VCS Methodology

# VM0045

# IMPROVED FOREST MANAGEMENT USING DYNAMIC MATCHED BASELINES FROM NATIONAL FOREST INVENTORIES

Version 1.~~1~~2 ~~-~~– Track changes

10 ~~April~~July 2025~~4~~

Sectoral Scope 14: Agriculture, forestry and other land use (AFOLU)

Version 1.0 of this methodology was developed by the Family Forest Carbon Program. The lead authors ~~ar~~were David Shoch, Erin Swails, Edie Sonne Hall, Ethan Belair, Ben Rifkin, Bronson Griscom, and Greg Latta.

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# CONTENTS

# 1 SOURCES

No sources are referenced within this methodology.

# 21 SUMMARY DESCRIPTION OF THE METHODOLOGY

| Additionality, and Crediting Method, and Mitigation Outcome | |
|---|---|
| Additionality | Performance Method |
| Crediting Baseline | Performance Method |
| Mitigation Outcome | Reductions and Removals |

This methodology is applicable to a wide range of improved forest management (IFM) practices and employs standardized approaches for demonstration of additionality and derivation of project baselines to simplify application of the methodology.

The focus of accounting is on estimation of greenhouse gas (GHG) emissions and/or carbon stock change in permanent plots, not on estimation of stocks per se, therefore improving the precision of reported GHG emission reductions and/or carbon dioxide removals.

The methodology employs a broad monitoring and accounting framework that captures the GHG impacts of IFM practices aimed at avoiding emissions (from harvest or natural disturbance) or enhancing sequestration. Projects may apply a combination of practices implemented together in the same area.

Examples of potential activities include enrichment planting, release of natural regeneration via management of competing vegetation, stand irrigation and/or fertilization, reducing timber harvest levels, deferring harvest/extending rotations or cutting cycles, designating reserves, and altering fire severity via fuel load treatments.

For all activities, the methodology uses a matching approach to construct a quasi-experimental design with matched pairs of treatments (project) and controls (baseline), with baseline plots sourced from existing continuously measured national or sub-national forest inventory data. Carbon stock change is directly monitored in permanent sample units representing the project and baseline scenarios. The baseline is represented by a collection of sample plots outside of the project area that match the initial conditions of each paired project plot. Ex-post monitoring of the baseline in this way provides a more robust estimate of impacts compared to model- or

default-driven approaches, which reflect the effects of exogenous factors like climate and timber markets on achieved GHG emission reductions.

Most IFM methodologies are dependent on long-term projections using forest growth and yield models. An important distinguishing feature of this methodology is that no forest growth and yield modeling is required to quantify GHG emission reductions and/or carbon dioxide removals. This methodology uses a dynamic performance benchmark approach, where the baseline scenario is represented by constituent baseline plots that are continuously monitored, paired with sample units representing the project scenario. ~~Most IFM methodologies are dependent on long-term projections using forest growth and yield models.~~

# 2 SOURCES

No sources are referenced within this methodology.

# 3 DEFINITIONS

**Composite baseline**
A group of constituent baseline plots representing the baseline scenario, located outside of the project area. A composite baseline is paired to each sample unit used to monitor the project scenario and is updated over time to establish a dynamic performance benchmark for additionality and crediting baselines. Each composite baseline is derived as the optimally weighted k-nearest neighbor combination of plots that matches the initial conditions of its paired project sample unit.

**Constituent baseline plot**
An individual sample plot representing the baseline scenario, located outside of the project area, that constitutes a component of one or more composite baselines

**Donor pool**
A population of potential sample plots located outside of the project area, from which constituent baseline plots are sourced. The donor pool is a representatively sampled, continuously measured national or sub-national forest inventory.

**Project sample unit**
A permanent forest inventory plot (either fixed area or variable radius plot) used as the primary sample unit selected for measuring and monitoring carbon stock change and emissions in the project scenario. “Plot” and “sample unit” are used interchangeably within this methodology. A sample unit may constitute a collection of plots (e.g., a cluster), provided that the collection of plots is sampled from within a single stand. Sample units are paired with a composite baseline.

**Stand**[1]
A contiguous, defined area composed of trees sufficiently uniform in age-class distribution, composition, and structure and growing on a site of sufficiently uniform quality to be a distinguishable unit. Relevant in accounting as the primary building block (i.e., a minimum mapping unit of variable size) for quantifying project area and identifying areas subject to harvest or disturbance.

# 4 APPLICABILITY CONDITIONS

This methodology applies to all improved forest management activities, including activities representing discrete interventions and activities representing changes in management regime realized over long time horizons.

The methodology is applicable under the following conditions:

1) The project area qualifies as forests remaining as forests, and the project activity involves an intervention expected to achieve improved net carbon emission outcomes relative to business-as-usual practices.[2]

2) The project is located in a national or sub-national jurisdiction for which approved data sources, and matching covariates, and procedures in which they occur, are specified in an appendix to this methodology.

This methodology is not applicable under the following conditions:

3) The project activity involves reducing the frequency and/or intensity of timber harvest and the project area is subject to any pre-existing legal encumbrance specifically restricting timber harvest.

4) The project activity involves a change in hydrology and/or soil disturbance exceeding 10% percent of the project area. Note that the absence of changes in hydrology and soil disturbance exceeding 10% of the project area, resulting from the project activity, must be verified on an ongoing basis.[3]

4)5) Thise methodology is not applicable to Wetland Restoration and Conservation (WRC) activities.

[1] Definition adapted from Helms, J. A. (Eed.). (1998). *Dictionary of Forestry*. Society of American Foresters.

[2] Including but not limited to extended rotations/cutting cycles, designating reserves, fuel load treatments to mitigate fire risk, enrichment planting, release of natural regeneration via management of competing vegetation, stand irrigation, and/or fertilization.

[3] Note that the absence of changes in hydrology and soil disturbance exceeding 10% percent of the project area, resulting from the project activity, must be verified on an ongoing basis.

6) The project activity involves any deliberate reduction in lying dead wood stocks that is expected to exceed ~~five percent (~~5%~~)~~ of net GHG emission reductions.~~.~~[4]

~~5)~~

# 5 PROJECT BOUNDARY

**Spatial boundary**

The spatial extent of the project boundary encompasses all lands subject to implementation of ~~the~~ project activities.

**GHG boundary**

Selected carbon pools and sources included in the project boundary are listed in Tables 1 and 2.

Appendix 2 of this methodology must be applied to test the significance of carbon pools and GHG emission~~s~~ sources to determine whether they are ~~be deemed~~ de minimis. Overall, specific carbon pools and GHG sources that cause project emissions may be deemed de minimis and do not have to be accounted for, where~~if~~ together~~,~~ the sum of all decreases in carbon stocks or increases in GHG emissions (from GHG sources) amounts to less than ~~five percent~~5% of the total reductions and/or removals ~~and/or reductions~~ generated by the project. ~~san ss~~

**Table 1.~~:~~ Selected carbon pools[5]**

| Source | Included? | Justification/Explanation |
|---|---|---|
| Aboveground tree biomass | Yes | Required pool. Expected to be subject to significant change due to ~~the project~~project activity. |
| Aboveground ~~woody~~ non-tree woody biomass | Yes/ ~~O~~oOptional ~~Conditional on project activity~~ | Where this pool is subject to significant decrease due to ~~the project~~project activity (e.g., due to site preparation), it must be included in the project scenario (and may be included in or excluded from ~~in~~ the baseline scenario). |

[4] As determined by applying Appendix ~~the CDM *Tool for testing significance of GHG emissions in A/R CDM project activities*. Available at:~~ 2 of this methodology.

[5] Significance defined by applying Appendix 2 of this methodology~~Significance defined by applying the CDM *Tool for testing significance of GHG emissions in A/R CDM project activities*.~~

| Source | Included? | Justification/Explanation |
|---|---|---|
| | | Otherwise, this pool may be included only where it is possible to account in both the project and baseline scenarios (i.e., above-ground non-tree woody biomass must be included in the national forest inventory data used for the composite baseline). |
| Aboveground non-tree herbaceous biomass | No | Conservative to exclude~~Not required due to insignificance~~ |
| Belowground biomass | Yes | Expected to be subject to significant change due to the project activity |
| Dead wood | Yes | Standing dead wood is required, while lying dead wood ~~should~~must be included unless deemed ~~as non-~~insignificant as per Appendix 2.~~Required pool. Accounting boundary restricted to standing dead wood (lying dead wood not included).~~ |
| Litter | Yes-/~~0-o~~ptional ~~No~~ | Must be included ~~if~~ where the project activity significantly reduces the carbon pool. Project proponents ~~could~~ may choose to ~~optionally~~ include this~~e~~ source ~~even if~~ where the change is deemed ~~to~~ insignificant~~ly reduce the carbon pool~~. ~~Not required due to insignificance~~ |
| Soil organic carbon | Yes-/~~-o~~Optional ~~No~~ | Must be included where~~if~~ the project activity significantly reduces the carbon pool. Project proponents ~~could optionally~~ may choose to include this~~e~~ source ~~even~~ where the change is~~f~~ deemed ~~to~~ insignificant~~ly reduce the carbon pool~~. ~~Not expected to be subject to significant change due to the project activity~~ |
| Wood products | Not included for reduced impact logging (RIL) with no or minimal (<25%) effect on total timber extracted<br><br>Yes for all other activities | Required pool, except where the project activity involves RIL with no or minimal (<25%) effect on total timber extracted, in which case wood products must not be included. |

**Table 2.: GHG sources included in or excluded from the project boundary[6]**

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| Baseline and Project | Emissions from nitrogen-containing soil amendments or from decomposition of plant materials with fixed nitrogen | $CO_2$ | N/A | N/A |
| | | $CH_4$ | N/A | N/A |
| | | $N_2O$ | ~~Conditional on~~ Conditional on project activity | $N_2O$ emissions from nitrogen-containing soil amendments are included in the scenario where nitrogen fertilizer is applied as part of the project activity. $N_2O$ emissions are conservatively set to zero in the baseline. |
| | | Other | N/A | N/A |
| | Burning of tree biomass (emissions from burning of non-tree biomass not included because they are de minimis) | $CO_2$~~$CO_2$~~ | N/A~~Conditional on project activity~~ | CO2 from burning is effectively always included because it will be accounted for by monitoring gains and losses in required carbon pools~~N/ACO$_2$,~~ |
| | | $CH_4$ | Conditional on project activity | $CH_4$ and $N_2O$ emissions from fire are included in the baseline and project scenarios where incidence and/or severity of fires is impacted by the project activity (e.g., in the project scenario where the project activity involves burning woody biomass, or in the project and baseline scenarios where the project activity is aimed at altering the probability and/or magnitude of emissions from forest fires). |
| | | $N_2O$ | Conditional on project activity | |
| | | Other | N/A | N/A |
| | Burning of fossil fuels | $CO_2$ | No~~Excluded~~ | De minimis |

[6] Significance defined by applying Appendix 2 of this methodology~~Significance defined by applying the CDM *Tool for testing significance of GHG emissions in A/R CDM project activities*~~.

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| | | $CH_4$ | NoExcluded | De minimis |
| | | $N_2O$ | NoExcluded | De minimis |
| | | Other | NoExcluded | De minimis |

# 6 BASELINE SCENARIO

The crediting baseline uses a dynamic performance benchmark approach, where the baseline scenario is represented by designated composite baselines (made up of forest measurement plots located outside of the project area) that are continually monitored. These are paired with sample units representing the project scenario.

A group of constituent baseline plots sourced from a donor pool of national or sub-national forest inventory plots is collectively matched to project sample units and designated as a "composite baseline." Matching is achieved using a k-nearest neighbor optimal matching approach, deriving weights for constituent baseline plots to produce a weighted combination (composite baseline) that conforms to the initial conditions of the paired project sample unit. Matching conditions are defined by referencing one or more covariates representing biophysical and anthropogenic factors driving carbon stock change.

Initial conditions of composite baselines and project sample units must be matched at $t = 0$ (prior to initiation of the project activity). The selection and weighting of constituent baseline plots must be subsequently held constant throughout the project crediting period (with rare exceptions, see Section 8.1).

A two-stage sample is recommended for the project scenario, with primary units (e.g., stands) selected via probability proportional to size (acreage) and secondary units (e.g., plots) selected via simple random sampling (SRS) or systematic sampling with a fixed sample size within each selected primary unit (which is self-weighting and simplifies calculations). In this case, a composite baseline is matched to each primary unit on the basis of initial covariate values averaged across the secondary units.

Constituent baseline plots may be sourced from new or existing continuously measured national or sub-national forest inventories and must meet the following requirements:

1) Sample plots must be located outside of the project area.
2) Sample plot populations from which constituent baseline plots are sourced must be from unbiased, representative sampling at a regional scale.
3) Sample plots must be subject to continuous, periodic re-measurement throughout the project crediting period. Constituent baseline plots need not be on the same re-

measurement ~~schedule, but~~schedule but must be re-measured ~~at least~~ every 10 years or more frequently.

4) Initial conditions must be quantified from measurements collected at time *t* − 10 or more recently.

5) Sample plots must be located in the same ecoregion (e.g., referencing ecological sections from Cleland et al. (2007)[7] in the US or Holdridge life zones[8] elsewhere).

6) Trees on sample plots must be given unique identification numbers to permit tracking of individual stems.

7) Measurement parameters (e.g., minimum diameter at breast height) must be paired with the project sample units.

Project proponents must use approved data sources, matching covariates, and procedures for the national or sub-national jurisdiction in which they occur, as specified in the methodology appendices (e.g., Appendix 1). Where not specified in the current version of the methodology, approved data sources, matching covariates, and procedures for other national or sub-national jurisdictions may be developed through revisions to the methodology.

# 7 ADDITIONALITY

Additionality must be demonstrated using a performance method, following the steps below.

### Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the ~~latest~~ most recent version of the *VCS Methodology Requirements*.

### Step 2: Performance Benchmark

*Composite* baselines *derived per the procedures set out in Section 6 represent the without-project activity, or baseline scenario. Updating the composite baselines periodically throughout the project crediting period produces a dynamic and spatially variable performance benchmark in terms of periodic carbon stock change. At each monitoring event, where reductions and removals yield a positive value, the project is deemed additional*.

[7] Cleland, D. T., J. A. Freeouf, ~~J. A.,~~ J. E. Keys~~, J. E.~~, G. J. Nowacki, C. A. ~~G. J.,~~ Carpenter, ~~C. A., &~~ and W. H. McNab~~, W. H.~~ (~~2007~~). *Ecological Subregions: Sections and Subsections for the Conterminous United States.* Gen. Tech. Report WO-76D. USDA Forest Service. https://doi.org/10.2737/WO-GTR-76D

[8] Leemans, R. (~~1992~~). *Global Holdridge Life Zone Classifications*. IIASA. ~~Available at:~~ https://resources.unep-wcmc.org/products/31d5e80482834f6ba6ee51a2813b82e7

$$ER_t = \left(\left(A_t \times \overline{ER_t}\right) + LK_{ER,t}\right) \text{~~}\left(A_t \times \overline{ER_t} + LK_{ER,t}\right)\text{~~} \times (1 - UNC_t) \quad (1)$$

Where:

| | | |
|---|---|---|
| $ER_t$ | = | Net GHG emission reductions in year *t* (t $CO_2e$) |
| $A_t$ | = | Project area in year *t* (unit area) |
| $\overline{ER_t}$ | = | Mean GHG emission reductions in year *t* (t $CO_2e$/unit area/year) |
| $LK_{ER,t}$ | = | Leakage allocated to emission reductions in year *t* (t $CO_2e$) |
| $UNC_t$ | = | Uncertainty in year *t* (percent) |

$$CR_t = \left(\left(A_t \times \overline{CR_t}\right) + LK_{CR,t}\right) \text{~~}\left(A_t \times \overline{CR_t} + LK_{CR,t}\right)\text{~~} \times (1 - UNC_t) \quad (2)$$

Where:

| | | |
|---|---|---|
| $CR_t$ | = | Net carbon dioxide removals in year *t* (t $CO_2e$) |
| $A_t$ | = | Project area in year *t* (unit area) |
| $\overline{CR_t}$ | = | Mean carbon dioxide removals in year *t* (t $CO_2e$/unit area/year) |
| $LK_{CR,t}$ | = | Leakage allocated to carbon dioxide removals in year *t* (t $CO_2e$) |
| $UNC_t$ | = | Uncertainty in year *t* (percent) |

# 8 QUANTIFICATION OF ~~ESTIMATED GHG EMISSION~~ REDUCTIONS AND REMOVALS

## 8.1 Baseline Emissions

Baseline quantification is focused on measured carbon stock change in the composite baselines, representing the absence of ~~the~~ project ~~activity~~activities. Each project sample unit *i* has a corresponding paired composite baseline *i,* composed of one or more constituent baseline plots *j*.

