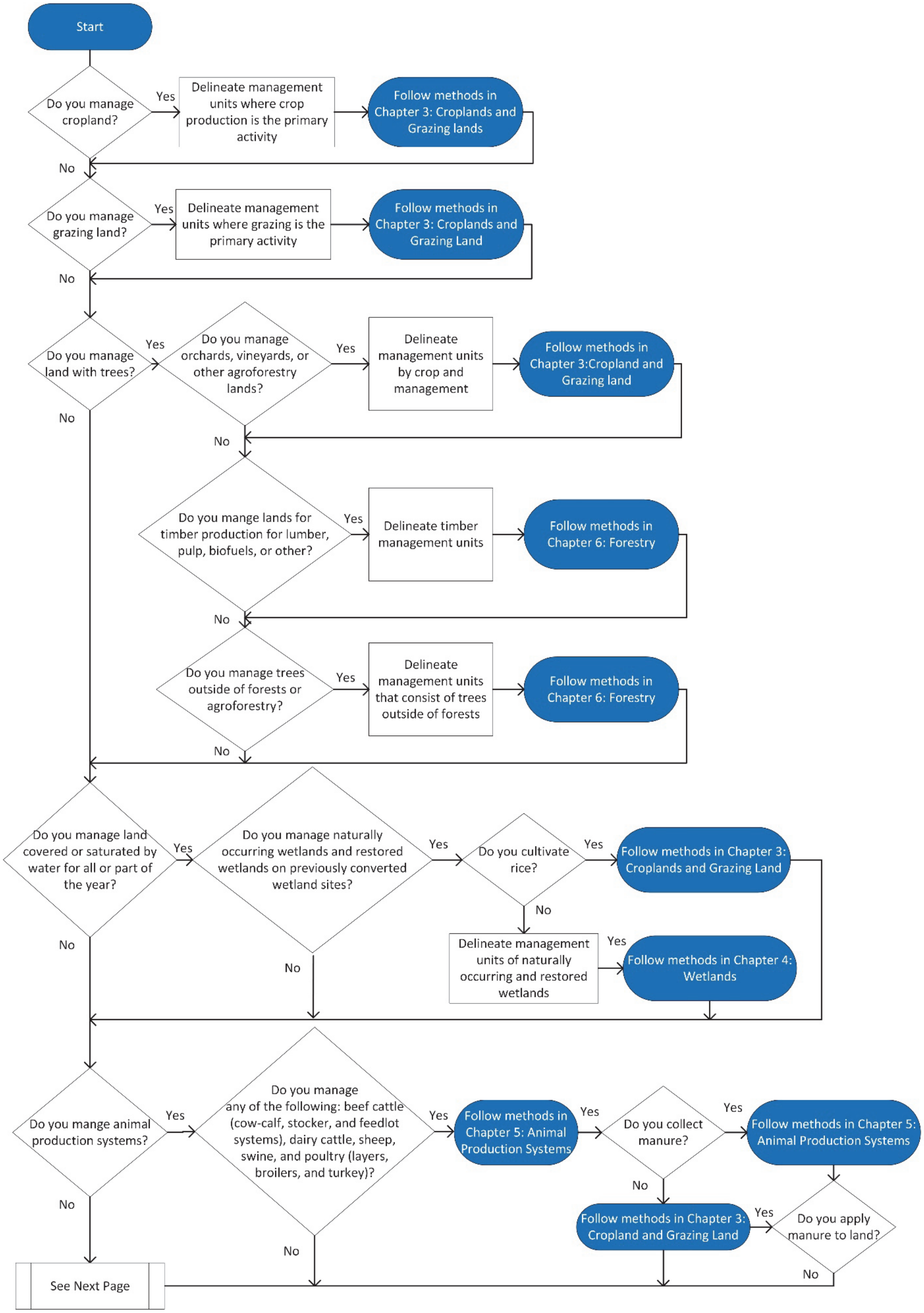
