Tree Planting Protocol

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Appendix A
Quantification Methods

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Introduction

This City Forest Credits Tree Planting Protocol Appendix A on Quantification for Tree Planting Projects consists of three parts.

Part One sets out the three quantification methods based on the design of each planting project and describes the requirements for each quantification method.

Part Two contains a description of the scientific basis and methods underlying quantification of CO_2 and co-benefits in city trees.

Part Three contains a Summary of Quantification Steps, which is a more detailed walk-though of quantification methods using examples.

The principal authors of this Appendix A on Quantification are Dr. E.G. McPherson and Dr. Gordon Smith. Dr. McPherson also led the science teams that developed quantification methods for the State of California Air Resources Board Urban Forest Carbon Protocol in 2011 and the Climate Action Reserve Urban Forest Protocols in 2014. Dr. Smith has over two decades of experience in forest carbon, carbon protocol, and verification standards for forest carbon projects.

Note that quantification methods for Tree Preservation Projects, as distinct from Tree Planting Projects, are contained within the Tree Preservation Protocol.

Part One - Quantification Methods and Project Operator Requirements

1. Summary

Project Operators must use one of three different methods for quantifying carbon dioxide (CO_2) storage in urban forest carbon projects. Selection of the quantification method depends on the planting project design:

- Single Tree Method - trees planted in a dispersed or scattered design and that are planted at least 10 feet apart (i.e. street trees). This method requires tracking of individual trees and tree survival for sampling and quantification.

- Clustered Method - to trees planted at least 10 feet apart but are relatively contiguous and designed to create canopy over an area (i.e park-like settings). This method requires tracking change in canopy, not individual tree survival

- Area Reforestation Method – tree planting areas greater than 5 acres and where many trees are planted closer than 10 feet. Higher tree mortality is expected and the goals are to create canopy and a forest ecosystem. Project Operators have several quantification models to choose from, all of which produce a carbon index on a per-acre basis.

In all cases, the estimated amount of CO_2 stored 26-years after planting is calculated. The forecasted amount of CO_2 stored during this time is the value from which the Registry issues ex ante Carbon Forward Removal Credits.™

To ensure performance of the credits, the Registry issues Carbon Forward Removal Credits at five times during the 26-year Project Duration:

- 10% after planting

- 30% in Year 4, after sampling and mortality check or imaging and calculating canopy

- 30% in Year 6, after sampling and mortality check or imaging and calculating canopy

- 10% in Year 14, after measuring sampled trees or imaging and calculating canopy and

- "True-up" credits at the end of the initial Project Duration in Year 26, when CO2e is quantified from tree measurement and final credits are issued for CO2e stored minus credits already issued.

The mortality checks at Years 4 and 6 correspond to nationality mortality data that shows increased survival rates after three years and six years.

The Registry will issue 95% of Project Credits earned and will hold 5% of total credits in the Registry's Reversal Pool Account. This 5% Reversal Pool Account deduction is applied in all three quantification methods before calculation of any crediting, with these funds going into a program-wide pool to insure against unavoidable reversals due to catastrophic loss of trees.

All ex ante Carbon Forward Removal Credits convert to ex post City Forest Carbon+ Credits at Year 26 and are marked in the registry of credits.

2. Requirements for Each Quantification Method

2.1 Single Tree Quantification Method

In the Single Tree Method, the amount of CO_2 stored in project trees 26-years after planting is calculated as the product of tree numbers and the 26-year CO_2 index (kg/tree) for each tree-type (e.g., Broadleaf Deciduous Large = BDL).

Registry scientists have developed a spreadsheet tool that Project Operators must complete. The Single Tree Quantification Tool requires the Project Operator to input the following data into the Tool:

- Species
- Number of each species
- A default, initial, top-line mortality deduction of 20%, unless the Project Operator provides historical data justifying a different mortality deduction
- Data collection for trees, including species, location via GPS or address, and date planted

The Single Tree Quantification Tool contains equations for each climate zone that calculate CO2 stored and co-benefits in Resource Units and Avoided Costs for rainfall interception, air quality, and energy savings.