Harvest or disturbance emissions include carbon emitted from live tree above- and below-ground biomass, dead wood, and harvested wood products (i.e., carbon not retained in harvested wood products for 100 years or more after harvest).

For each constituent baseline plot, carbon stock change is calculated at re-measurement time *mt*, and annualized as:

$$\Delta LAG_{bsl,i,j,mt} = \left(LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X_{bsl,i,j,t}}\right) \times (1/X_{bsl,i,j,t}) \quad (3)$$

$$\Delta LBG_{bsl,i,j,mt} = (LBG_{bsl,i,j,t} - LBG_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad (4)$$

$$\Delta DW_{bsl,i,j,mt} = (DW_{bsl,i,j,t} - DW_{bsl,i,j,t-X_{bsl,i,j,t}}) \times (1/X_{bsl,i,j,t}) \quad (5)$$

Where:

| | | |
|---|---|---|
| $\Delta LAG_{bsl,i,j,mt}$ | = | Annual change in live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t $CO_2e$/unit area/year) |
| $LAG_{bsl,i,j,t}$ | = | Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $LAG_{bsl,i,j,t-X\_(bsl,i,j,t)}$ | = | Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t $CO_2e$/unit area) |
| $\Delta LBG_{bsl,i,j,mt}$ | = | Annual change in live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t $CO_2e$/unit area/year) |
| $LBG_{bsl,i,j,t}$ | = | Live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $LBG_{bsl,i,j,t-X\_(bsl,i,j,t)}$ | = | Live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t $CO_2e$/unit area) |
| $\Delta DW_{bsl,i,j,mt}$ | = | Annual change in dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t $CO_2e$/unit area/year) |
| $DW_{bsl,i,j,t}$ | = | Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $DW_{bsl,i,j,t-X\_(bsl,i,j,t)}$ | = | Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t $CO_2e$/unit area) |
| $X_{bsl,i,j,t}$ | = | Length of measurement interval ending at time *t* for constituent baseline plot *ij* (years) |

Note that re-measurement time *mt* is expected to precede the project start date for the initial measurement intervals.

For each reporting year *t*, annual carbon stock change calculated for re-measurement times *mt* ~~(calculated in Equations (6), (7) and (8))~~ (~~—~~where $t - mt$ is less than the length of the measurement interval corresponding to re-measurement time $mt = X_{bsl,i,j,t}$)~~—~~ is summed for each constituent baseline plot. Then, the composite baseline *i* is calculated as the weighted sum of carbon stock change across constituent baseline plots.

$$\Delta LAG_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta LAG_{bsl,i,j,mt} \; [t - mt < X_{bsl,i,j,t}] \quad (6)$$

$$\Delta LBG_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta LBG_{bsl,i,j,mt} \ [t - mt < X_{bsl,i,j,t}] \quad (7)$$

$$\Delta DW_{bsl,i,t} = \sum_{j=1}^{n} W_{bsl,i,j} \sum_{mt=-10}^{t} \Delta DW_{bsl,i,j,mt} \ [t - mt < X_{bsl,i,j,t}] \quad (8)$$

Where:

| | | |
|---|---|---|
| $\Delta LAG_{bsl,i,t}$ | = | Annual change in live aboveground biomass stocks in the baseline scenario at composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $\Delta LAG_{bsl,i,j,mt}$ | = | Annual change in live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t $CO_2e$/unit area/year) |
| $\Delta LBG_{bsl,i,t}$ | = | Annual change in live belowground biomass stocks in the baseline scenario at composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $\Delta LBG_{bsl,i,j,mt}$ | = | Annual change in live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t $CO_2e$/unit area/year) |
| $\Delta DW_{bsl,i,t}$ | = | Annual cChange in dead wood stocks in the baseline scenario at composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $\Delta DW_{bsl,i,j,mt}$ | = | Annual change in dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* calculated at re-measurement time *mt* (t $CO_2e$/unit area/year) |
| $W_{bsl,i,j}$ | = | Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless) |

Note that constituent plots within a given composite baseline need not be on the same re-measurement schedule, nor have the same or fixed measurement intervals over a crediting period.

Table 3 gives an example of applying Equations (3) and (6) to derive live aboveground biomass stock change for a composite baseline.

Table 3.~~:~~ Illustrative derivation of live aboveground biomass stock change for a composite baseline applying Equations (3) and (6)

a) Periodic measurement of live aboveground biomass in constituent baseline plots ($LAG_{bsl,i,j,t}$)

| Plot *bsl,i,j* | Year *t* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | −7 | −6 | −5 | −4 | −3 | −2 | −1 | 0 | 1 | 2 | 3 | 4 | 5 |
| 1 | 430.3 | | | | | | | 325.7 | | | | 338.7 | |
| 2 | | | 260.1 | | | | | 284.6 | | | | | |
| 3 | | 233.7 | | | | | 247.3 | | | | | | 238.2 |
| 4 | 335.6 | | | | | 361.7 | | | | | | | 387.4 |
| 5 | | | 459.4 | | | | | 474.8 | | | | | |
| 6 | | | | 214.2 | | | | 230.2 | | | | | |
| 7 | | | 195.8 | | | | | 216.2 | | | | | |
| 8 | 195.0 | | | | | 145.4 | | | | | 165.3 | | |
| 9 | | 80.0 | | | | | 91.2 | | | | | 86.7 | |
| 10 | | 190.0 | | | | 152.0 | | | | | 170.0 | | |

Table 3 (cont…). Illustrative derivation of live aboveground biomass stock change for a composite baseline applying Equations (3) and (6)

b) Calculation of annual change in live aboveground biomass stocks in constituent baseline plots at re-measurement time *mt* ($\Delta LAG_{bsl,i,j,mt}$)

| Plot *bsl,i,j* | Time *mt* – $X_{bsl,i,j,t}$ | Time *mt* | $LAG_{bsl,i,j,t-X_{(bsl,i,j,t)}}$ (t $CO_2$e/unit area) | $LAG_{bsl,i,j,t}$ (t $CO_2$e/unit area) | $X_{bsl,i,j,t}$ (years) | $LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X_{(bsl,i,j,t)}}$ (t $CO_2$e/unit area) | $\Delta LAG_{bsl,i,j,mt}$ (t $CO_2$e/unit area/year) |
|---|---|---|---|---|---|---|---|
| 1 | −7 | 0 | 430.3 | 325.7 | 7 | −104.6 | −14.9 |
| 1 | 0 | 4 | 325.7 | 338.7 | 4 | 13.0 | 3.32 |
| 2 | −5 | 0 | 260.1 | 284.6 | 5 | 24.5 | 4.9 |
| 3 | −6 | −1 | 233.7 | 247.3 | 5 | 13.6 | 2.7 |
| 3 | −1 | 5 | 247.3 | 238.2 | 6 | −9.1 | −1.5 |
| 4 | −7 | −2 | 335.6 | 361.7 | 5 | 26.1 | 5.2 |
| 4 | −2 | 5 | 361.7 | 387.4 | 7 | 25.7 | 3.7 |
| 5 | −5 | 0 | 459.4 | 474.8 | 5 | 15.4 | 3.1 |
| 6 | −4 | 0 | 214.2 | 230.2 | 4 | 16.0 | 4.0 |
| 7 | −5 | 0 | 195.8 | 216.2 | 5 | 20.4 | 4.1 |
| 8 | −7 | −2 | 195.0 | 145.4 | 5 | −49.6 | −9.9 |
| 8 | −2 | 3 | 145.4 | 165.3 | 5 | 19.9 | 4.0 |
| 9 | −6 | −1 | 80 | 91.2 | 5 | 11.2 | 2.2 |
| 9 | −1 | 4 | 91.2 | 86.7 | 5 | −4.5 | −0.9 |
| 10 | −6 | −2 | 190 | 152 | 4 | −38.0 | −9.5 |
| 10 | −2 | 3 | 152 | 170 | 5 | 18.0 | 3.6 |

Table 3 (cont…). Illustrative derivation of live aboveground biomass stock change for a composite baseline applying Equations (3) and (6)

c) Calculation of change in live aboveground biomass stocks in composite control *i* in year *t* ($\Delta LAG_{bsl,i,t}$)

| Plot *bsl,i,j* | $W_{bsl,i,j}$ | Year *t* | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | 0.08 | −14.9 | −14.9 | −14.9 | −11.7 | −11.7 |
| 2 | 0.05 | 4.9 | 4.9 | 4.9 | 4.9 | 0.0 |
| 3 | 0.05 | 2.7 | 2.7 | 2.7 | 0.0 | −1.5 |
| 4 | 0.05 | 5.2 | 5.2 | 0.0 | 0.0 | 3.7 |
| 5 | 0.17 | 3.1 | 3.1 | 3.1 | 3.1 | 0.0 |
| 6 | 0.11 | 4.0 | 4.0 | 4.0 | 0.0 | 0.0 |
| 7 | 0.10 | 4.1 | 4.1 | 4.1 | 4.1 | 0.0 |
| 8 | 0.17 | −9.9 | −9.9 | 4.0 | 4.0 | 4.0 |
| 9 | 0.16 | 2.2 | 2.2 | 2.2 | −0.9 | −0.9 |
| 10 | 0.05 | −9.5 | 0.0 | 3.6 | 3.6 | 3.6 |
| $\Delta LAG_{bsl,i,t}$ | | −1.0 | −0.5 | 1.7 | 0.9 | −0.2 |

~~Note that for~~

*Note that in this example, ~~Plot 1,~~ initial measurement occurred at t = -7 or seven years prior to t = 0. In plot 1, for example, -14.9 t $CO_2$e/unit area/year is the annual change in live aboveground biomass for the first measurement period ~~of plot 1~~. Y~~y~~ears 4 and 5 reflect ~~erence~~ the annual stock change after plot 1 was remeasured at year 4 (-14.9 + 3.2 = -11.7). See Table 3a and 3b above.~~from re measurement times mt = 0 and 4 respectively.~~*

~~Note that w~~Weights for constituent baseline plots ($W_{bsl,i,j}$) are determined at $t$ = 0 and fixed throughout the project crediting period, except where a constituent baseline plot has become invalid (e.g., where a unit is no longer in a forest condition or has not been re-measured in over 10 years; see Section 6). In this case, all weights in the respective composite baseline are recalculated to sum to one, holding relative weights of the remaining valid constituent plots constant.

Harvested wood product stocks ($HWP_{bsl,i,j,t}$) are calculated using Equation (9).

$$HWP_{bsl,i,j,t} = \left(BBremoved_{saw,wt=sfw,bsl,i,j,t} \times SF_{saw,wt=sfw} + BBremoved_{pulp,wt=sfw,bsl,i,j,t} \times SF_{pulp,wt=sfw}\right) + \left(BBremoved_{saw,wt=hwd,bsl,i,j,t} \times SF_{saw,wt=hwd} + BBremoved_{pulp,wt=hwd,bsl,i,j,t} \times SF_{pulp,wt=hwd}\right) \quad (9)$$

Where:

| | | |
|---|---|---|
| $HWP_{bsl,i,j,t}$ | = | Harvested wood products remaining stored for 100 years in the baseline scenario at constituent baseline plot *j* in composite baseline *i*, harvested in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $BBremoved_{saw,wt,bsl,i,j,t}$ | = | Saw log bole biomass stocks in wood type *wt* in commercial species removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i,* harvested in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $BBremoved_{pulp,wt,bsl,i,j,t}$ | = | Pulpwood bole biomass stocks in wood type *wt* in commercial species removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i,* harvested in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $SF_{saw,wt}$ | = | Saw log 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (dimensionless) |
| $SF_{pulp,wt}$ | = | Pulpwood 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (dimensionless) |
| *wt* | = | Wood type, defined as softwood (sfw) or hardwood (hwd) |

Where burning occurs in the monitoring interval ending at time *t*, $CH_4$ and $N_2O$ emissions from fire are included and calculated using Equation (10), assuming that all stock change is subject to burning. Otherwise, $Bburn_{bsl,i,j,t}$ is set equal to zero.

$$Bburn_{bsl,i,j,t} = \sum_{g=1}^{G} GWP_g \times \Big( (LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X_{bsl,i,j,t}}) + (DW_{bsl,i,j,t} - DW_{bsl,i,j,t-X_{bsl,i,j,t}}) \Big) \cancel{((LAG_{bsl,i,j,t} - LAG_{bsl,i,j,t-X_{bsl,i,j,t}}) + (DW_{bsl,i,j,t} - DW_{bsl,i,j,t-X_{bsl,i,j,t}}))} \times \frac{12}{44} \times \frac{1}{CF} \times C_f \times EF_g \times 10^{-3} \quad (10)$$

Where:

| | | |
|---|---|---|
| $Bburn_{bsl,i,j,t}$ | = | Emissions of $CH_4$ and $N_2O$ in the baseline scenario from biomass burning at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $GWP_g$ | = | Global warming potential of gas *g* |
| $LAG_{bsl,i,j,t}$ | = | Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* (t $CO_2e$/unit area) |
| $LAG_{bsl,i,j,t-X\_(bsl,i,j,t)}$ | = | Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t $CO_2e$/unit area) |
| $DW_{bsl,i,j,t}$ | = | Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time *t* (t $CO_2e$/unit area) |
| $DW_{bsl,i,j,t-X\_(bsl,i,j,t)}$ | = | Dead wood stocks in the baseline scenario at constituent baseline plot *j* in composite baseline *i* at time $t - X_{bsl,i,j,t}$ (t $CO_2e$/unit area) |
| $CF$ | = | Carbon fraction; 0.5 |
| $C_f$ | = | Combustion factor (dimensionless) |
| $EF_g$ | = | Emission factor for gas *g* (g/kg dry matter burned) |

Carbon stock change and emissions in the baseline scenario are then estimated for each composite baseline *i* at time *t* (net sequestration), which serves as the performance benchmark (crediting baseline) for each paired project sample unit *i*, as:

$$\Delta CO2_{bsl,i,t} = \Delta LAG_{bsl,i,t} + \Delta LBG_{bsl,i,t} + \Delta DW_{bsl,i,t} + \sum_{j=1}^{n} (HWP_{bsl,i,j,t} \times W_{bsl,i,j}) \quad (11)$$

Where:

| | | |
|---|---|---|
| $\Delta CO2_{bsl,i,t}$ | = | Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $\Delta LAG_{bsl,i,t}$ | = | Annual c~~C~~hange in live aboveground biomass stocks in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |

$\Delta LBG_{bsl,i,t}$ = Annual c~~C~~hange in live belowground biomass stocks in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year)

$\Delta DW_{bsl,i,t}$ = Annual c~~C~~hange in dead wood stocks in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year)

$HWP_{bsl,i,j,t}$ = Harvested wood products remaining stored over 100 years in the baseline scenario at constituent baseline plot *j* in composite baseline *i,* harvested in the monitoring interval ending at time *t* (t $CO_2e$/unit area)

$$BE_{i,t} = Nfert_{bsl,i,t} + \sum_{j=1}^{n}(Bburn_{bsl,i,j,t} \times W_{bsl,i,j}) \quad (12)$$

Where:

$BE_{i,t}$ = Baseline emissions in composite baseline *i* in year *t* (t $CO_2e$/unit area/year)

$Nfert_{bsl,i,t}$ = Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the baseline scenario in composite baseline *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area)

$Bburn_{bsl,i,j,t}$ = Emissions of ~~$CH_4$~~ methane and ~~$N_2O$~~ nitrous oxide in the baseline scenario from biomass burning at constituent baseline plot *j* in composite baseline *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area)

$W_{bsl,i,j}$ = Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)

Nitrous oxide emissions due to nitrogen fertilizer use in the baseline scenario ($Nfert_{bsl,i,t}$) are conservatively set to zero.