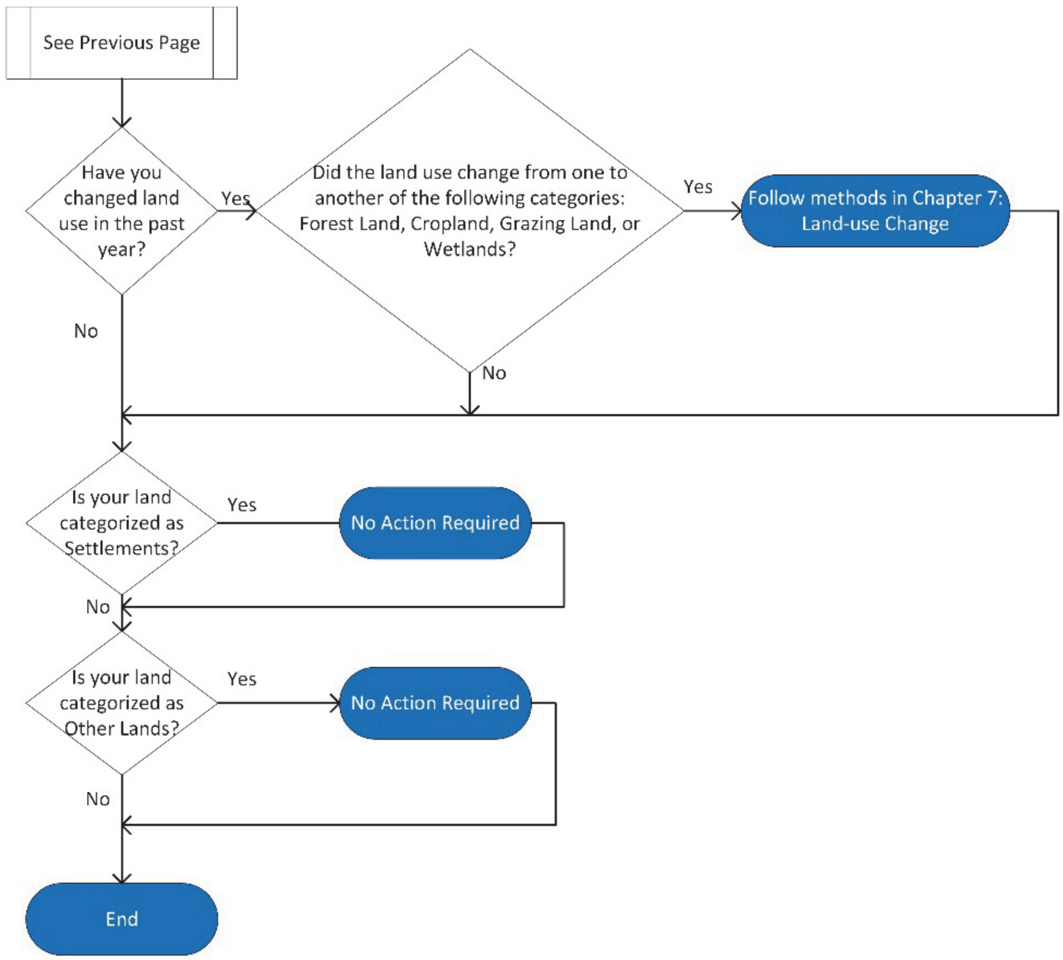