2.1.1 Single Tree Quantification Requirements After Planting and at Years 4, 6, 14, and 26

A. After Planting

The Single Tree Quantification Tool for each project contains a worksheet called "Data Collection" for use in tracking each tree. In that file, Project Operators must document the GPS coordinates for each tree planted. Project Operators may also use another tree inventory system, approved by the Registry.

In addition, The Single Tree Quantification Tool requires the Project Operator to input the following data into the Tool:

- Species planted
- Number of each species planted
- A default, initial, top-line mortality deduction of 20%, unless the Project Operator provides historical data justifying a different mortality deduction

Project Operators must also document the planting through the following templates provided by the Registry:

- Project Design Document, including maps or other items to meet eligibility requirements
- Ownership or Eligibility to Receive Potential Credits
- Attestation of Planting, with supporting documentary evidence of planting such as invoices and event photos
- Attestation of Planting Affirmation, signed by a participating organization attesting to the planting
- Single Tree Quantification Tool, including "Data Collection" for use in tracking each tree
- Attestation of Additionality
- Attestation of No Double Counting and No Net Harm

This credit issuance requires validation by the Registry and third-party verification.

B. Year 4

Project Operators must generate a random sample of project tree sites using the Single Tree Quantification Tool. Project Operators must visit those sampled tree sites and collect data on whether the sample contains a live tree, standing dead tree, or no tree.

Project Operators must submit geocoded photos or imaging of the sampled trees. The Single Tree Quantification Tool includes a column where each tree is assigned a unique serial number to help with tracking each coordinate and tree picture or image. Project Operators may also use their own inventory software, as approved by the Registry.

Based on this data, the number and species of project trees is adjusted and a new CO2 projected amount by Year 26 is generated. Credits may be issued based on this adjusted amount. This credit issuance requires validation by the Registry and third-party verification.

C. Year 6

Project Operators must generate a random sample of project tree sites using the Single Tree Quantification Tool. Project Operators must visit those sampled tree sites and collect data on whether the sample contains a live tree, standing dead tree, or no tree.

Project Operators must submit geocoded photos or imaging of the sampled trees. The Single Tree Quantification Tool includes a column where each tree is assigned a unique serial number to help with tracking each coordinate and tree picture or image. Project Operators may also use their own inventory software, as approved by the Registry.

Based on this data, the number and species of project trees is adjusted and a new CO2 projected amount by Year 26 is generated. Credits may be issued based on this adjusted amount. This credit issuance requires validation by the Registry and third-party verification.

D. Year 14

Project Operators must follow the same process as stated above for Years 4 and 6, except they must also measure DBH on the sample of trees. The DBH will be used to ensure growth curve consistent with the projected CO2 storage at Year 26. If the actual growth curves of project trees are less than was projected, the number of credits issued at Year 14 will be adjusted downward.

E. Year 26

Project Operators must generate a random sample of project trees and measure DBH on the sample of trees. The DBH will be used to calculate CO2 storage at that time. Project operators must also submit geocoded photos of the sampled trees. Credits may be issued based on the actual CO2 storage at this Year 16 time, minus credits already issued. This credit issuance requires validation by the Registry and third-party verification.

2.2. Clustered Quantification Method

In the Clustered Planting Method, Registry scientists have developed a spreadsheet tool that Project Operators must complete. The Clustered Quantification Tool requires the Project Operator to input the following data into the Tool:

- Species planted
- Number of each species planted
- A default, initial, top-line mortality deduction of 20%, unless the Project Operator provides historical data justifying a different mortality deduction
- Mapping and boundaries for the area planted (the Project Area)

The Clustered Quantification Tool contains equations for each climate zone that calculate CO2 stored and co-benefits in Resource Units and Avoided Costs for rainfall interception, air quality, and energy savings.