## 8.2 Project Emissions

Stock change in live aboveground biomass in the project scenario in sample unit *i* over the monitoring interval ending at time *t* is annualized as:

$$\Delta LAG_{wp,i,t} = (LAG_{wp,i,t} - LAG_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \quad (13)$$

$$\Delta LBG_{wp,i,t} = (LBG_{wp,i,t} - LBG_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \quad (14)$$

$$\Delta DW_{wp,i,t} = (DW_{wp,i,t} - DW_{wp,i,t-X_{wp,i,t}}) \times (1/X_{wp,i,t}) \quad (15)$$

Where:

$\Delta LAG_{wp,i,t}$ = Average annual change in live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area/year)

$LAG_{wp,i,t}$ = Live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area)

| | | |
|---|---|---|
| $LAG_{wp,i,t-X\_(wp,i,t)}$ | = | Live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* − $X_{wp,i,t}$ (t $CO_2e$/unit area) |
| $\Delta LBG_{wp,i,t}$ | = | Average annual change in live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area/year) |
| $LBG_{wp,i,t}$ | = | Live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $LBG_{wp,i,t-X\_(wp,i,t)}$ | = | Live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* − $X_{wp,i,t}$ (t $CO_2e$/unit area) |
| $\Delta DW_{wp,i,t}$ | = | Average annual change in dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area/year) |
| $DW_{wp,i,t}$ | = | Dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $DW_{wp,i,t-X\_(wp,i,t)}$ | = | Dead wood stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* − $X_{wp,i,t}$ (t $CO_2e$/unit area) |
| $X_{wp,i,t}$ | = | Length of measurement interval ending at time *t* for sample unit *i* in the project scenario (years) |

As with constituent baseline plots, project sample units may be re-measured on a staggered basis (i.e., re-measurements of cohorts of sample units are scheduled in different years within a monitoring cycle) provided that subsets of sample units in the project scenario re-measured in different years are selected systematically or at random from the total sample population.

Harvested wood products remaining stored for 100 years ($HWP_{wp,i,t}$) and emissions of $CH_4$ and $N_2O$ from biomass burning ($Bburn_{wp,i,t}$) in the project scenario are estimated using Equations (9) and (10) respectively, substituting the subscript *bsl* with *wp* to make clear that the relevant values are being quantified for the project scenario. Note that no weighted summing operation is used in these equations in the project scenario.

Where nitrogen fertilizer is applied due to the project activity, nitrous oxide emissions are calculated using Equation (16).

$$Nfert_{wp,i,t} = Nfert_{wp,direct,i,t} + Nfert_{wp,indirect,i,t} \quad (16)$$

Where:

| | | |
|---|---|---|
| $Nfert_{wp,i,t}$ | = | Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $Nfert_{wp,direct,i,t}$ | = | Direct nitrous oxide emissions due to fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at *t* (t $CO_2e$/unit area) |
| $Nfert_{wp,indirect,i,t}$ | = | Indirect nitrous oxide emissions due to fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |

$$Nfert_{wp,direct,i,t} = \left(F_{wp,SN,i,t} + F_{wp,ON,i,t}\right) \times EF_{Ndirect} \times 44/28 \times GWP_{N2O} \quad (17)$$

$$F_{wp,SN,i,t} = M_{wp,SF,i,t} \times NC_{wp,SF,i,t} \quad (18)$$

$$F_{wp,ON,i,t} = M_{wp,OF,i,t} \times NC_{wp,OF,i,t} \quad (19)$$

Where:

| | | |
|---|---|---|
| $Nfert_{wp,direct,i,t}$ | = | Direct nitrous oxide emissions due to nitrogen fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at *t* (t $CO_2e$/unit area) |
| $F_{wp,SN,i,t}$ | = | Project synthetic ~~N~~ nitrogen fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area) |
| $F_{wp,ON,i,t}$ | = | Project organic nitrogen~~N~~ fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area) |
| $M_{wp,SF,i,t}$ | = | Mass of project nitrogen~~N~~-containing synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t fertilizer/unit area) |
| $M_{wp,OF,i,t}$ | = | Mass of project ~~N~~nitrogen-containing organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t fertilizer/unit area) |
| $NC_{wp,SF,i,t}$ | = | Nitrogen content of project synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/t fertilizer) |
| $NC_{wp,OF,i,t}$ | = | Nitrogen content of project organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/t fertilizer) |
| $EF_{Ndirect}$ | = | Emission factor for nitrous oxide emissions from nitrogen~~N~~ additions from synthetic fertilizers, organic amendments, and crop residues (t $N_2O$-N/t N applied) |
| $GWP_{N2O}$ | = | Global warming potential for ~~$N_2O$~~nitrous oxide; 298 |

$$Nfert_{wp,indirect,i,t} = Nfert_{wp,volat,i,t} + Nfert_{wp,leach,i,t} \quad (20)$$

$$Nfert_{wp,volat,i,t} = \left[\left(F_{wp,SN,i,t} \times Frac_{GASF}\right) + \left(F_{wp,ON,i,t} \times Frac_{GASM}\right)\right] \times EF_{Nvolat} \times 44/28 \times GWP_{N2O} \quad (21)$$

$$Nfert_{wp,leach,i,t} = \left(F_{wp,SN,i,t} + F_{wp,ON,i,t}\right) \times Frac_{LEACH} \times EF_{Nleach} \times 44/28 \times GWP_{N2O} \quad (22)$$

Where:

| | | |
|---|---|---|
| $Nfert_{wp,indirect,i,t}$ | = | Indirect nitrous oxide emissions due to nitrogen fertilizer use in the project scenario for sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $Nfert_{wp,volat,i,t}$ | = | Indirect nitrous oxide emissions produced from atmospheric deposition of nitrogen~~N~~ volatilized due to nitrogen fertilizer use in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |

| | | |
|---|---|---|
| $Nfert_{wp,leach,i,t}$ | = | Indirect nitrous oxide emissions produced from leaching and runoff of nitrogen~~N~~, in regions where leaching and runoff occurs, due to nitrogen fertilizer use in sample unit *i* in the monitoring interval ending at time *t*; ~~(t $CO_2e$/unit area). Value =~~ equal to zero ~~0~~ where average annual precipitation is less than potential evapotranspiration, unless subject to irrigation (t $CO_2e$/unit area)~~.~~ |
| $F_{wp,SN,i,t}$ | = | Project synthetic nitrogen~~N~~ fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area) |
| $F_{wp,ON,i,t}$ | = | Project organic nitrogen~~N~~ fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* (t N/unit area) |
| $Frac_{GASF}$ | = | Fraction of all synthetic nitrogen~~N~~ added to soils that volatilizes as ~~$NH_3$~~ ammonia and $NO_x$ (dimensionless) |
| $Frac_{GASM}$ | = | Fraction of all organic ~~N~~nitrogen added to soils that ~~volatilizes~~volatilizes as ~~$NH_3$~~ ammonia and $NO_x$ (dimensionless) |
| $Frac_{LEACH}$ | = | Fraction of ~~N~~nitrogen (synthetic ~~or~~ and organic) added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs (dimensionless) |
| $EF_{Nvolat}$ | = | Emission factor for nitrous oxide emissions from atmospheric deposition of ~~N~~nitrogen on soils and water surfaces (t $N_2O$-N/(t $NH_3$-N + $NO_x$-N volatilized)) |
| $EF_{Nleach}$ | = | Emission factor for nitrous oxide emissions from leaching and runoff (t $N_2O$-N/t N leached and runoff) |
| $GWP_{N2O}$ | = | Global warming potential for ~~$N_2O$~~nitrous oxide; 298 |

Carbon stock change and emissions in the project scenario are then estimated for each sample unit *i* in year *t* using Equations (23) and (24).

$$\Delta CO2_{wp,i,t} = \Delta LAG_{wp,i,t} + \Delta LBG_{wp,i,t} + \Delta DW_{wp,i,t} + HWP_{wp,i,t} \quad (23)$$

Where:

| | | |
|---|---|---|
| $\Delta CO2_{wp,i,t}$ | = | Average annual c~~C~~arbon stock change in the project scenario in~~at~~ sample unit *i* in the monitoring interval ending at time~~year~~ *t* (t $CO_2e$/unit area/year) |
| $\Delta LAG_{wp,i,t}$ | = | Average annual c~~C~~hange in live aboveground biomass stocks in the project scenario ~~at~~ in sample unit *i* in the monitoring interval ending at ~~year~~ time *t* (t $CO_2e$/unit area/year) |
| $\Delta LBG_{wp,i,t}$ | = | Average annual c~~C~~hange in live belowground biomass stocks in the project scenario ~~at~~ in sample unit *i* in the monitoring interval ending at time ~~year~~ *t* (t $CO_2e$/unit area/year) |
| $\Delta DW_{wp,i,t}$ | = | Average annual c~~C~~hange in dead wood stocks in the project scenario ~~at~~ in sample unit *i* in the monitoring interval ending at time ~~year~~ *t* (t $CO_2e$/unit area/year) |
| $HWP_{wp,i,t}$ | = | Harvested wood products remaining stored over 100 years in the project scenario ~~at~~ in sample unit *i,* harvested in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |

$$PE_{i,t} = Nfert_{wp,i,t} + Bburn_{wp,i,t} \quad (24)$$

Where:

| | | |
|---|---|---|
| $PE_{i,t}$ | = | Project emissions in composite baseline *i* in year *t* (t $CO_2e$/unit area) |
| $Nfert_{wp,i,t}$ | = | Direct and indirect nitrous oxide emissions due to nitrogen fertilizer use in the project scenario ~~at~~ for sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $Bburn_{wp,i,t}$ | = | Emissions of ~~$CH_4$~~ methane and ~~$N_2O$~~ nitrous oxide in the project scenario from biomass burning ~~at~~ in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |

Note that any emissions resulting from an initial project treatment (e.g., prescribed burn or thinning) are included in parameter $\Delta CO2_{wp,i,t}$ because the first monitoring interval begins immediately prior to application of the project activity.

## 8.3 Leakage Emissions

Leakage is due to a combination of activity-shifting leakage (outside the project area but within the project proponent's operations) and market leakage (outside both the project area and the project proponent's operations).

Leakage ($LK_t$) is calculated as:

$$LK_t = MIN\ (0,\ A_t \times \frac{1}{n}\sum_{i=1}^{n}\left(LTremoved_{wp,i,t} - \sum_{j=1}^{n} LTremoved_{bsl,i,j,t} \times W_{bsl,i,j}\right) \times LF_t\ ) \quad (25)$$

Where:

| | | |
|---|---|---|
| $LK_t$ | = | Leakage in year *t* (t $CO_2e$) |
| $LTremoved_{wp,i,t}$ | = | Live tree biomass stocks removed in the project scenario ~~at~~ in sample unit *i* subject to harvest in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $LTremoved_{bsl,i,j,t}$ | = | Live tree biomass stocks removed in the baseline scenario (without avoided emissions activity), at constituent baseline plot *j* in composite baseline *i* subject to harvest in the monitoring interval ending at time *t* (t $CO_2e$/unit area) |
| $W_{bsl,i,j}$ | = | Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless) |
| $LF_t$ | = | Leakage factor (percent) |
| $A_t$ | = | Project area in year *t* (unit area) |

The leakage factor ($LF_t$) is determined per the following stepwise process:

1) Determine whether the project activity involves any permanent reduction in timber supply (i.e., involves any ~~commitments~~commitment to reduce harvest levels for 100 years or longer), demonstrated at the project start date.

2) Where the project activity involves any permanent reduction in timber supply, calculate the national average ratio of merchantable stocking (on a volume or mass basis in commercial species) to total stocking and compare this to the equivalent ratio in the project area. The value of $LF_t$ is determined based on this comparison as follows:

   a) Where the two ratios are equal (i.e., national ratio within ±15% ~~percent~~ of the project area ratio): $LF_t$ = 0.4 (40% ~~percent~~)

   b) Where the national ratio is less than that in the project area (i.e., national ratio <85% ~~percent~~ of the project area ratio): $LF_t$ = 0.7 (70% ~~percent~~)

   c) Where the national ratio is greater than that in the project area (i.e., national ratio >115% ~~percent~~ of the project area ratio): $LF_t$ = 0.2 (20 ~~percent~~%)

3) Otherwise, where the project activity involves no permanent reduction in timber supply, $LF_t$ = 0.1 (10% ~~percent~~).

## 8.4 Net ~~GHG Emission~~ Reductions and ~~Carbon Dioxide~~ Removals

Net GHG emission reductions in each year are quantified as:

$$ER_t = \left(\left(A_t \times \overline{ER_t}\right) + LK_{ER,t}\right) \text{~~}\left(A_t \times \overline{ER_t} + LK_{ER,t}\right)\text{~~} \times (1 - UNC_t) \quad (26)$$

Where:

| | | |
|---|---|---|
| $ER_t$ | = | Net GHG emission reductions in year *t* (t $CO_2e$) |
| $A_t$ | = | Project area in year *t* (unit area) |
| $\overline{ER_t}$ | = | Mean GHG emission reductions in year *t* (t $CO_2e$/unit area/year) |
| $LK_{ER,t}$ | = | Leakage allocated to GHG emission reductions in year *t* (t $CO_2e$) |
| $UNC_t$ | = | Uncertainty in year *t* (percent) |

Net carbon dioxide removals in each year are quantified as:

$$CR_t = \left(\left(A_t \times \overline{CR_t}\right) + LK_{CR,t}\right) \text{~~}\left(A_t \times \overline{CR_t} + LK_{CR,t}\right)\text{~~} \times (1 - UNC_t) \quad (27)$$

Where:

| | | |
|---|---|---|
| $CR_t$ | = | Net carbon dioxide removals in year *t* (t $CO_2e$) |
| $A_t$ | = | Project area in year *t* (unit area) |
| $\overline{CR_t}$ | = | Mean carbon dioxide removals in year *t* (t $CO_2e$/unit area/year) |
| $LK_{CR,t}$ | = | Leakage allocated to carbon dioxide removals in year *t* (t $CO_2e$) |
| $UNC_t$ | = | Uncertainty in year *t* (percent) |

Leakage allocated to GHG emission reductions ($LK_{ER,t}$) is calculated as:

$$LK_{ER,t} = LK_t \times \frac{\overline{ER_t}}{\overline{ER_t} + \overline{CR_t}} \quad (28)$$

Where:

| | | |
|---|---|---|
| $LK_{ER,t}$ | = | Leakage allocated to GHG emission reductions in year *t* (t $CO_2e$) |
| $LK_t$ | = | Leakage in year *t* (t $CO_2e$) |
| $\overline{ER_t}$ | = | Mean GHG emission reductions in year *t* (t $CO_2e$/unit area/year) |
| $\overline{CR_t}$ | = | Mean carbon dioxide removals in year *t* (t $CO_2e$/unit area/year) |

Leakage allocated to carbon dioxide removals ($LK_{CR,t}$) is calculated as:

$$LK_{CR,t} = LK_t \times \frac{\overline{CR_t}}{\overline{ER_t} + \overline{CR_t}} \quad (29)$$

Where:

| | | |
|---|---|---|
| $LK_{CR,t}$ | = | Leakage allocated to carbon dioxide removals in year *t* (t $CO_2e$) |
| $LK_t$ | = | Leakage in year *t* (t $CO_2e$) |
| $\overline{ER_t}$ | = | Mean GHG emission reductions in year *t* (t $CO_2e$) |
| $\overline{CR_t}$ | = | Mean carbon dioxide removals in year *t* (t $CO_2e$) |

The mean GHG emission reductions and mean carbon dioxide removals in year *t* are affected by the carbon stock change in the baseline scenario in the following way:

1) Where the baseline carbon stock decreases from year *t* to year *t* + 1, emissions are occurring. In the project scenario, these emissions are avoided because of the project activities. Hence, a baseline carbon stock decrease results in GHG emission reductions in the same year.

2) Where the baseline carbon stock increases from year *t* to year *t* + 1, removals are occurring. The amount of removals occurring in the project scenario must be adjusted to reflect removals achieved in the absence of project activities. Hence, a baseline carbon stock increase results in decreased removals in the same year.