Figure 2-2: Decision Tree for Determining Which Methods to Follow in This Report (continued)



*Methods are not provided for land areas categorized as Settlements or Other Lands

The following sections provide an overview of the sectors covered in this report. For each sector, the emission sources and sinks are introduced as well as the management practices impacting GHG emissions.

2.4.1 Croplands and Grazing Lands

Croplands include all systems used to produce food, feed, and fiber commodities, in addition to feedstocks for bioenergy production. Most U.S. croplands are drylands (irrigated or unirrigated); rice and a few other crops are grown in wetlands. Some croplands are set aside in the Conservation Reserve Program. Croplands also include agroforestry systems that are a mixture of crops and trees, such as alley cropping, shelterbelts, and riparian woodlots. Grazing lands are systems that are used for livestock production and occur primarily on grasslands. Grasslands are composed principally of grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing; they include both pastures and native rangelands (EPA, 2011). Savannas, some wetlands and deserts, and tundra can be considered grazing lands if used for livestock production. Grazing land systems include managed pastures that may require periodic management to maintain the grass vegetation and native rangelands that typically require limited management to maintain.

Cropland and grazing lands are significant sources of CO_2, N_2O, and CH_4 emissions and can also be a sink for CO_2 and CH_4 (U.S. EPA, 2011). N_2O emissions from soils are influenced by land use and management activity, particularly nitrogen application. Land use and management also influence carbon stocks in biomass, dead biomass, and soil pools. Crop and grazing land systems can be either a source or sink for CO_2, depending on the net changes in these carbon pools. The main influences on nitrogen use efficiency and N_2O emissions are fertilizer rate, timing, placement, and nitrogen source. Tillage intensity, cropping intensity, and the use of crop rotation can have significant effects on soil carbon stocks.

Other management activities also affect GHG emissions from soils. Irrigation can impact CH_4 and N_2O emissions as well as carbon stocks. Burning decreases biomass carbon stocks and also soil organic carbon stocks due to decreased carbon input to the soil system. Burning will also lead to emissions of CH_4 and N_2O and other gases (CO, NO_x) that are GHG precursors. CH_4 can be removed from the atmosphere through the process of methanotrophy in soils, which occurs under aerobic conditions and generally in undisturbed soils. CH_4 is produced in soils through the process of methanogenesis, which occurs under anaerobic conditions (e.g., wetland soils used for production of rice). Both processes are driven by the activity of micro-organisms in soils, but the rate of activity is influenced by land use and management.

The influence of crop and grazing land management on GHG emissions is not typically the simple sum of each practice's effect. The influence of one practice can depend on another practice. For example, the influence of tillage on soil carbon will depend on residue management. The influence of nitrogen fertilization rates can depend on fertilizer placement and timing. Because of these interconnections, estimating GHG emissions from crop and grazing land systems will depend on a complete description of the practices used in the operation, as well as ancillary variables such as soil characteristics and weather or climate conditions. It is also important to note that trends in GHG emissions associated with a change in crop and grazing land management can be reversed if the landowner reverts to the original practice. For example, a farmer might switch from conventional tillage to no-till for 10 years and see an increase in soil carbon sequestration; if, however, the farmer then reverts to conventional tillage, the gains in soil carbon will be quickly lost as the stored soil carbon is released back into the atmosphere as CO_2, negating the GHG mitigation of the previous 10 years. However, reversals will not negate the GHG mitigation for CH_4 or N_2O that occurred prior to the reversion. If emissions are reduced for CH_4 or N_2O, the emission reduction is permanent and cannot be changed by subsequent management decisions.

The text box, Management Practices Impacting GHG Emissions from Croplands and Grazing Lands, lists the most significant mitigation practices discussed in Chapter 3. Additional mitigation practices are discussed in the chapter, but these often have sparse or conflicting evidence in support of their mitigation effects. Therefore, the text box lists the more robustly supported practices.

Management Practices Impacting GHG Emissions from Croplands and Grazing Lands

- Nutrient Management (Synthetic and Organic)
- Tillage Practices
- Crop Rotations and Cropping Intensity
- Irrigation
- Residue Management
- Set-Aside/Reserve Cropland
- Wetland Rice Cultivation
- Livestock Grazing Practices
- Forage Options
- Silvopasture

2.4.2 Wetlands

Wetlands occur across the United States on many landforms, particularly in floodplains and riparian zones, inland lacustrine, glaciated outwash, and coastal plains. The National Wetlands Inventory broadly classifies wetlands into five major systems, including (1) marine, (2) estuarine, (3) riverine, (4) lacustrine, and (5) palustrine (Cowardin et al., 1979). These systems are further classified by major vegetative life form. For example, forested wetlands are often classified as palustrine-forested. Similarly, most grassland wetlands are classified as palustrine wetlands with emergent vegetation (e.g., grasses and sedges). Wetlands also vary greatly with respect to groundwater and surface water interactions that directly influence hydroperiod, water chemistry, and soils (Cowardin et al., 1979; Winter et al., 1998). All these factors along with climate and land-use drivers influence overall carbon balance and GHG flux.