The mean GHG emission reductions and mean carbon dioxide removals in year *t* are affected by the cumulative carbon stock change in the project scenario in the following way:

a) Where the cumulative carbon stock change in the project scenario is positive (i.e., the project carbon stock is greater in year *t* than at the project start date), removals are generated.

b) Where the cumulative carbon stock change in the project scenario is negative (i.e., the project carbon stock is smaller in year *t* than at the project start date), reductions are generated.

Emission reductions are calculated for each sample unit *i* in year *t*, and the mean GHG emission reduction is quantified as:

$$\overline{ER_t} = I(\Delta CO2_{wp}) \times \frac{1}{n} \times \sum_{i=1}^{n} ( - PE_{i,t} - MIN(0, \Delta CO2_{bsl,i,t}) + MIN(0, \Delta CO2_{wp,i,t})) + (1 - I(\Delta CO2_{wp})) \times \frac{1}{n} \times \sum_{i=1}^{n} (PE_{i,t} - BE_{i,t} - MIN(0, \Delta CO2_{bsl,i,t}) + MIN(0, \Delta CO2_{wp,i,t}) + MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \quad (30)$$

Where:

$I(\Delta CO2_{wp}) = 1$ , if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ , if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} \leq 0$

| | | |
|---|---|---|
| $\overline{ER_t}$ | = | Mean GHG emission reductions in year *t* (t $CO_2e$/unit area/year) |
| $PE_{i,t}$ | = | Project emissions in composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $BE_{i,t}$ | = | Baseline emissions in composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $\Delta CO2_{bsl,i,t}$ | = | Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |
| $\Delta CO2_{wp,i,t}$ | = | Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t $CO_2e$/unit area/year)~~Carbon stock change in the project scenario at in sample unit *i* in year *t* (t $CO_2e$/unit area/year)~~ |
| $\Delta CO2_{wp,i,m}$ | = | Carbon stock change in the project scenario ~~at~~ in sample unit *i* in year *m* (t $CO_2e$/unit area/year) |
| *n* | = | Number of sample units in which stock change values are available for both the project and baseline scenarios |

Carbon dioxide removals are calculated for each sample unit *i* in year *t*, and the mean carbon dioxide removal is quantified as:

$$\overline{CR_t} = I(\Delta CO2_{wp}) \times \frac{1}{n} \times \sum_{i=1}^{n} (MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \quad (31)$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_{i=1}^{n} \sum_{m=1}^{t} \Delta CO2_{wp,i,m} \leq 0$

| | | |
|---|---|---|
| $\overline{CR_t}$ | = | Mean carbon dioxide removals in year *t* (t $CO_2e$/unit area/year) |
| $\Delta CO2_{wp,i,t}$ | = | Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO2e/unit area/year)~~Carbon~~ |

~~stock change in the project scenario at~~ in ~~sample unit *i* in year *t* (t $CO_2$e/unit area/year)~~

$\Delta CO2_{wp,i,m}$ = Carbon stock change in the project scenario ~~at~~ in sample unit *i* in year *m* (t $CO_2$e/unit area/year)

$\Delta CO2_{bsl,i,t}$ = Carbon stock change in the baseline scenario in composite baseline ~~at sample unit~~ *i* in year *t* (t $CO_2$e/unit area/year)

*n* = Number of sample units in which stock change values are available for both the project and baseline scenarios

Mean carbon stock change and GHG emission reductions are calculated using unbiased estimators, such as from Cochran, W. G. 1977. *Sampling Techniques*. ~~(~~3rd ed.~~).~~ John Wiley & Sons or Som, R. K. 1995. *Practical Sampling Techniques*. ~~(~~2nd ed.~~).~~ Taylor & Francis. ~~-~~Equations (30), (31), and (32), used to calculate $ER_t$, $CR_t$, and $UNC_t$, assume either:

1) ~~A~~a simple random sample (SRS) design; or

2) ~~A~~a two-stage sample with primary units (e.g., stands) selected via probability proportional to size (acreage) and secondary units (e.g., plots) selected via SRS or systematic sampling with a fixed sample size within each selected primary unit. In the latter case, a composite baseline would be matched to each primary unit on the basis of initial conditions averaged across the secondary units (many-to-many matching).

Other statistically robust sample designs (e.g., stratified samples) may be employed and the estimators of the mean and standard error reconfigured to permit unbiased estimation. Note that in Equations (30) and (31) only sample units *i* for which calculated stock change values at time *t* are available for both the project and baseline scenarios are included (i.e., two measurement events must have taken place in a sample unit and all of its matched constituent control plots before a paired sample *i* is included in the calculation of net GHG emission reductions). Calculations are summarized in~~-~~ Figure 1~~Figure 8~~.

~~**Figure 8: Summary of calculations**~~

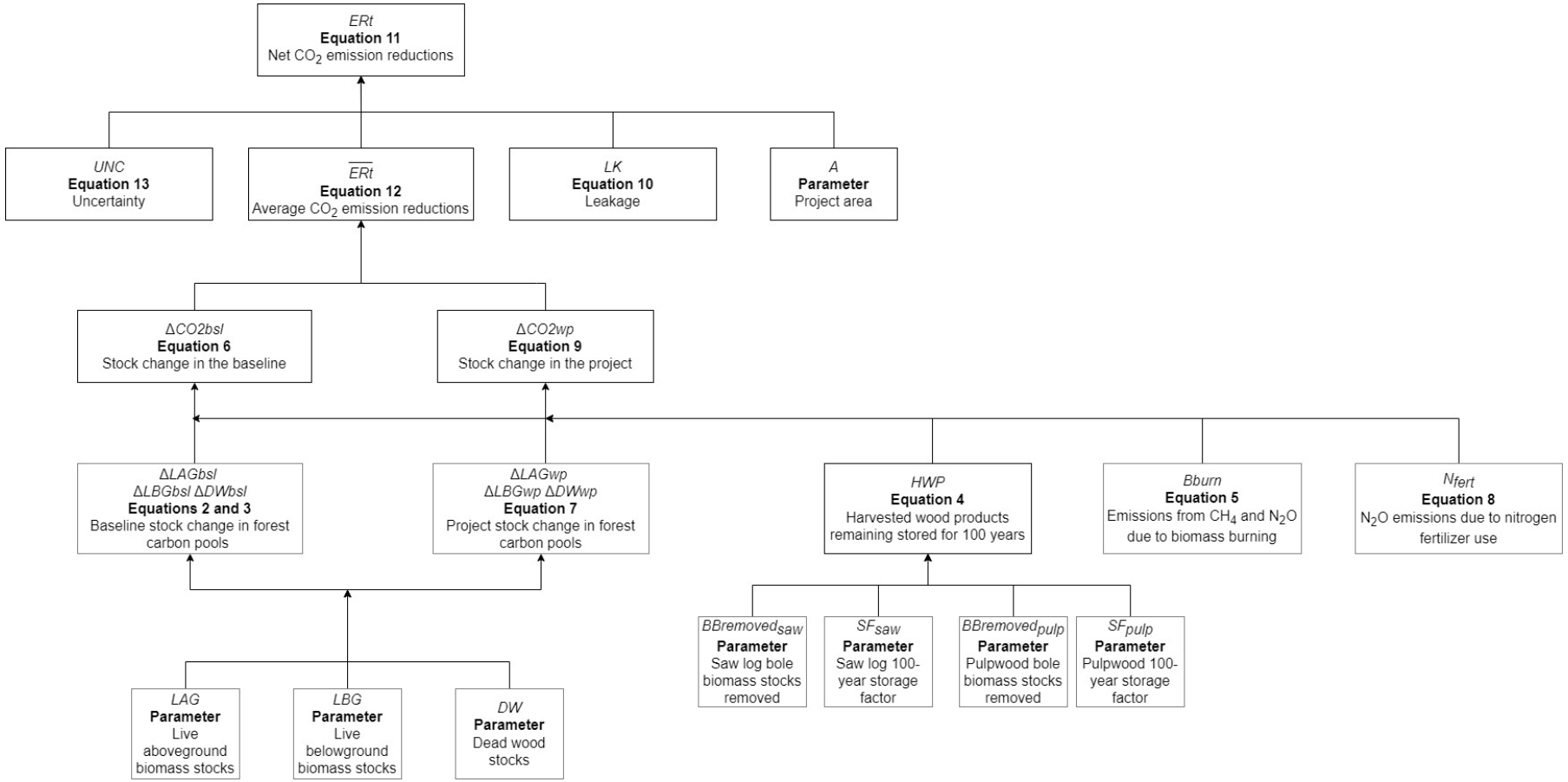


Figure 1. Summary of calculations

## 8.5 Uncertainty

Uncertainty associated with sampling error is quantified and accounted for. Uncertainty in area estimation is assumed to be zero and is addressed via using complete (and accurate) GIS boundaries of the project ~~area, and~~area and applying quality assurance / quality control (QA/QC) procedures specified in the parameter table for $A_t$[9]. When using the US Forest Service (USFS) Forest Inventory and Analysis (FIA) plot data to estimate forest area and construct composite baselines, project proponents must recognize that uncertainty in area estimates is unlikely to be zero due to the spatial distribution and sampling density of FIA plots. To address this, project proponents must implement a matching and weighting procedure that ensures composite baseline plots are appropriately representative of project conditions. The ~~methodology's~~ weighting term (~~e.g., $W_{bsl,i,j}$~~) accounts for the relative influence of each constituent plot, and project proponents ~~shall~~must quantify and propagate associated uncertainty in baseline emissions or removals using Equation (32)~~32~~. By applying weighted combinations of well-matched plots and excluding poorly matched outliers, this approach minimizes potential bias and supports the conservativeness of baseline estimates.

GHG ~~E~~emission reductions and carbon dioxide removals are estimated from paired composite baselines and project sample units, and uncertainty ($UNC_t$) is calculated as follows:

$$UNC_t = MIN(100\%, MAX\ (0, T \times \left(\left|\frac{1}{n} \times s_{wp,t}^2 + \frac{1}{n^2} \times \sum_{j=1}^{c}(\sum_{i=1}^{n} W_{bsl,i,j}{}^2 \times s_{bsl,t}^2\right|)\right)^{\frac{1}{2}} \times \left(\frac{1}{\overline{ER_t} + \overline{CR_t}}\right) - 15\%)) \quad (32)$$

Where:

| | | |
|---|---|---|
| $UNC_t$ | = | Uncertainty in year *t*, expressed as the half width of the 95% ~~percent~~ confidence interval as a percentage of the mean (percent) |
| $s_{wp,t}^2$ | = | Variance of stock change in the project scenario in the monitoring interval ending in year *t* (dimensionless) |
| $s_{bsl,t}^2$ | = | Variance of stock change in the baseline scenario in the monitoring interval ending in year *t* (dimensionless) |
| $W_{bsl,i,j}$ | = | Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless) |
| *T* | = | Critical value of a student's t distribution for significance level $\alpha$ = 0.05 (i.e., 1 – $\alpha$ = 95% ~~percent~~ confidence interval) |
| $\overline{ER_t}$ | = | Mean GHG emission reductions in year *t* (t $CO_2e$) |

[9] ~~When using FIA plot data to estimate forest area and construct composite baselines, project proponents shall recognize that uncertainty in area estimates is unlikely to be zero due to the spatial distribution and sampling density of FIA plots. To address this, proponents must implement a matching and weighting procedure that ensures composite baseline plots are appropriately representative of project conditions. The methodology's weighting term (e.g., $W_{bsl,i,j}$) accounts for the relative influence of each constituent plot, and project proponents shall quantify and propagate associated uncertainty in baseline emissions or removals using Equation 32. By applying weighted combinations of well-matched plots and excluding poorly matched outliers, this approach minimizes potential bias and supports the conservativeness of baseline estimates.~~

| | | |
|---|---|---|
| $\overline{CR_t}$ | = | Mean carbon dioxide removals in year *t* (t $CO_2e$) |
| *n* | = | Number of sample units for which stock change values are available in both the project and baseline scenarios |
| *c* | = | Total number of unique constituent baseline plots *j* |

Note that in Equation (32), only sample units *i* for which calculated stock change values at time *t* are available for both the project and baseline scenarios are included (i.e., two measurement events must have taken place in a sample unit and all of its matched constituent control plots before a paired sample *i* is included in the calculation of net GHG emission reductions).[10]

## 8.6 Calculation of Verified Carbon Units

To calculate the number of Verified Carbon Units (VCUs) that may be issued, the project proponent must consider the number of buffer credits which must be deposited in the AFOLU pooled buffer account. The number of buffer credits that must be deposited is calculated by multiplying the non-permanence risk rating by the net change in carbon stocks (see ~~Section 3.2.30 in~~ the ~~latest~~ most recent version of the *VCS Standard*):[11]

$$Bu_{CR,t} = I(\Delta CO2_{wp}) \times A_t \times \frac{1}{n} \times \sum_{i=1}^{n} \left( MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t}) \right) \times NPR\% \quad (33)$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} \leq 0$

| | | |
|---|---|---|
| $Bu_{CR,t}$ | = | Buffer credits to be deducted from removals in year *t* (t $CO_2e$) |
| $A_t$ | = | Project area in year *t* (unit area) |
| *n* | = | Number of sample units in which stock change values are available for both the project and baseline scenarios |
| $\Delta CO2_{wp,i,t}$ | = | Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO2e/unit area/year)~~Carbon stock change in the project scenario at in sample unit *i* in year *t* (t $CO_2e$/unit area/year)~~ |
| $\Delta CO2_{bsl,i,t}$ | = | Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year) |

[10] The aggregated uncertainty calculation presented in Equation ~~32~~(32) inherently reflects the uncertainties of individual input parameters— – such as carbon stock change, area, and plot-level measurements – —provided that standardized measurement protocols are properly applied. This ensures that overall uncertainty captures the combined effect of component-level variability, supporting robust and conservative quantification of baseline emissions or removals.

[11] Section ~~number~~3.15.16 from *VCS Standard, v4.7*

*NPR%* = Overall project non-permanence risk rating converted to a percentage

$$Bu_{ER,t} = I(\Delta CO2_{wp}) \times A_t \times \frac{1}{n} \times \sum_{i=1}^{n} (MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \times NPR\% + \left(1 - I(\Delta CO2_{wp})\right) \times A_t \times \frac{1}{n} \times \sum_{i=1}^{n} (MIN(0, \Delta CO2_{wp,i,t}) - MIN(0, \Delta CO2_{bsl,i,t}) + MAX(0, \Delta CO2_{wp,i,t}) - MAX(0, \Delta CO2_{bsl,i,t})) \times NPR\% \quad (34)$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_{i=1}^{n} \sum_{j=1}^{t} \Delta CO2_{wp,i,j} \leq 0$

$Bu_{ER,t}$ = Buffer credits to be deducted from reductions in year *t* (t $CO_2e$)

$A_t$ = Project area in year *t* (unit area)

*n* = Number of sample units in which stock change values are available for both the project and baseline scenarios

$\Delta CO2_{wp,i,t}$ = Average annual carbon stock change in the project scenario in sample unit *i* in the monitoring interval ending at time *t* (t CO2e/unit area/year)~~Carbon stock change in the project scenario at in sample unit *i* in year *t* (t $CO_2e$/unit area/year)~~

$\Delta CO2_{bsl,i,t}$ = Carbon stock change in the baseline scenario in composite baseline *i* in year *t* (t $CO_2e$/unit area/year)

*NPR%* = Overall project non-permanence risk rating converted to a percentage (percent)

$$VCU_{CR,t} = CR_t - Bu_{CR,t} \quad (35)$$

Where:

$VCU_{CR,t}$ = Number of Verified Carbon Units, in year *t*, that result from project activities leading to removals

$CR_t$ = Net carbon dioxide removals in year *t* ~~since the start of the project activity, in the project scenario~~ (t $CO_2e$)

$Bu_{CR,t}$ = Buffer credits to be deducted from removals in year *t* (t $CO_2e$)

$$VCU_{ER,t} = ER_t - Bu_{ER,t} \quad (36)$$

Where:

| | | |
|---|---|---|
| $VCU_{ER,t}$ | = | Number of Verified Carbon Units, in year *t*, that result from project activities leading to reductions |
| $ER_t$ | = | Net GHG emission reductions in year *t* ~~since the start of the project activity, in the project scenario~~ (t $CO_2e$) |
| $Bu_{ER,t}$ | = | Buffer credits to be deducted from reductions in year *t* (t $CO_2e$) |