Grassland and forested wetlands are subject to a wide range of land use and management practices that influence the carbon balance and GHG flux (Faulkner et al., 2011; Gleason et al., 2011). For example, forested wetlands may be subject to silvicultural prescriptions and intensity of management, and hence, the carbon balance and GHG emissions should be evaluated on a rotation basis. In contrast, grassland wetlands may be grazed, hayed, or directly cultivated to produce a harvestable commodity. All these manipulations influence the overall GHG flux. This report will focus primarily on restoration and management practices associated with riverine and palustrine systems in forested, grassland, and riparian ecosystems; although other major wetlands systems are significant in the global carbon cycle (e.g., estuarine), these wetlands systems have received the most attention in terms of implementation of restoration and management practices to conserve wetlands habitats and sustain ecosystems services (Brinson and Eckles, 2011). Wetlands that have been drained for a commodity production, such as annual crops, are not considered wetlands in this guidance. Therefore, management of drained wetlands is addressed in other sections of the guidance, such as in Chapter 3.

Wetland emissions are largely controlled by the degree of water saturation as well as climate and nutrient availability. In aerobic conditions, common in most upland wetland ecosystems, decomposition releases of CO_2, and CH_4 emissions are more prevalent in anaerobic conditions. Typically, wetlands are a source of CH_4, with estimated global emissions of 55 to 150 million metric tons CH_4 per year (Blain et al., 2006). N_2O emissions from wetlands are typically low, unless an outside source of nitrogen is entering the wetland. If wetlands are drained, N_2O emissions are largely controlled by the fertility of the soil. Wetland drainage results in lower CH_4 emissions and an increase in CO_2 emissions due to oxidation of soil organic matter and an increase in N_2O emissions in nutrient rich soil. On the other hand, the creation of wetlands generates higher levels of CH_4 and lower levels of CO_2 (Blain et al., 2006).

Management Practices Impacting GHG Emissions from Wetlands

- Silvicultural Water Table Management
- Forest Harvesting Systems
- Forest Regeneration Systems
- Fertilization
- Conversion to Open Wetland
- Forest Type Change
- Water Quality Management
- Wetland Management for Waterfowl
- Constructed Wetlands for Wastewater Treatment
- Land-Use Change to Wetlands
- Actively Restoring Wetlands
- Actively Restoring Scrub-Grass Wetlands
- Constructing Wetlands
- Passive Restoration of Wetlands

Biomass carbon can change significantly with management of wetlands, particularly in peatlands, forested wetlands, or changes from forest to wetlands dominated by grasses and shrubs or open water. Peatlands cover approximately 400 million hectares or three percent of the global land surface, accounting for 450 billion metric tons of stored carbon (Couwenbert, 2009). Emissions from peatland degradation and fires are estimated at 2 billion metric tons of CO_2-eq per year (IPCC, 2011). In forested wetlands, there can also be significant carbon in dead wood, coarse woody debris, and fine litter. Harvesting practices will also influence the carbon stocks in wetlands to the extent that the wood is collected for products, fuel, or other purposes. Wetlands are also a source of N_2O emissions, primarily because of nitrogen runoff and leaching into groundwater from agricultural fields and/or livestock facilities. N_2O emissions from wetlands due to nitrogen inputs from surrounding fields or livestock facilities are considered an indirect emission of N_2O (de Klein et al., 2006). Direct N_2O emissions can also occur if management practices include nitrogen fertilization of the wetlands.