# 9 MONITORING

## 9.1 Data and Parameters Available at Validation

| | |
|---|---|
| **Data/Parameter** | $A_t$ |
| **Data unit** | Unit area |
| **Description** | Project area at time *t* |
| **Equations** | (1), (2), (25), (26), (27) |
| **Source of data** | Calculated from GIS data, composed of an aggregate of stands individually delineated at *t* = 0 (or time of inclusion as an instance of a grouped project) |
| **Value applied** | N/A |
| **Justification of choice of data or description of measurement methods and procedures applied** | Delineation of the project area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks, or other intersection points. |
| **Purpose of data** | Reference for other area measures |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $W_{bsl,i,j}$ |
| **Data unit** | Dimensionless |
| **Description** | Weight of constituent baseline plot *j* in matched composite baseline *i* |

| | |
|---|---|
| **Equations** | (6), (7), (8), (12), (25), (32) |
| **Source of data** | Derived following procedures in Appendix 1. ~~Weights are derived to produce an optimal match to the paired project sample unit in terms of one or more specified initial condition covariates.~~ |
| **Value applied** | Between 0 and 1 |
| **Justification of choice of data or description of measurement methods and procedures applied** | Weights are derived to produce an optimal match to the paired project sample unit in terms of one or more specified initial condition covariates. |
| **Purpose of data** | Calculation of baseline emissions |
| **Comments** | Weight for each constituent baseline plot is determined at $t$ = 0 and fixed throughout the crediting period, except where a constituent baseline plot has become invalid (e.g., where a unit is now located within a registered GHG mitigation project area, or where it has not been re-measured in >10 years; see Section 6), in which case all weights in the respective composite baseline are recalculated to sum to 1, retaining the relative weights of the remaining constituent plots. |

| | |
|---|---|
| **Data/Parameter** | $SF_{~~*~~saw,wt}$<br>$SF_{pulp,wt}$ |
| **Data unit** | Dimensionless |
| **Description** | ~~Mass remaining stored in use and landfills over 100 years in wood component * (saw log or pulpwood) in wood type *wt* (softwood, sfw or hardwood, hwd)~~ Saw log 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type *wt* (softwood, sfw, or hardwood, hwd)<br>Pulpwood 100-year average storage factor (mass remaining stored in use and landfills over 100 years) for wood type ~~*wt* (softwood,~~ (sfw or ~~hardwood,~~ hwd) |
| **Equations** | (9) |
| **Source of data** | Table 6-A-5 in Hoover, C., R. Birdsey, B. ~~R.,~~ Goines, et al. ~~B., Lahm, P., Fan, Y., Nowak, D., Prisley, S., Reinhardt, E., Skog, K., Skole, D., Smith, J., Trettin, C., & Woodall, C. (2014).~~ "Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems." In *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*. Technical Bulletin Number 1939, edited by M. Eve, D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, ~~&~~and S. Biggar ~~(Eds.), *Quantifying greenhouse gas fluxes in agriculture and forestry:*~~ |

| | |
|---|---|
| | ~~*Methods for entity scale inventory*. Technical Bulletin Number 1939 (pp. 6.1–6.114)~~. USDA Office of the Chief Economist.[12] |
| Value applied | |

| US region and timber type | $SF_{saw}$ Saw log mass remaining stored in use and landfills after 100 years | $SF_{pulp}$ Pulpwood mass remaining stored in use and landfills after 100 years |
|---|---|---|
| Northeast softwood | 0.402 | 0.136 |
| Northeast hardwood | 0.437 | 0.323 |
| North Central softwood | 0.442 | 0.138 |
| North Central hardwood | 0.411 | 0.370 |
| Pacific Northwest (east) softwood | 0.415 | 0.415 |
| Pacific Northwest (west) softwood | 0.511 | 0.119 |
| Pacific Northwest (west) hardwood | 0.284 | 0.284 |
| Pacific Southwest softwood | 0.444 | 0.444 |
| Rocky Mountain softwood | 0.463 | 0.463 |
| Southeast softwood | 0.423 | 0.191 |
| Southeast hardwood | 0.417 | 0.242 |
| South Central softwood | 0.415 | 0.215 |
| South Central hardwood | 0.393 | 0.229 |
| Other West hardwood | 0.357 | 0.357 |

| | |
|---|---|
| Justification of choice of data or description of measurement methods and procedures applied | An explanation of the 100-year average method for ~~HWP~~ harvested wood product carbon storage is given in Hoover et al. (2014) in Section 6.5.1 (p. 6-67 "The intent of this measure is to approximate the average annual climate benefit of withholding carbon from the atmosphere by a certain amount each year for 100 years as described by a "decay" |

[12] Available at: https://www.fs.usda.gov/treesearch/pubs/46322

| | |
|---|---|
| | curve. This average benefit is one that can be credited in the year of harvest. This estimate of average effect is conceptually similar to the measure of the radiative forcing impact of a current year emission of $CO_2$, $CH_4$, or other GHG. One ton of $CO_2$ emissions—in GHG accounting—is equated to the radiative forcing it causes over the 100 years following the emission. The radiative forcing caused in each year is weighted the same over each of the 100 years. We are suggesting the same convention in weighting the carbon storage in wood products equally for each of 100 years.") |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | Regions are defined in Hoover et al. (2014). Parameter values above are for application in the United States. Outside of the United States, parameters may be derived from other relevant published sources (e.g., Winjum et al. 1998[13]). |

| | |
|---|---|
| **Data/Parameter** | $GWP_g$ |
| **Data unit** | Dimensionless |
| **Description** | Global warming potential of gas *g* |
| **Equations** | (10) |
| **Source of data** | As set out in the ~~latest~~ most recent version of the *VCS Standard* |
| **Value applied** | ~~A global warming potential of 25 and 298 are applied for $CH_4$ and $N_2O$ respectively.~~See the most recent version of the *VCS Standard.* |
| **Justification of choice of data or description of measurement methods and procedures applied** | Unless otherwise directed by the VCS Program, the ~~latest~~ most recent version of the *VCS Standard* requires that $CH_4$ and $N_2O$ must be converted to $CO_2e$ using the 100-year global warming potential derived from the IPCC Fourth Assessment Report. |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $C_f$ |

[13] Winjum, J. K., S. Brown, ~~S., &~~ and B. Schlamadinger~~, B.~~ (~~1~~1998~~)~~). "Forest Harvests and Wood Products: Sources and Sinks of Atmospheric Carbon Dioxide." *Forest Science*~~,~~ 44 (2)~~:~~ 272–~~2~~84.

| | |
|---|---|
| **Data unit** | Proportion of pre-fire fuel biomass consumed |
| **Description** | Combustion factor |
| **Equations** | (10) |
| **Source of data** | Table 3A.1.12 in IPCC (2003). *Good Practice Guidance for Land Use, Land-use Change and Forestry*[14] |
| **Value applied** | The combustion factor is selected based on the forest type. |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $EF_g$ |
| **Data unit** | g/kg dry matter burned |
| **Description** | Emission factor for gas *g* |
| **Equations** | (10) |
| **Source of data** | Table 3A.1.16 in IPCC (2003). *Good Practice Guidance for Land Use, Land-use Change and Forestry* |
| **Value applied** | The emission factor is selected based on the forest type. |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | None |

[14] Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf

| | |
|---|---|
| **Data/Parameter** | $EF_{Ndirect}$ |
| **Data unit** | t $N_2O$-N/t N applied |
| **Description** | Emission factor for direct nitrous oxide emissions from ~~N~~nitrogen additions from synthetic fertilizers, organic amendments, and crop residues |
| **Equations** | (17) |
| **Source of data** | Table 11.1 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[15] |
| **Value applied** | 0.01 |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | Emission factor applicable to N additions from mineral fertilizers, organic amendments, and crop residues |

| | |
|---|---|
| **Data/Parameter** | $Frac_{GASF}$ |
| **Data unit** | Dimensionless |
| **Description** | Fraction of all synthetic nitrogen~~N~~ added to soils that volatilizes as ~~$NH_3$~~ ammonia and $NO_x$ |
| **Equations** | (21) |
| **Source of data** | Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* |
| **Value applied** | 0.1 |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |

[15] Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

| | |
|---|---|
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $Frac_{GASM}$ |
| **Data unit** | Dimensionless |
| **Description** | Fraction of all organic nitrogen~~N~~ added to soils that volatilizes as ~~$NH_3$~~ ammonia and $NO_x$ |
| **Equations** | (21) |
| **Source of data** | Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* |
| **Value applied** | 0.3 |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $EF_{Nvolat}$ |
| **Data unit** | t $N_2O$-N/(t $NH_3$-N + $NO_x$-N volatilized) |
| **Description** | Emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen~~N~~ on soils and water surfaces |
| **Equations** | (21) |
| **Source of data** | Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* |
| **Value applied** | 0.01 |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |

| | |
|---|---|
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $Frac_{LEACH}$ |
| **Data unit** | Dimensionless |
| **Description** | Fraction of nitrogen~~N~~ (synthetic or organic) added to soils that is lost through leaching and runoff, in regions where leaching and runoff occurs |
| **Equations** | (22) |
| **Source of data** | Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* |
| **Value applied** | 0.3 |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $EF_{Nleach}$ |
| **Data unit** | t $N_2O$-N/t N leached and runoff |
| **Description** | Emission factor for nitrous oxide emissions from leaching and runoff |
| **Equations** | (22) |
| **Source of data** | Table 11.3 in Chapter 11, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* |
| **Value applied** | 0.0075 |
| **Justification of choice of data or description of measurement methods and procedures applied** | See source of data |
| **Purpose of data** | Calculation of baseline and project emissions |

| | |
|---|---|
| **Comments** | None |

## 9.2 Data and Parameters Monitored

| | |
|---|---|
| **Data/Parameter** | $X_{bsl,i,j,t}$ ~~and~~ $X_{wp,i,t}$ |
| **Data unit** | Years |
| **Description** | Length of measurement interval ending at time *t* for constituent baseline plot *ij*~~, and~~<br>Length of measurement interval ending at time *t* for sample unit *i* in the project scenario |
| **Equations** | (3), (4), (5)<br>~~and~~ (13), (14), (15) |
| **Source of data** | Monitored |
| ~~Justification of choice of data or d~~**Description of measurement methods and procedures to be applied** | N/A |
| ~~Frequency of monitoring/recording~~ | Subject to measurement interval of baseline and project plots |
| ~~QA/QC procedures to be applied~~ | N/A |
| **Purpose of data** | Calculation of project and baseline emissions |
| ~~Calculation method~~ | N/A |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $LAG_{bsl,i,j,t}$<br>$LAG_{wp,i,t}$ ~~and $LAG_{bsl,i,j,t}$~~ |
| **Data unit** | t $CO_2$e/unit area |
| **Description** | ~~Live aboveground biomass stocks in the project scenario at sample unit *i* at time *t*, and~~ |

| | |
|---|---|
| | Live aboveground biomass stocks in the baseline scenario at constituent baseline plot *j* of composite baseline *i* at time *t*<br>Live aboveground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* |
| **Equations** | ~~(13)~~(13) and (3), (10)<br>(13)<br><br>Derivation of $BBremoved_{saw}$ and $BBremoved_{pulp}$ parameters |
| **Source of data** | Measured in project area |
| **Description of measurement methods and procedures to be applied** | Live aboveground biomass is measured via plot-based sampling. Acknowledging the wide range of valid approaches, and that relative efficiency and robustness are circumstance-specific, procedures for sampling, measurement, and estimation are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Project proponents must ensure that forest carbon stock estimates are representative of the diversity of conditions present across the project area. To this end, sampling must adhere to best practices in sample plot design, including the establishment of a minimum number of plots per primary sampling unit, determined as a function of project area and heterogeneity. Stratification should be used to capture variation in forest types, site productivity, disturbance history, and management regimes. The sampling design must be capable of supporting robust estimates across all strata, with justification provided for plot allocation and design choices to ensure transparency and reproducibility.~~Stratification may be employed to improve precision but is not required.~~ In general, s~~S~~ample measurements must:<br>1) b~~B~~e demonstrated to be unbiased and derived from representative sampling.~~;~~<br>2) ~~Ensure accuracy of measurements through~~ adhere~~nce~~ to best practices and ~~quality assurance/quality control (~~QA/QC~~)~~ procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection) to ensure accuracy.~~; and~~<br>3) a~~A~~pply fixed diameter at breast height (dbh) and any other size thresholds.<br><br>Aboveground biomass of each sampled tree ~~will be~~is estimated using published allometric equations (in the United States, using Jenkins et al. (2003) or stem volume-referenced component ratio methods per Woodall et al. (2011)) applied to one or more measured tree attributes, minimally including dbh. Where using component ratio methods, stem volumes must be estimated by applying published volume equations (in the United States, using equations included in the USFS ~~Forest Service~~ |

| | |
|---|---|
| | National Volume Estimator Library, NVEL[16]) specific to species, genus, or family, in descending order of preference, as available.<br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in:<br>• Kershaw Jr, J. A., M. J. Ducey, T. W. ~~M. J., B.~~ Beers, ~~T. W., &~~ and B. Husch~~, B~~. ~~(~~2016~~)~~. *Forest Mensuration*. John Wiley & Sons.<br>• Avery, T. E., ~~&~~ and H. E. Burkhart~~, H. E~~. ~~(~~2015~~)~~. *Forest Measurements*. Waveland Press.<br>• US Forest Service Department of Agriculture. ~~(~~2019~~)~~. *Field Data Collection Procedures for Phase 2 Plots*. Forest Inventory and Analysis National Core Field Guide.[17]<br>Measurement protocols must be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br>Carbon is calculated from biomass by applying a carbon fraction of 0.5, and carbon dioxide equivalent ($CO_2e$) is calculated from carbon applying the factor 44/12. |
| **Frequency of monitoring/recording** | Initial measurement at or preceding time *t* = 0 and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline |
| **QA/QC procedures to be applied** | N/A |
| **Purpose of data** | Calculation of project and baseline emissions |
| **Calculation method** | See description of measurement methods and procedures to be applied |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $LBG_{bsl,i,j,t}$<br>$LBG_{wp,i,t}$ ~~and $LBG_{bsl,i,j,t}$~~ |
| **Data unit** | t $CO_2e$/unit area |
| **Description** | ~~Live belowground biomass stocks in the project scenario at sample unit *i* at time *t*, and~~<br>Live belowground biomass stocks in the baseline scenario at constituent baseline plot *j* of composite baseline *i* at time *t* |

[16] Available at: https://www.fs.usda.gov/forestmanagement/products/measurement/volume/nvel/index.php

[17] Available at: https://www.fia.fs.usda.gov/library/field-guides-methods-proc/docs/2022/core_ver9-2_9_2022_SW_HW%20table_rev_12_13_2022.pdf

| | |
|---|---|
| | Live belowground biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t* |
| **Equations** | (4)<br>(14)<br>~~and (4)~~(4)<br>Derivation of $BBremoved_{saw}$ and $BBremoved_{pulp}$ parameters |
| **Source of data** | Measured in project area |
| **Description of measurement methods and procedures to be applied** | Live belowground biomass is estimated via component ratio methods (e.g., root to shoot ratios) applied to direct measurements from plot-based sampling. Acknowledging the wide range of valid approaches, and that relative efficiency and robustness are circumstance-specific, procedures for sampling, measurement, and estimation are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required.<br>Sample measurements must:<br>1) be demonstrated to be unbiased and derived from representative sampling.~~;~~<br>2) ~~ensure accuracy of measurements through~~ adhere~~nce~~ to best practices and ~~quality assurance/quality control (~~QA/QC~~)~~ procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection) to ensure accuracy.~~;~~ ~~and~~<br>3) apply fixed dbh and any other size thresholds.<br>Belowground biomass of each sampled tree is estimated using published component ratios (in the United States, using Jenkins et al. (2003)).<br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in:<br>Kershaw Jr, J. A., M. J. Ducey, T. W. ~~M. J., Beers, T. W., &~~ and B. Husch~~, B. (~~2016~~)~~. *Forest Mensuration*. John Wiley & Sons.<br>Avery, T. E., ~~&~~and H. E. Burkhart~~,~~. ~~H. E. (~~2015~~)~~. *Forest Measurements*. Waveland Press.<br>US Forest Service Department of Agriculture. ~~(~~2019~~)~~. *Field Data Collection Procedures for Phase 2 Plots*. Forest Inventory and Analysis National Core Field Guide.<br>Measurement protocols must be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br>Carbon is calculated from biomass by applying a carbon fraction of 0.5, and carbon dioxide equivalent ($CO_2e$) is calculated from carbon applying the factor 44/12. |

| | |
|---|---|
| Frequency of monitoring/recording | Initial measurement at or preceding time *t* = 0 and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline |
| QA/QC procedures to be applied | N/A |
| Purpose of data | Calculation of project and baseline emissions |
| Calculation method | See description of measurement methods and procedures to be applied |
| Comments | None |

| | |
|---|---|
| Data/Parameter | $DW_{bsl,i,j,t}$<br>$DW_{wp,i,t}$ and ~~$DW_{bsl,i,j,t}$~~ |
| Data unit | t $CO_2$e/unit area |
| Description | Dead wood biomass stocks in the project scenario in sample unit *i* in the monitoring interval ending at time *t*~~, and~~<br>Dead wood biomass stocks in the baseline scenario in constituent baseline plot *j* of composite baseline *i* at time *t* |
| Equations | (5), (10)<br>(15) ~~and (5)(5), (10)(10)~~ |
| Source of data | Field measurements |
| Description of measurement methods and procedures to be applied | Standing dead wood is sampled via plot-based forest inventory methods, and lying dead wood via line intersect sampling,[18] perpendicular distance sampling,[19] or other unbiased approaches. Specific sample designs/intensities, and measurement and estimation procedures may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required. |

[18] Warren, W. G., ~~&~~and P. F. Olsen~~, P. F.~~ (~~1964~~). "A Line Intersect Technique for Assessing Logging Waste." *Forest Science*~~,~~ 10 (3)~~:~~ 267–~~2~~76.

Van Wagner, C. E. (~~1968~~). "The Line Intersect Method in Forest Fuel Sampling." *Forest Science*~~,~~ 14 (1)~~:~~ 20–~~2~~6.

[19] Williams, M. S., ~~&~~and J. H. Gove~~,~~ ~~J. H.~~ (~~2003~~). "Perpendicular Distance Sampling: An Alternative Method for Sampling Downed Coarse Woody Debris." *Canadian Journal of Forest Research*~~,~~ 33 (8)~~:~~ 1564–~~15~~79. https://doi.org/10.1139/x03-056

Williams, M. S., H. T.~~,~~ Valentine, J. H.~~,~~ ~~H. T.,~~ Gove, ~~J. H., &~~ ~~J. H.,~~ and M. J. Ducey~~,~~ ~~M. J.~~ (~~2005~~). "Additional Results for Perpendicular Distance Sampling." *Canadian Journal of Forest Research*~~,~~ 35 (4)~~:~~ 961–~~96~~6. https://doi.org/10.1139/x05-023

Ducey, M. J., M. S.~~,~~ Williams, J. H.~~,~~ ~~M. S.,~~ Gove, S. ~~J. H.,~~ Roberge, ~~S., &~~and R. S. Kenning~~,~~ ~~R. S.~~ (~~2013~~). "Distance-limited Perpendicular Distance Sampling for Coarse Woody Debris: Theory and Field Results." *Forestry*~~,~~ 86 (1)~~:~~ 119–~~1~~28. https://doi.org/10.1093/forestry/cps059

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| | Sample measurements must:<br>1) be demonstrated to be unbiased and derived from representative sampling.~~;~~<br>2) ~~ensure accuracy of measurements through~~ adhere~~nce~~ to best practices and ~~quality assurance/quality control (~~QA/QC~~)~~ procedures (to be determined by the project proponent and outlined in standard operating procedures governing field data collection) to ensure accuracy.~~; and~~<br>3) apply fixed size thresholds.<br>For each standing dead tree, stem volume must be estimated using published volume equations (in the United States, using equations included in the USFS ~~Forest Service~~ National Volume Estimator Library, NVEL) specific to species, genus, or family, in descending order of preference, as available. The equations must be applied to one or more measured tree attributes, minimally including dbh and remaining stem height. Note that standing dead wood is restricted here to aboveground stem (bole) biomass.<br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field, applying established best practices such as those found in:<br>Kershaw Jr, J. A., M. J. Ducey, T. W. ~~M. J.,~~ Beers, ~~T. W., &~~ and B. Husch~~,~~ ~~B.~~ ~~(~~2016~~)~~. *Forest Mensuration*. John Wiley & Sons.<br>Avery, T. E., ~~&~~and H. E. Burkhart~~.,~~ ~~H. E. (~~2015~~)~~. *Forest Measurements*. Waveland Press.<br>US Forest Service Department of Agriculture. ~~(~~2019~~)~~. *Field Data Collection Procedures for Phase 2 Plots*. Forest Inventory and Analysis National Core Field Guide.<br>Measurement protocols must be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br>Biomass of standing and lying dead wood must be estimated from sampled volumes using published wood densities specific to species, genus, or family, in descending order of preference, as available and density reduction factors referencing decomposition states (e.g., procedures per Harmon et al. 2011[20]).<br>Carbon is calculated from biomass by applying a carbon fraction of 0.5, and carbon dioxide equivalent ($CO_2e$) calculated from carbon applying the factor 44/12. |
| **Frequency** of monitoring/recording | Initial measurement at or preceding time $t$ = 0 and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline |

[20] Harmon, M. E., Woodall, C. W., Fasth, B., Sexton, J., & Yatkov, M. (2011). *Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species*. Res. Pap. NRS-15. US Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RP-15

| | |
|---|---|
| QA/QC procedures to be applied | N/A |
| Purpose of data | Calculation of project and baseline emissions |
| Calculation method | See description of measurement methods and procedures to be applied |
| Comments | None |

| | |
|---|---|
| Data/Parameter | $BBremoved_{saw,wt,bsl,i,j,t}$ ~~and~~ $BBremoved_{saw,wt,wp,i,t}$ |
| Data unit | t $CO_2$e/unit area |
| Description | Saw log bole biomass stocks in wood type *wt* (*wt* = softwood, sfw or hardwood, hwd) in commercial species removed in the baseline scenario in constituent baseline plot *j* of composite baseline *i* in the monitoring interval ending at time *t*~~, and~~<br>Saw log bole biomass stocks in wood type *wt* (*wt* = softwood, sfw or hardwood, hwd) in commercial species removed in the project scenario ~~at~~ in sample unit *i* in the monitoring interval ending at time *t* |
| Equations | (9) |
| Source of data | Field measurements from permanent plots subject to harvest in the monitoring interval ending at time *t* |
| Description of measurement methods and procedures to be applied | Saw logs will be distinguished from pulpwood on the basis of dbh:<br>1) Softwood saw logs are from trees with at least 22.9 cm (9 in) dbh.<br>2) Hardwood saw logs are from trees with at least 27.9 cm (11 in) dbh.<br>Saw log bole biomass is estimated for saw log-sized stems cut and removed in the monitoring interval ending at time *t,* from the most recent pre-harvest measurements preceding time *t* (i.e., $LAG_{i,t-x}$), via either of the following two approaches.<br><br>**Approach 1 – Estimate bole volume and apply wood density**<br>Bole biomass is estimated by applying published volume equations (e.g., those included in the USFS ~~Forest Service~~ National Volume Estimator Library, NVEL) and wood densities (specific to species, genus, or family, in descending order of preference, as available).<br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in:<br>Kershaw Jr, J. A., M. J. Ducey, T. W. ~~M. J.,~~ Beers, ~~T. W., &~~ and B. Husch~~,~~ ~~B.~~ ~~(~~2016~~)~~. *Forest Mensuration*. John Wiley & Sons. |

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|---|---|
| | Avery, T. E., and H. E.~~&~~ Burkhart~~,~~. ~~H. E. (~~2015~~)~~. *Forest Measurements*. Waveland Press.<br>US Forest Service Department of Agriculture. ~~(~~2019~~)~~. *Field Data Collection Procedures for Phase 2 Plots.* Forest Inventory and Analysis National Core Field Guide.<br>Measurement protocols must be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br>**Approach 2 – Estimate aboveground biomass and apply stem component ratio**<br>Bole biomass is estimated by applying a published stem component ratio to total aboveground biomass estimated using a published allometric equation (e.g., in the United States, using Jenkins et al. (2003) for stem component ratios and total aboveground biomass equations).<br>Carbon is calculated from biomass by applying a carbon fraction of 0.5, and carbon dioxide equivalent ($CO_2e$) is calculated from carbon applying the factor 44/12.<br>Note that these parameters are restricted to commercial species. In the United States, commercial species are defined as those not from species groups 23, 43, ~~and~~ or 48 (see FIA Database User Guide Appendix E[21]). |
| **Frequency of monitoring/recording** | Initial measurement at or preceding time $t$ = 0 and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline |
| **QA/QC procedures to be applied** | N/A |
| **Purpose of data** | Calculation of project and baseline emissions |
| **Calculation method** | See description of measurement methods and procedures to be applied |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $BBremoved_{pulp,wt,bsl,i,j,t}$<br>~~and~~ $BBremoved_{pulp,wt,wp,i,t}$ |
| **Data unit** | t $CO_2e$/unit area |
| **Description** | Pulpwood bole biomass stocks in wood type *wt* (*wt* = softwood, sfw or hardwood, hwd) in commercial species removed in the baseline |

[21] Available at: https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

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|---|---|
| | scenario at constituent baseline plot *j* of composite baseline *i* in the monitoring interval ending at time *t*~~, and~~<br>Pulpwood bole biomass stocks in wood type *wt* (*wt* = softwood, sfw or hardwood, hwd) in commercial species removed in the project scenario ~~at~~ in sample unit *i* in the monitoring interval ending at time *t* |
| **Equations** | (9) |
| **Source of data** | Field measurements from permanent plots subject to harvest in the monitoring interval ending at time *t* |
| **Description of measurement methods and procedures to be applied** | Pulpwood logs are distinguished from saw logs on the basis of diameter at breast height:<br>1) Softwood pulpwood is from trees with 12.7 to 22.8 cm (5.0 to 8.9 in) dbh.<br>2) Hardwood pulpwood is from trees with 12.7 to 27.8 cm (5.0 to 10.9 in) dbh.<br>Pulpwood bole biomass is estimated for pulpwood-sized stems cut and removed in the monitoring interval ending at time *t,* from the most recent pre-harvest measurements (i.e., $LAG_{i,t-X}$), via either of the following two approaches.<br><br>**Approach 1 – Estimate bole volume and apply wood density**<br>Bole biomass is estimated by applying published volume equations (e.g., equations included in the USFS ~~Forest Service~~ National Volume Estimator Library, NVEL) and wood densities (specific to species, genus, or family, in descending order of preference, as available).<br>Tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be directly measured in the field applying established best practices, such as those found in:<br>Kershaw Jr, J. A., M. J. Ducey, T. W. ~~M. J.,~~ Beers, ~~T. W., &~~ and B. Husch~~, B.~~ (2016~~)~~. *Forest Mensuration*. John Wiley & Sons.<br>Avery, T. E., and H. E.~~&~~ Burkhart~~, H. E.~~ (2015~~)~~. *Forest Measurements*. Waveland Press.<br>US Forest Service Department of Agriculture. (2019~~)~~. *Field Data Collection Procedures for Phase 2 Plots.* Forest Inventory and Analysis National Core Field Guide.<br>Measurement protocols must be detailed in standard operating procedures. Parameter tables for all tree attributes (e.g., dbh, total height) incorporated as independent variables in allometric equations must be included in the project description under Data and Parameters Monitored.<br>**Approach 2 – Estimate aboveground biomass and apply stem component ratio**<br>Bole biomass is estimated by applying a published stem component ratio to total aboveground biomass estimated using a published allometric equation (e.g., in the United States using Jenkins et al. |

| | |
|---|---|
| | (2003) for stem component ratios and total aboveground biomass equations).<br>Carbon is calculated from biomass by applying a carbon fraction of 0.5, and carbon dioxide equivalent ($CO_2e$) is calculated from carbon applying the factor 44/12.<br>Note that these parameters are restricted to commercial species. In the United States, commercial species are defined as those not from species groups 23, 43, ~~and~~ or 48 (see FIA Database User Guide Appendix E[22]). |
| Frequency of monitoring/recording | Initial measurement at or preceding time *t* = 0 and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline |
| QA/QC procedures to be applied | N/A |
| Purpose of data | Calculation of project and baseline emissions |
| Calculation method | See description of measurement methods and procedures to be applied |
| Comments | None |

| | |
|---|---|
| Data/Parameter | $M_{wp,SF,i,t}$ |
| Data unit | t fertilizer/unit area |
| Description | Mass of project nitrogen~~N~~-containing synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time ~~year~~ *t* |
| Equations | (18) |
| Source of data | Application records, substantiated with one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts, or invoices) |
| Description of measurement methods and procedures to be applied | See source of data |
| Frequency of monitoring/recording | Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project |

[22] Available at: https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

| | |
|---|---|
| QA/QC procedures to be applied | N/A |
| Purpose of data | Calculation of project emissions |
| Calculation method | N/A |
| Comments | None |

| | |
|---|---|
| Data/Parameter | $NC_{wp,SF,i,t}$ |
| Data unit | t N/t fertilizer |
| Description | Nitrogen content of project synthetic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* |
| Equations | (18) |
| Source of data | N content is determined following fertilizer manufacturer's specifications. |
| Description of measurement methods and procedures to be applied | See source of data |
| Frequency of monitoring/recording | Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project |
| QA/QC procedures to be applied | N/A |
| Purpose of data | Calculation of project emissions |
| Calculation method | N/A |
| Comments | None |

| | |
|---|---|
| Data/Parameter | $M_{wp,OF,i,t}$ |
| Data unit | t fertilizer/unit area |
| Description | Mass of project nitrogen~~N~~-containing organic fertilizer applied to sample unit *i* in the monitoring interval ending at ~~year~~ time *t* |
| Equations | (19) |

| | |
|---|---|
| Source of data | Application records, substantiated with one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts, or invoices) |
| Description of measurement methods and procedures to be applied | See source of data |
| Frequency of monitoring/recording | Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project |
| QA/QC procedures to be applied | N/A |
| Purpose of data | Calculation of project emissions |
| Calculation method | N/A |
| Comments | None |

| | |
|---|---|
| Data/Parameter | $NC_{wp,OF,i,t}$ |
| Data unit | t N/t fertilizer |
| Description | Nitrogen content of project organic fertilizer applied to sample unit *i* in the monitoring interval ending at time *t* |
| Equations | (19) |
| Source of data | Peer-reviewed published data may be used. For example, default manure N content may be selected from Edmonds et al. (2003) cited in US Environmental Protection Agency, (2011). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009. EPA 430-R-11-005*. |
| Description of measurement methods and procedures to be applied | See source of data |
| Frequency of monitoring/recording | Initial measurement at or preceding time t = 0 and to be re-measured every 5 years or more frequently in the project |
| QA/QC procedures to be applied | N/A |

| | |
|---|---|
| **Purpose of data** | Calculation of project emissions |
| **Calculation method** | N/A |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | $LTremoved_{bsl,i,j,t}$<br>$LTremoved_{wp,i,t}$ ~~and $LTremoved_{bsl,i,j,t}$~~ |
| **Data unit** | t $CO_2e$/unit area |
| **Description** | Live tree biomass stocks removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i* subject to harvest in the monitoring interval ending at time *t*<br>Live tree biomass stocks removed in the project scenario ~~at~~ in sample unit *i* subject to harvest in the monitoring interval ending at time *t*~~, and Live tree biomass stocks removed in the baseline scenario at constituent baseline plot *j* in composite baseline *i* subject to harvest in the monitoring interval ending at time *t*~~ |
| **Equations** | (25) |
| **Source of data** | Measured on permanent sample plots in project area and on without-treatment (baseline) sites respectively |
| **Description of measurement methods and procedures to be applied** | Includes pre-existing live tree above- and below-ground biomass that is killed, removed, or emitted on plots subject to harvest.<br>Estimated via pre- and post-harvest cruises as:<br>$LTremoved_{\bullet,i,t} = (LAG_{\bullet,i,t} - LAG_{\bullet,i,t-x}) + (LBG_{\bullet,i,t} - LBG_{\bullet,i,t-x})$<br>Where:<br>$LTremoved_{\bullet,i,t}$ Live tree biomass stocks removed in scenario • (with or without ~~avoided emissions~~project activity) ~~at~~ in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t* (t $CO_2e$/unit area)<br>$LAG_{\bullet,i,t}$ Live aboveground biomass stocks in scenario • (with or without ~~avoided emissions~~ project activity) ~~at~~ in sample unit *i* (or constituent sample *j* in composite baseline *i*), subject to harvest in the monitoring interval ending at time *t*, measured at time *t* (t $CO_2e$/unit area)<br>$LAG_{\bullet,i,t-x}$ Live aboveground biomass stocks in scenario • (with or without ~~avoided emissions~~ project activity) ~~at~~ in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring |

| | |
|---|---|
| | interval ending at time *t*, measured at time *t* − *x* where *t* ~~–~~ *x* is the time of the most recent measurement preceding the harvest (t ~~-~~$CO_2e$/unit area)<br>$LBG_{\bullet,i,t}$ Live belowground biomass stocks in scenario • (with or without ~~avoided emissions~~ project activity) ~~at~~ in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t*, measured at time *t* (t $CO_2e$/unit area)<br>$LBG_{\bullet,i,t-x}$ Live belowground biomass stocks in scenario • (with or without ~~avoided emissions~~ project activity) ~~at~~ in sample unit *i* (or constituent sample *j* in composite baseline *i*) subject to harvest in the monitoring interval ending at time *t*, measured at time *t* − *x*, where *t* ~~–~~ *x* is the time of the most recent measurement preceding the harvest (t ~~-~~$CO_2e$/unit area)<br>Where harvest does not occur in a given sample unit *i* or *j* in the monitoring interval ending at time *t*, $LTremoved_{wp,i,t}$ and $LTremoved_{bsl,i,j,t}$ are set to zero. |
| **Frequency** ~~of monitoring/recording~~ | Initial measurement at or preceding time *t* = 0 and to be re-measured every 5 years or more frequently in the project and every 10 years or more frequently in the baseline |
| **QA/QC procedures to be applied** | N/A |
| **Purpose of data** | ~~Determination~~ Calculation of leakage |
| **Calculation method** | Description of measurement methods and procedures to be applied |
| **Comments** | None |