The text box, Management Practices Impacting GHG Emissions from Wetlands, lists the management practices in wetlands that have an influence on GHG emissions (CH_4 or N_2O) or carbon stock changes, and will be covered in more detail later in the report. Individual sections will deal with different types of wetlands including forested, grassland, and constructed wetlands that could occur in agricultural and forestry operations. The methods are restricted to estimation of emissions on palustrine wetlands that are influenced by a variety of management options such as water table management, timber or other plant biomass harvest, and wetlands that are managed with fertilizer applications.

2.4.3 Animal Production

GHG emissions from animal production systems consist of three main categories: enteric fermentation, housing, and manure management. The three categories are described in the sections that follow. Discussion about enteric fermentation and housing are addressed together in this report.

2.4.3.1 Enteric Fermentation and Housing

Enteric fermentation refers to the methane emissions resulting from animal digestive processes, while housing emissions refer to GHG emissions from manure that is stored within the housing structure (i.e., manure stored under a barn floor). GHG emissions arising from manure stored in housing have similar emissions to manure that is managed in stockpiles. More discussion on housing manure emissions can be found in Section 2.4.3.2 and Chapter 5.

For enteric fermentation, CH_4-producing micro-organisms, called methanogens, exist in the gastrointestinal tract of many animals. Ruminant animals (hoofed mammals) that have three or four chambered stomachs (and chew cud as a part of the digestive process), produce much more CH_4 than do other animals because of the presence and fermentative capacity of the rumen (the first stomach in a ruminant animal).

In the rumen, CH_4 formation is a disposal mechanism by which excess hydrogen from the anaerobic fermentation of dietary carbohydrate can be released. Control of hydrogen ions through methanogenesis assists in maintenance of an efficient microbial fermentation by reducing the partial pressure of hydrogen to levels that allow normal functioning of microbial energy transfer enzymes (Martin et al., 2010). CH_4 can also arise from hindgut fermentation, but the levels associated with hindgut fermentation are much lower than those of foregut fermentation. Although animals produce CO_2 through

Management Practices Impacting GHG Emissions from Enteric Fermentation and Housing

- Dietary Fat
- Grain Source, Grain Processing, Starch Availability
- Feeding Co-Product Ingredients
- Roughage Concentration and Form
- Level of Intake
- Feed Additives and Growth Promoters
- Novel Microorganisms and Their Products
- Genetics

respiration, the only gas of concern in enteric fermentation processes is CH_4. In field studies, respiration chambers equipped with N_2O and NH_3 analyzers have confirmed that enteric fermentation does not result in the production of N_2O or NH_3 (Reynolds et al., 2010).

The text box, Management Practices Impacting GHG Emissions from Enteric Fermentation and Housing, lists several of the practices that can modify enteric fermentation emissions. Most of the practices relate to diet composition. These practices are covered in greater detail in Chapter 5.

2.4.3.2 Manure Management

Storage of animal manure (dung and urine) is a popular management practice because it reduces the need to buy commercial fertilizer, allows for more control over manure application, and has lower demands on farm labor. The treatment and storage of manure in management systems contributes to the GHG emissions of the agricultural sector. Anaerobic conditions, as found in many long-term storage systems, produce CH_4 through anaerobic decomposition. N_2O is produced either directly, as part of the nitrogen cycle through nitrification and denitrification, or indirectly, as a result of volatilization of nitrogen as NH_3 and nitrogen oxides (NO, NO_2, or NO_3) and runoff during handling.

Animal manure can be classified as:

- Slurry, where the dry matter is greater than 10 percent;
- Solid, where the dry matter is greater than 15 percent; or
- Liquid, where the dry matter is lower than 10 percent.

The four solid manure storage/treatment practices are: (1) temporary stack; (2) long-term stockpile; (3) composting; and (4) thermo-chemical conversion. The eight main liquid manure storage/treatment practices are: (1) anaerobic digestion; (2) nutrient removal; (3) anaerobic lagoon/runoff holding pond/storage tanks; (4) aerobic lagoon; (5) constructed wetland; (6) sand-manure separation; (7) combined aerobic treatment system; and (8) solid-liquid separation. Greater analysis of each of these systems is provided in Chapter 5.

Management Practices Impacting GHG Emissions from Manure Management

- Thermo-Chemical Conversion
- Anaerobic Digestion
- Liquid Manure Storage and Treatment-Sand-Manure Separation
- Liquid Manure Storage and Treatment–Solid-Liquid Separation

The magnitude of CH_4 and N_2O emissions that result from animal manure is dependent largely on the environmental conditions that the manure is subjected to. CH_4 is emitted when oxygen is not available for bacteria to decompose manure. Storage of manure in ponds, tanks, or pits, as is typical with liquid/slurry flushing systems, promote anaerobic conditions and the formation of CH_4. Storage of solid manure in stacks or dry lots or deposition of manure on pasture, range, or paddock lands tend to result in more oxygen-available conditions, and little or no CH_4 will be formed. Other factors that influence CH_4 generation include the ambient temperature, moisture content, residency time, and manure composition (which is dependent on the diet of the livestock, growth rate, and type of digestive system) (U.S. EPA, 2011).

The production of N_2O from managed livestock manure depends on the composition of the manure and urine, the type of bacteria involved, the oxygen and liquid content of the system, and the environment for the manure after excretion (U.S. EPA, 2011). N_2O occurs when the manure is first subjected to aerobic conditions where NH_3 and organic nitrogen are converted to nitrates and nitrites (nitrification), and if conditions become sufficiently anaerobic, the nitrates and nitrites can be denitrified (reduced to nitrogen oxides and nitrogen gas) (Groffman et al., 2000). N_2O is an intermediate product of both nitrification and denitrification and can be directly emitted from soil as a result of either of these processes. Dry waste handling systems are generally oxygenated but have pockets of anaerobic conditions from decomposition; these systems have conditions that are most conducive to the production of N_2O (USDA, 2011).

Some manure management systems can effectively mitigate the release of GHG emissions from livestock manure. The text box, Management Practices Impacting GHG Emissions from Manure Management, lists several of the practices that can modify manure management emissions.

2.4.4 Forestry

Forest systems represent a significant opportunity to mitigate GHGs through the sequestration and temporary storage of forest carbon stocks. Forests remove CO_2 from the atmosphere through photosynthesis and store carbon in forest biomass (e.g., stems, root, bark, leaves). Respiration releases CO_2 to the atmosphere. Net forest carbon stocks increase over time when carbon sequestration during photosynthesis exceeds carbon released during respiration. Other GHGs are also exchanged by forest ecosystems—e.g., CH_4 from microbial communities in forest soil and N_2O from fertilizer use.

Harvesting forests releases some sequestered carbon to the atmosphere, while the remaining carbon passes in HWPs, the fate of which (e.g., combustion for energy, manufacture of durable wood products, disposal in landfills) determines the rate at which the carbon is returned to the atmosphere.

There are many forestry activities (i.e., management practices) relevant to reducing GHG emissions and/or increasing carbon stocks in the forestry sector including establishing and/or re-establishing forest, avoided forest clearing, and forest management. More information on each is included below.

The Chapter 6 describes methods for the various source categories contributing to the GHG flux from forests. These source categories include forest carbon accounting—e.g., live trees, understory, standing dead, down dead wood, forest floor or litter, forest soil organic carbon—establishing, re-establishing, and clearing forest, forest management, HWPs, urban forestry, and natural disturbances (e.g., forest fires). This subsection briefly describes these source categories. Descriptions of the current tools and methods used to estimate GHG flux from these source categories is discussed later in Chapter 6.

Management Practices Impacting Net GHG Emissions from Forestry

- Establishing and Reestablishing Forest
- Avoiding Clearing Forest
- Stand Density Management
- Site Preparation Techniques
- Vegetation Control
- Planting
- Natural Regeneration
- Fertilization
- Selection of Rotation Length
- Harvesting and Utilization Techniques
- Fire and Fuel Load Management
- Reducing the Risk of Emissions from Natural Disturbances
- Short Rotation Woody Crops

Forest Carbon. Accounting for forest carbon (i.e., forest biomass) typically divides the forest into forest carbon pools—e.g., live trees, understory, standing dead, down dead wood, forest floor or litter, forest soil organic carbon—the definitions for which are developed around a common set in use by a number of publications, which are further outlined in Chapter 6. The methods for estimating the key forest carbon pools are well developed and fairly standard.