## 9.3 Description of the Monitoring Plan

Monitoring is conducted for both the baseline and project scenarios. Monitoring employs a quasi-experimental design where carbon stock change is directly monitored in paired permanent project sample units and constituent baseline plots (located outside of the project area). Monitored stock parameters are collected and recorded at the sample unit scale, and emission reductions are estimated independently for each sample unit.

Project proponents must detail the procedures for collecting and reporting all data and parameters listed in Section 9.2. The monitoring plan must contain at least the following information:

1) A description of each monitoring task to be undertaken, and the technical requirements therein~~;~~
2) Definition of the accounting boundary~~;~~
3) Parameters to be measured, including parameter tables for all directly measured tree attributes (e.g., diameter at breast height, total height) incorporated as independent variables in allometric equations~~;~~
4) Data to be collected and data collection techniques, documented in a standard operating procedure for field data collection. Sample designs must be specified (clearly delineate ~~spatially~~ the sample population spatially, and justify sampling intensities, and selection of sample units and sampling stages, where applicable) and unbiased estimators of population parameters identified, which will be applied in calculations.~~;~~
5) Anticipated frequency of monitoring~~;~~
6) ~~Quality assurance and quality control (~~QA/QC~~)~~ procedures to ensure accurate data collection and to screen for, and where necessary, correct anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate~~;~~
7) Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as a part of the monitoring process, including QA/QC data, must be archived electronically and kept for at least two years after the end of the last project crediting period~~; and~~.
8) Roles, responsibilities, and capacity ~~of~~for monitoring team and management~~.~~

As part of ~~the~~ monitoring, project proponents must describe the mitigation activities that have been implemented during the monitoring period. This must be supported by verifiable documentation, such as management records, field reports, or remote sensing data, to demonstrate alignment between project implementation and the methodology's statistical framework.

~~8) As part of the Monitoring Report,, it is required that project proponents must provide confirmation using the most recent version of the monitoring report template (under the Implementation Status of the Project Activity Section), that the mitigation activities have been executed in accordance with the project description. This must be supported by verifiable documentation, such as management records, field reports, or remote sensing data, to demonstrate alignment between project implementation and the methodology's statistical framework.~~

**Permanent sample plots (constituting project sample units)**

Permanent plot measurements must be archived, and all trees assigned unique identification numbers. Individual trees on permanent plots must be marked in the field (e.g., painted or tagged) and stems mapped with azimuth and distance from plot center recorded.

**Composite baseline**

A database must be maintained detailing constituent baseline plots and their respective weights (derived at $t = 0$), with unique identifiers ascribed to each composite baseline, its constituent baseline plots, and all trees in those plots. The monitoring plan must specify the schedule and procedures for periodically acquiring, archiving, and processing re-measurement data from the constituent plots.

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# APPENDIX 1: PERFORMANCE METHOD – UNITED STATES

## A1.1 Introduction

This appendix must be used in tandem with the main methodology body for all projects in the United States. The appendix focuses on a step-by-step process for developing a composite baseline using US~~DA~~ Forest Service Forest Inventory and Analysis (FIA) data. All steps included in this appendix must be considered a requirement of the methodology unless explicitly labeled as optional. Similar appendices may be required for additional geographies based on available national or regional forest inventory data that meet all requirements within the main methodology body.

## A1.2 Applicability Conditions

This appendix is applicable ~~under~~ where both of the following conditions are met:

1) The project activity meets all applicability conditions set out in Section 4 of the methodology.; ~~and~~

2) The project area is located within the conterminous United States.

Note that application of the performance benchmark effectively excludes, based on comparative outcomes, crediting of project activities that may be expected to be implemented without carbon incentives. It also ensures that credited projects produce performance improvements relative to the business-as-usual case (represented by the crediting baseline). The most plausible baseline scenario is defined by the level of carbon stock change observed in the matched control (without carbon finance) plots. For example:

- **IFM activity implementing constraints on timber harvest:** Matched control plots may be expected to witness business-as-usual timber harvests of greater magnitude and/or higher frequency than the project activity that imposes constraints on timber harvest.

- **IFM activity implementing management of competing vegetation to release natural regeneration:** Matched control plots, subject to business-as-usual minimal or no treatment of competing invasive shrubs may be expected to witness continued suppression of natural regeneration and lower tree growth than the project activity that reduces the extent of competing vegetation and releases the regenerating trees.

## A1.3 Baseline Scenario

The baseline scenario is represented by business-as-usual practice on US Forest Service (USFS) Forest Inventory and Analysis (FIA) inventory plots matched to specific project sample units.[23]~~,~~ FIA inventory plots are an appropriate source for establishing business-as-usual practices in the US, selected via representative sampling at a national scale and meeting all other requirements specified in Section 6 of the methodology. Selection of appropriately matched FIA inventory plots is ensured through requirements regarding donor pool selection (see Section A1.5).

## A1.4 Performance Benchmark

The performance benchmark is set equal to weighted average stock ~~change as~~change measured on FIA plots matched to specific project sample units (with weighting proportional to the closeness of the match), representing business-as-usual practice. Equation (1) in the methodology derives and applies the performance benchmark for demonstration of additionality. Equation (6) derives the performance benchmark for the crediting baseline. The performance benchmarks essentially represent expected business-as-usual practice in forest stands similar to the project area. Equations (1) and (6) are dependent on periodic measurement of matched FIA plots. Procedures to match FIA plots to project sample units are provided below. Nearest-neighbor matching is an established impact evaluation approach in the environmental field[24] and has been previously applied to evaluate the impacts of incentive programs on forest management using US Forest Service National Woodland Owner Survey data.[25]

## A1.5 Procedure for Developing Composite Baselines in the United States

In the United States, composite baselines (used to derive performance benchmarks for additionality and crediting baselines) must be developed using data derived from the USFS FIA database. The following steps must be followed to develop matches for the population of sample units:

[23] The measurement frequency of control plots in *VM0045* is currently constrained by the availability of FIA sampling data. The FIA program collects and updates forest inventory data on a rolling basis via a rotating panel design (Bechtold and~~&~~ Patterson~~,~~ 2005), where a fraction of the total plots is measured each year, ensuring a steady stream of updated data. The data are collected continuously, measuring a subset (~10 ~~–~~20%) of total plots each year. This means that full forest inventories are completed every 5–10 years, depending on the state or region (i.e., each FIA plot is revisited every 5–7 years in the Eastern U~~.~~S~~.~~ while ~~and~~ in the Western U~~.~~S~~.~~, where forest change is generally slower, plots are remeasured every 10 years) (see Appendix J in the 2024 FIA user guide). As a result, at any given time, the FIA dataset contains both newly measured plots and older measurements awaiting updates. In consequence, in this methodology, carbon stock change is annualized over the length of the measurement interval, mitigating the potential delay in reflecting changes by smoothing data over time.

[24] Ferraro, P. J., ~~&~~and ~~M. M.~~ Hanauer~~, M. M.~~ ~~(~~2014~~)~~. "Advances in Measuring the Environmental and Social Impacts of Environmental Programs." *Annual Review of Environment and Resources*~~,~~ 39 (1)~~,~~ 495–517. https://doi.org/10.1146/annurev-environ-101813-013230

[25] Song, N., F. X.~~,~~ Aguilar, ~~F. X., &~~ ~~F. X.,~~ and B. J. Butler~~,~~ ~~B. J. (~~2014~~)~~. "Cost-share Program Participation and Family Forest Owners' Past and Intended Future Management Practices." *Forest Policy and Economics*~~,~~ 46~~,~~ 39–46. https://doi.org/10.1016/j.forpol.2014.06.003

1) **Donor pool selection:** The donor pool for each sample unit is set by a process that involves the application of both exact matching criteria and calipers (maximum permitted difference between sample unit and individual control plots).

   a) Subset the FIA database to select eligible FIA plots. Begin with the most recent measurement of potential donor plots (i.e., exclude plots whose PLT_CN is listed as another plot's PREV_PLT_CN in the FIA PLOT table). Then, exclude plots that meet any of the following criteria (plots ~~may~~ must not be excluded on the basis of any criteria other than those provided below):

      i) Lacking at least two completed measurement cycles (i.e., KINDCD in FIA PLOT table is equal to 2) or lacking measurement from the most recently completed re-measurement cycle~~;~~;

      ~~ii) Plot measurements (MEASYEAR) are more than 2 years older than the standard re-measurement period (standard re-measurement period is 5 years for eastern and 10 years for western FIA regions);~~

      ~~iii)~~ii) Spanning more than one condition code (i.e., FIA COND table variable CONDPROP_UNADJ is equal to 1)~~;~~

      ~~iv)~~iii) Located inside of the project area (to assess the location of any FIA plot, the nearest project area boundary is buffered externally by 1.6 kilometers)~~;~~

      ~~v)~~iv) Optional – Located within a registered GHG mitigation project area (where this is possible to determine;[26] to assess the location of any FIA plot, the nearest project area boundary is buffered externally by 1.6 kilometers)~~;~~

      ~~vi)~~v) Not of the same stand origin category as the project sample unit (i.e., STDORGCD from FIA COND table)~~;~~

      ~~vii)~~vi) Not of the same forest type group[27] as the project sample unit~~;~~

      ~~viii)~~vii) Not within the same land ownership class (public, private) as the project sample unit~~; and~~

      ~~ix)~~viii) Not within the same US Forest Service ecological section[28] as the project sample unit.

[26] Note that (iv)~~(v)~~ is optional and it is conservative to include plots located within a registered GHG mitigation project area.

[27] Forest type groups are listed in Appendix D in Burrill, E. A., G. A.~~,~~ Christensen, B. L.~~,~~ ~~G. A.,~~ Conkling, et al. ~~A. M., B. L., DiTommaso, A. M., Lepine, C. J., L., Perry, S. A., C. J., Pugh, J. A., S. A., Turner, J. A., Walker, D., & Williams, M. A. (~~2023~~)~~. *The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.1 for Phase 2*. US Department of Agriculture, Forest Service. ~~Available at:~~ https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

[28] Cleland, D. T., J. A.~~,~~ Freeouf, J. E.~~,~~ ~~J. A.,~~ Keys, G. J.~~,~~ ~~J. E.,~~ Nowacki, C. A.~~,~~ ~~G. J.,~~ Carpenter, ~~C. A., &~~ C. A., and W. H. McNab~~,~~ ~~W. H. (~~2007~~)~~. *Ecological Subregions: Sections and Subsections for the Conterminous United States.* Gen. Tech. Report WO-76D. USDA Forest Service. https://doi.org/10.2737/WO-GTR-76D

~~x)~~ix) Optional – calipers: FIA plots may be excluded where they exceed a user-specified caliper value (an absolute value of the difference between the sample unit and FIA plot value) for one or more of the included continuous covariates (see Table A1.1). The magnitude of any calipers applied may be set by the project proponent, justified based on the expected relationship between the covariate and stock change (in the context of the IFM project activity), and number of available FIA plots (see Part b).

b) Where after donor pool selection there are fewer than 50 plots available for matching, redefine the donor pool in a stepwise fashion following the criteria below. After each step, assess the size of the donor pool; when it exceeds 50 plots, proceed to matching in Step 2 below.

i) Remove any calipers applied in Step (ix)~~(x)~~ above.

ii) Remove the restriction to ecological section, incorporating all FIA plots within the ecological province where that ecological section is found.~~;~~

iii) Remove the restriction to ecological province, incorporating all FIA plots within the states where that ecological province is found.

2) **Matching:** Matching applies a k-nearest neighbor optimal matching approach with replacement,[29] with *k* equal to 10. For each FIA plot in the donor pool, calculate initial condition covariates from the most recent plot measurements collected prior to project start, then calculate Mahalanobis distances relative to each project sample unit. For each project sample unit, select the 10 FIA plots with the lowest Mahalanobis distances and derive relative weights proportional to the inverse of the Mahalanobis distance, that sum to 1 (Equation (A1) below). The vector of initial condition covariates must include the covariates specified in Table A1.1. Additional covariates may be incorporated provided that there is a theoretically sound or empirically demonstrated basis for including them (e.g., peer-reviewed study), they are derived from direct measurements or published sources (e.g., US Census Bureau data), and minimum match quality is obtained (see below).

$$W_{bsl,i,j} = \frac{{}^{1}/_{MD_{ij}} \times 100}{\sum_{j=1}^{10} {}^{1}/_{MD_{ij}} \times 100} \quad \text{(A1)}$$

Where:

$W_{bsl,i,j}$ = Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1 (dimensionless)

$MD_{ij}$ = Mahalanobis distance of constituent baseline plot *ij* relative to project sample unit *i* (dimensionless)

[29] See Stuart, E. A. ~~(~~2010~~).~~ "Matching Methods for Causal Inference: A Review and a Look Forward." *Statistical Science*~~,~~ 25 (1)~~;~~ 1–21. https://doi.org/10.1214/09-STS313

Mahalanobis distance is a multivariate measure defining the "nearness" or similarity of two individuals, here a project sample unit and a FIA plot in the donor pool. The R package optmatch[30] may be used to calculate Mahalanobis distances and implement the matching approach outlined above. Calculation of Mahalanobis distance is further explained in Rosenbaum (2010[31]) and Stuart (2010[32]).