Establishing, Re-Establishing, and Clearing Forest. In addition to forestland remaining forestland, there are three distinct processes that can significantly alter forest carbon stocks, and are termed:

forest establishment (i.e., afforestation), forest re-establishment (i.e., reforestation), and forest clearing (i.e., deforestation). Each of these processes alters stocks of carbon in aboveground and belowground carbon pools. Establishment involves the intentional planting (or allowing the natural process of secondary succession) on land that was not previously forest. Reestablishment is returning land that was recently forest back into forest. In either case, establishing forest will generally increase the carbon stocks in aboveground and belowground carbon pools over time. Forest clearing is the removal and/or conversion of a forest system into another land cover (cropland, grazing land, etc.) and is the most significant source of GHG emissions from forests.

Forest Management. Forest management describes the range of practices employed by landowners to meet their objectives (e.g., timber production) while satisfying biological, economic, and social constraints. A number of the practices used by forest managers to achieve their objectives impact the carbon dynamics in forests either by enhancing forest growth or accelerating the loss of forest carbon. The management practices include: stand density management (e.g., under planting, pre-commercial and commercial thinning); site preparation techniques (e.g., mechanical methods, chemical application, prescribed burning); vegetation control; planting (e.g., planting density, species selection, genetic improvement); natural regeneration; fertilization (e.g., nitrogen and phosphorous fertilizer application); selection of rotation lengths; harvesting and utilization techniques; fire and fuel load management; reducing the risk of emissions from pests and disease; and establishing biomass plantations (i.e., short rotation woody crops).

Harvested Wood Products. A proportion of the wood carbon harvested from forests ends up in solid wood, paper, or other products, which are collectively known as HWPs. The carbon contained in these products can remain stored for years or decades depending on the end use, and may eventually be combusted, decay, or be diverted to landfills.

Urban Forestry. Urban (or urban community) forest describes the population of trees within an urban area. Urban trees directly store atmospheric carbon as woody biomass and also affect local climate (e.g., secondary effects). The maintenance of urban trees also affects GHG emissions in urban areas (i.e., indirect effects).

Natural Disturbances. Natural disturbances in forest systems (e.g., forest fires, pests and disease, storms) can significantly impact forest carbon stocks either directly in the case of combustion from forest fires or indirectly by converting live biomass to dead or converting standing trees to downed dead wood and accelerating decomposition.

The text box, Management Practices Impacting Net GHG Emissions from Forestry, lists the management practices relevant to reducing GHG emissions and/or increasing carbon stocks in the forestry sector including establishing and/or reestablishing forest, avoiding forest clearing, and improving forest management.

2.5 Land-Use Change

Converting land parcels from one land-use category to another can have a significant effect on a parcel's carbon stocks. For example, carbon stock gains can be realized by converting cropland soils to wetlands or forestland, while carbon stock losses often result from a conversion from forestlands to grazing lands. A land-use categorization system that is consistent and complete (both temporally and spatially) is needed in order to assess land use and land-use change status within an entity's boundaries. All of the land within an entity's boundary should be classified according to the following land-use types: cropland, grazing land, forestland, wetland, settlements (e.g., residential and commercial buildings), and other land (e.g., bare soil, rock); see definitions provided above. Individual parcel areas should sum to the total land area before and after land-use change.

In many cases, the methods proposed to estimate contributions to the GHG flux resulting from land-use change are the same as those used to estimate carbon stock changes in the individual cropland and grazing land, wetland, and forestry chapters; although, in specific cases, guidance is also provided on reconciling carbon-stock estimates between discrete data sets and estimation methods (e.g., reconciling forest soil carbon estimates and cropland soil carbon estimates for land-use change from forestland to cropland). The methods for quantifying GHG flux from land-use change are intended for use at the entity scale on lands managed to enhance the production of food, feed, fiber, and renewable energy. Methods are currently not provided for estimating emissions from energy used when converting land use from one category to another. Neither are methods provided for land-use change from settlements or the "other land" category to cropland, grazing land, wetland or forestland. The methods have been developed for U.S. conditions and are considered applicable to agricultural and forestry production systems in the United States. This subsection briefly describes the source categories covered. Further descriptions of the current tools and methods used to estimate GHG flux from these source categories are discussed later in Chapter 7.

Annual Change in Carbon Stocks in Dead Wood and Litter Due to Land Conversion. Live and dead biomass carbon stocks and soil organic carbon constitute a significant carbon sink in many forest and agricultural lands. Following land-use conversion, the estimation of dead biomass carbon stock changes during transition periods requires that the area subject to land-use change on the entity's operation be tracked for the duration of a 20-year transition period.

Change in Soil Organic Carbon Stocks for Mineral Soils. Soil organic carbon stocks are influenced by land-use change (Aalde et al., 2006) due to changes in productivity that influence carbon inputs and to changes in soil management that influence carbon outputs (Davidson and Ackerman, 1993; Ogle et al., 2005; Post and Kwon, 2000). The most significant changes in soil organic carbon occur with land-use change, particularly conversions to croplands, due to changes in the disturbance regimes and associated effects on soil aggregate dynamics (Six et al., 2000).

Specific mitigation practices are not explicitly described in Chapter 7; however, avoiding land-use conversions that result in significant carbon losses could mitigate net GHG emissions (e.g., avoiding the conversion of forestlands to grazing lands).

2.6 Uncertainty

Quantifying the uncertainty of GHG emissions and reductions from agriculture and forestry practices is an important aspect of decisionmaking for farmers and landowners as the uncertainty range for each GHG estimate communicates our level of confidence that the estimate reflects the actual balance of GHG exchange between the biosphere and the atmosphere. In particular, a farm, ranch, or forest landowner may be more inclined to invest in management practices that reduce net GHG emissions if the uncertainty range for an estimate is low, meaning that higher confidence in the estimates exists. This report presents the approach for accounting for the uncertainty in the estimated net emissions based on the methods presented in this report.[6] A Monte Carlo approach

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[6] The IPCC Good Practice Guidance (IPCC, 2000) recommends two approaches—Tier 1 and Tier 2—for developing quantitative estimates of uncertainty for emissions estimates for source categories. The Tier 1 method uses error propagation equations. These equations combine the uncertainty associated with the activity data and the uncertainty associated with the emission (or other) factors. This approach is appropriate where emissions (or removals) are estimated as the product of activity data and an emission factor or as the sum of individual sub-source category values. The Tier 2 method utilizes the Monte Carlo Stochastic Simulation technique. Using this technique, an estimate of emission (or removal) for a particular source category is generated many times via an uncertainty model, resulting in an approximate PDF for the estimate.

was selected as the method for estimating the uncertainty around the outputs from the methodologies in this report, as it is currently the most comprehensive, sound method available to assess the uncertainty at the entity scale. Limitations and data gaps exist; however, as new data become available, the method can be improved over time. Implementation of a Monte Carlo analysis is complicated and requires the use of a statistical tool to produce a probability density function (PDF)[7] around the GHG emissions estimate.[8] From the probability density function, the uncertainty estimate can be derived and reported.

Chapter 2 References

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Where sufficient and reliable uncertainty data for the input variables are available, the Tier 2 method is the preferred option.

[7] The integral of a PDF over a given interval of values is the probability for a random variable to take on some value in the interval. That is, the PDF is a function giving probability "densities" and its integral gives probabilities. A narrower PDF for an estimate indicates smaller variance around the central/most likely value, i.e., a higher probability of the value to be closer to the central/most likely value. The uncertainty for such an estimate is lower.

[8] Given the complexity of Monte Carlo analysis and the necessity for a tool, the approach presented here is not intended for development by a landowner, rather it is intended for use in developing a tool that a landowner would use to assess uncertainty estimates.

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