**Table A1.1.: Required covariates for obtaining matches of composite baselines from USFS FIA plots (see also Data and parameters available at validation for project sample unit, below)**

| Covariate | FIA Database Code[33] | Unit |
|---|---|---|
| **Distance to sample (treatment/project case) unit** | | Kilometers |
| **Stand age** | STDAGE | Years |
| **Site productivity class code** | SITECLCD | FIA Classes 1–7 (in cubic feet/acre/year) |
| **Regeneration Stocking** – Total relative density per acre (Ducey and Knapp 2010[34]) of all live trees ≥1" and <5" dbh, of commercial species from FIA's SEEDLING and TREE tables. Commercial species are defined as those not from species groups 23, 43, and 48 (see FIA Database User Guide Appendix E). Relative density | Derived from FIA database (FIADB) data regeneration microplot and tree subplot | Dimensionless (0 to 1) |

[30] Hansen, B. B., & S. O. Klopfer, S. O. (2006). "Optimal Full Matching and Related Designs Via Network Flows." *Journal of Computational and Graphical Statistics*, 15 (3): 609–627. https://doi.org/10.1198/106186006X137047

[31] Rosenbaum, P. R. (2010). *Design of Observational Studies*. (1st ed.). Springer. https://doi.org/10.1007/978-1-4419-1213-8

[32] Stuart, E. A. (2010). "Matching Methods for Causal Inference: A Review and a Look Forward." *Statistical Science*, 25 (1): 1–29. https://doi.org/10.1214/09-STS313

[33] Burrill, E. A., G. A. Christensen, B. L. G. A. Conkling, et al. B. L., DiTommaso, A. M., Lepine, L., Perry, C. J., Pugh, S. A., Turner, J. A., Walker, D., & Williams, M. A. (2023). *The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.1 for Phase 2*. US Department of Agriculture, Forest Service. Available at: https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

[34] Ducey, M. J., and R. A. Knapp. R. A. (2010). "A Stand Density Index for Complex Mixed Species Forests in the Northeastern United States." *Forest Ecology and Management*, 260 (9): 1613–1622. https://doi.org/10.1016/j.foreco.2010.08.014

| Covariate | FIA Database Code[33] | Unit |
|---|---|---|
| (RD) per acre is calculated for each individual as $RD_{per\ acre}$ = 2.47 × (0.00015 + (0.00218 × $SpecificGravity_{Species}$)) × $(dbh/10)^{1.6}$ | | |
| **Elevation** (optional) | ELEV | Feet (in 10 or 100 foot categories) |
| **Slope** | SLOPE | Percent |
| **Commercial Stocking –** Total relative density per acre (Ducey ~~&~~and Knapp 2010) of live trees of commercial species ≥5" dbh, with at least one sound, straight eight-foot section. Commercial species are defined as above. | Derived from FIADB data, uses TREECLCD to identify trees with requisite form characteristics | Dimensionless (0 to 1) |
| **Quadratic mean diameter** = diameter of tree with average basal area (considering only live trees ≥5" dbh) | Derived from FIADB data | Inches |
| **Horizontal distance to improved road** | RDDISTCD | Code (~~0~~ 1 to 9~~)~~ |

3) **Match quality:** Match quality is assessed across the sample population of matched pairs (project sample units and matched composite baselines). For each included covariate *x*, calculate the standardized difference of means (SDM) as:

$$SDM = = \left|\overline{x}_{wp,x} - \overline{x}_{bsl,x}\right| \Big/ \sqrt{\left(\frac{\sigma^2_{wp,x} + \sigma^2_{bsl,x}}{2}\right)} \quad \sim\sim ABS(\bar{x}_{wp,x} - \bar{x}_{bsl,x})/\sigma_{wp,x} \sim\sim \qquad \text{(A2)}$$

Where:

| | | |
|---|---|---|
| SDM | = | Standardized difference of means |
| $\overline{x}_{wp,x}$ | = | Mean value of covariate *x* in the population of sample units representing the project scenario |
| $\overline{x}_{bsl,x}$ | = | Mean value of weighted sum of covariate *x* in the population of matched composite baselines representing the baseline scenario |
| $\sigma^2_{wp,x}$ ~~$\sigma_{wp,x}$~~ | = = | Sample variance of covariate *x* in the population ~~Standard deviation of covariate x in the population~~ of sample units representing the project scenario |
| $\sigma^2_{bsl,x}$ | = | Sample variance of covariate *x* in the population of sample units representing the baseline scenario |

The mean value of the weighted sum of covariate *x* in the population of matched composite baselines representing the baseline scenario is calculated as:

$$\overline{x}_{bsl,x} = \left(\frac{1}{n}\right) \times \sum_{i=1}^{n} \sum_{j=1}^{10} Covariate_{x,i,j} \times W_{bsl,i,j} \quad \text{(A3)}$$

Where:

| | | |
|---|---|---|
| $Covariate_{x,i,j}$ | = | Value of covariate *x* for constituent baseline plot *j* in matched composite baseline *i* |
| $W_{bsl,i,j}$ | = | Weight of constituent baseline plot *j* in matched composite baseline *i;* value between 0 and 1, derived in Equation (A1) (dimensionless) |
| *n* | = | Number of matched composite baselines |

*Note – ~~d~~Distance to sample unit (a required covariate) will necessarily be equal to 0 for all sample units. As a result, distance to sample unit must be replaced with latitude and longitude for calculation of SDMs and matching quality assessment.*

Overall match results are deemed valid where *SDM* for each covariate is less than or equal to 0.25. Where the overall match is deemed valid, component plots and their respective weights across the population of composite baselines are fixed for the duration of the crediting period. If the overall match is not deemed valid, the donor pool selection and matching steps above are repeated with progressively smaller *k* values until a valid overall match is achieved.

**Data and parameters available at validation for project sample units (sources of covariate values for project sample units)**

| | |
|---|---|
| **Data/Parameter** | Distance to sample (treatment/project case) unit |
| **Data unit** | Kilometers |
| **Description** | Distance to sample (treatment/project case) unit |
| **Equations** | N/A |
| **Source of data** | Calculated from GIS analysis of geo-referenced locations |
| **Value applied** | N/A |
| **Justification of choice of data or description of measurement methods and procedures applied** | Sample unit centers must be geo-referenced in the field with GPS using latitude/longitude. Where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), the relevant location is the centroid of the primary unit.<br>"Fuzzed" (uncorrected) locations of FIA plots recorded in the FIADB are used for the analysis. |

| | |
|---|---|
| **Purpose of data** | Matching |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | STDAGE |
| **Data unit** | Years |
| **Description** | Stand age |
| **Equations** | N/A |
| **Source of data** | Increment cores taken at breast height from sampled trees, obtained via plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*) |
| **Value applied** | N/A |
| **Justification of choice of data or description of measurement methods and procedures applied** | Stand age calculated as average total age (age at breast height + the number of years that passed from germination until the tree reached the point of core extraction).<br>Stand age is estimated from increment cores from three or more representatively sampled live trees ≥5" dbh, and not over-topped, from within the project sample unit.<br>Core each tree at the point of diameter measurement and count the rings between the outside edge and the core to the pith. Add in the number of years that passed from germination until the tree reached the point of core extraction to determine the total age of the tree: 5 years for all eastern species, 5 years for western hardwoods, and 10 years for western softwoods. Compute the average age across all cored trees in the project sample unit.[35] |
| **Purpose of data** | Matching |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | SITECLCD |
| **Data unit** | FIA Classes 1–7 (in cubic feet/acre/year) ~~–~~ ~~S~~see definitions in the FIADB User Guide |
| **Description** | Site productivity class code |

[35] Taken from USFS FIA Regional Field Guides for Standard (Phase 2) Measurements. Available at: https://www.fia.fs.usda.gov/library/field-guides-methods-proc/

| | |
|---|---|
| **Equations** | N/A |
| **Source of data** | NRCS Web Soil Survey Database[36] |
| **Value applied** | N/A |
| **Justification of choice of data or description of measurement methods and procedures applied** | SITECLCD is determined for the sample unit location (center), or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), SITECLCD is determined as the area-weighted average value for the primary unit.<br>For each map unit, the relevant reference tree species in the NRCS Web Soil Survey is identified as the available tree species with the highest relative basal area, determined from plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*).<br>Where a map unit has <NULL> site productivity values, SITECLCD is sourced from the map unit nearest to the project sample unit for which site productivity values are available. |
| **Purpose of data** | Matching |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | Regeneration stocking |
| **Data unit** | Dimensionless |
| **Description** | Total relative density per acre (Ducey and~~&~~ Knapp 2010) of all live trees ≥1" and <5" dbh of commercial species. Commercial species are defined as those not from species groups 23, 43, ~~and~~ or 48 (see FIA Database User Guide Appendix E). |
| **Equations** | N/A |
| **Source of data** | Plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*) |
| **Value applied** | Between 0 and 1 |
| **Justification of choice of data or description of measurement methods and procedures applied** | Relative density (RD) per acre is calculated for each individual tree as follows and is then summed for the sample unit:<br>$RD_{per\ acre} = 2.47 \times \left((0.00015 + \left(0.00218 \times Specific\ Gravity_{Species}\right)\right) \sout{(0.00015 + \left(0.00218 \times Specific\ Gravity_{Species}\right))} \times \left(\frac{dbh}{10}\right)^{1.6}$ |

[36] Available at: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

| | |
|---|---|
| **Purpose of data** | Matching |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | Commercial stocking |
| **Data unit** | Dimensionless |
| **Description** | Total relative density per acre (Ducey ~~&~~and Knapp 2010) of live trees of commercial species, ≥5" dbh, with at least one sound, straight eight-foot section. Commercial species are defined as those not from species groups 23, 43, ~~and~~ or 48 (see FIA Database User Guide Appendix E). |
| **Equations** | N/A |
| **Source of data** | Plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*) |
| **Value applied** | Between 0 and 1 |
| **Justification of choice of data or description of measurement methods and procedures applied** | Relative density (RD) per acre is calculated for each individual tree as follows and then summed for the sample unit.<br>$RD_{per\ acre} = 2.47 \times \left((0.00015 + \left(0.00218 \times Specific\ Gravity_{Species}\right)\right) ~~(0.00015 + \left(0.00218 \times Specific\ Gravity_{species}\right))~~ \times \left(\frac{dbh}{10}\right)^{1.6}$ |
| **Purpose of data** | Matching |
| **Comments** | None |

| | |
|---|---|
| **Data/Parameter** | ELEV |
| **Data unit** | Feet (in 10 or 100 foot categories) |
| **Description** | Elevation |
| **Equations** | N/A |
| **Source of data** | GPS or digital elevation model |
| **Value applied** | N/A |
| **Justification of choice of data or description of** | ELEV is determined for the sample unit location (center), or where a two-stage sample is used (e.g., with a stand as the primary unit and |

| | |
|---|---|
| measurement methods and procedures applied | plots as the secondary unit), ELEV is determined as the average value for the secondary units. |
| Purpose of data | Matching |
| Comments | As per Table A1.1, elevation ~~can~~ may be considered optional. |

| | |
|---|---|
| Data/Parameter | SLOPE |
| Data unit | Percent |
| Description | Slope |
| Equations | N/A |
| Source of data | Digital elevation model or plot-based sampling with hypsometer or clinometer (sample unit average slope) |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | Where determined referencing a digital elevation model, SLOPE is determined for the sample unit location, or where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), SLOPE is determined as the area-weighted average value for the primary unit. |
| Purpose of data | Matching |
| Comments | None |

| | |
|---|---|
| Data/Parameter | Quadratic mean diameter |
| Data unit | Inches (to the nearest 0.1 inch) |
| Description | Diameter of tree with average basal area |
| Equations | N/A |
| Source of data | Plot-based sampling (see description of measurement methods for live aboveground biomass, *LAG*) |
| Value applied | N/A |
| Justification of choice of data or description of | Based on live trees ≥5” dbh only |

| | |
|---|---|
| measurement methods and procedures applied | |
| Purpose of data | Matching |
| Comments | None |

| | |
|---|---|
| Data/Parameter | RDDISTCD |
| Data unit | Code (0 to 9) ~~-~~. ~~S~~ see definitions in the FIADB User Guide[37] |
| Description | Horizontal distance to improved road |
| Equations | N/A |
| Source of data | GIS analysis |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | Calculated as the shortest straight line, over-land distance from the sample unit center to the nearest improved road. An improved road is a road of any width that is maintained as evidenced by pavement, gravel, grading, ditching, and/or other improvements.<br>Where a two-stage sample is used (e.g., with a stand as the primary unit and plots as the secondary unit), the relevant location is the centroid of the primary unit. |
| Purpose of data | Matching |
| Comments | None |

[37] Burrill, E. A., G. A., Christensen, B. L., ~~G. A.,~~ Conkling, ~~B. L., DiTommaso, A. M., Lepine, L., Perry, C. J., Pugh, S. A., Turner, J. A., Walker, D., & Williams, M. A~~et al. ~~(~~2023~~)~~. *The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.1 for Phase 2*. US Department of Agriculture, Forest Service. ~~Available at:~~ https://www.fia.fs.usda.gov/library/database-documentation/current/ver91/FIADB%20User%20Guide%20P2_9-1_final.pdf

# APPENDIX 2: TESTING THE SIGNIFICANCE OF CARBON POOLS AND GHG EMISSIONS

This appendix outlines a stepwise procedure for determining the significance of decreases in optional carbon pools and GHG emission sources, ($E_s$). All $E_s$ may be deemed de minimis and excluded from quantification if their combined impact (in $tCO_2e$) is less than 5% of the total amount of carbon removals and reductions expected from the project, see Step 1, Equation (A4). Where the combined significance of optional pools and emissions sources is greater than 5% proceed to Step 2 Equation (A5) to determine which individuals carbon pools and GHG emissions sources must be included.

**Step 1: Determine Combined Significance of $E_s$**

$$CSR = \frac{\sum E_s}{CR} \text{ x } 100 \qquad \text{(A4)}$$

| | | |
|---|---|---|
| $CSR$ | = | Combined Significance Ratio (%) |
| $CR$ | = | Net carbon removals and reductions during the project crediting period |
| $E_s$ | = | GHG project emissions and decreases in optional carbon pools |
| s | = | 1, 2, 3, …, S sources of project GHG emissions (excluding leakage) and decreases in carbon pools |

1) If CSR < 0.05 (i.e., less than 5%), all optional sources are deemed de minimis,

2) If CSR ≥ 0.05, proceed to Step 2 to determine which decreases in carbon pools and GHG emissions must be included.

**Step 2: Determine Significance of Individual $E_s$**

For each $E_s$, calculate its relative contributions ($RC_{Es}$ ) to the total carbon pool decrease and GHG emissions sources ($E_s$)

$$RC_{Es} = \frac{E_s}{\sum E_s} \qquad \text{(A5)}$$

Where:

| | | |
|---|---|---|
| $RC_{Es}$ | = | Relative contribution of each source s to the sum of project and leakage GHG emissions and decreases in optional carbon pools |
| $E_s$ | = | GHG project emissions, and decreases in optional carbon pools |
| s | = | 1, 2, 3, …, S sources of project GHG emissions (excluding leakage) and decreases in carbon pools |

1) Order $E_s$ according to their ranks from largest sources to smallest.

2) Sum $RC_{Es}$ starting from the largest. Stop when the cumulative sum equals or exceeds 0.95.

3) Include all the sources that add up to, or exceed, 0.95.

4) Any remaining sources (those that make up the last 5%) may be excluded, but only if their combined impact is also less than 5% of total CR. If not, keep adding GHG emissions sources until that condition is met.

# DOCUMENT HISTORY

| Version | Date | Comment |
|---|---|---|
| v1.0 | 26 Oct 2022 | Initial version |
| v1.1 | 12 Mar 2024 | • Separation of GHG emission reductions and carbon dioxide removals in Section 8<br>• Minor clarifications and edits |
| C&C Issued for v1.1 | 13 Dec 2024 | • ~~Greenlined edits indicate~~C ~~c~~orrections to Equations 30 to 34 |
| v1.2 | 10 July~~y~~ 2025 | • Clarification of the~~n~~ FIA data collection process (Appendix 1, S~~s~~ection A1.3)<br>• Clarification of~~n~~ the significance of carbon pools (Tables 1 and 2) and inclusion of~~.~~ Appendix 2 ~~added~~ to test ~~this significance~~ itsignificance~~.~~<br>• ~~Correction~~Updates to ~~the Monitoring Plan~~ Ssection 9.3 (Description of the Monitoring Plan) to require projects to provide confirmation of mitigation activities~~.~~<br>• Correction to Equation A2 to calculate the standardized difference of means ~~(SDM)~~ during the match quality assessment<br>• Clarifications to Table A.1 regarding required covariates for Obtaining Matches of Composite Baselines from USFS FIA plot, including e~~:E~~levation as "~~'~~o~~O~~ptional'~~.~~"<br>• ~~due to the obfuscation of this data from the FIA program.~~General ~~typesetting~~edits for clarity~~.~~ |