2.2.1 Clustered Quantification Requirements After Planting and at Years 4, 6, 14, and 26

A. After Planting

In the Clustered Planting Method, Registry scientists have developed a spreadsheet tool that Project Operators must complete. The Clustered Quantification Tool requires the Project Operator to input the following data into the Tool:

- Species planted
- Number of each species planted
- A default, initial, top-line mortality deduction of 20%, unless the Project Operator provides historical data justifying a different mortality deduction

In addition, Project Operators must provide maps of the site, with boundaries, as well as a map showing the site within a larger context of land area, such as within a neighborhood, city, or region.

Project Operators must also document the planting through the following templates provided by the Registry:

- Project Design Document, including maps or other items to meet eligibility requirements
- Ownership or Eligibility to Receive Potential Credits
- Attestation of Planting, with supporting documentary evidence of planting such as invoices and event photos
- Attestation of Planting Affirmation, signed by a participating organization attesting to the planting
- Single Tree Quantification Tool, including "Data Collection" for use in tracking each tree
- Attestation of Additionality
- Attestation of No Double Counting and No Net Harm
- Imaging of the Project Area showing trees planted

Here is guidance for the imaging required after planting:

Projects must document the planting through photos or imaging. Select points and take geo-coded photos that when taken together capture the newly planted trees in the project area. If site is rectilinear, take a photo at each of the corners. If the site is large, take photos at points along the perimeter looking into the project area. If necessary to capture the trees, take photos facing each of the cardinal directions while standing in the middle of the project area. If site is nonrectilinear, identify critical points along property boundaries and take photographs at each point facing in towards the middle of the site. Next, take photographs from the middle of the project area facing out at each cardinal direction.

This credit issuance requires validation by the Registry and third-party verification.

B. Year 4

Project Operators provide images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).

- Imaging from Google Earth with leaf-on may be used. Project Operators will calculate the percent of canopy cover from the Google Earth imaging
- Projects can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. i-Tree Canopy will supply you with the standard errors.
- If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.

If the canopy coverage equals or exceeds 2.8% (400 trees per acre with an average canopy area of 3.14 square feet per tree (2-foot diameter of canopy) is 2.8% of an acre), then the credits projected in the Clustered Quantification Tool may be issued. If canopy coverage is below 2.8%, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 2.8%. This credit issuance requires validation by the Registry and third-party verification.

C. Year 6

Project Operators provide images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).

- Imaging from Google Earth with leaf-on may be used. Project Operators will calculate the percent of canopy cover from the Google Earth imaging
- Projects can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. i-Tree Canopy will supply you with the standard errors.
- If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.

If the canopy coverage equals or exceeds 11.5% (400 trees per acre with an average canopy area of 12.56 square feet per tree (4-foot diameter of canopy) is 11.5% of an acre), then the credits projected in the Clustered Parks Quantification Tool may be issued. If canopy coverage is below 11.5%, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 11.5%. This credit issuance requires validation by the Registry and third-party verification.

D. Year 14

Project Operators provide images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).

- Imaging from Google Earth with leaf-on may be used. Project Operators will calculate the percent of canopy cover from the Google Earth imaging
- Projects can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. i-Tree Canopy will supply you with the standard errors.
- If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.

If the canopy coverage equals or exceeds 46% (400 trees per acre with an average canopy area of 50 square feet per tree (8-foot diameter of canopy) is 46% of an acre), then the credits projected in the Clustered Quantification Tool may be issued. If canopy coverage is below 46%, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 46%. This credit issuance requires validation by the Registry and third-party verification.

E. Year 26

Project Operators provide images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).

- Imaging from Google Earth with leaf-on may be used. Project Operators will calculate the percent of canopy cover from the Google Earth imaging
- Projects can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. i-Tree Canopy will supply you with the standard errors.

- If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.

If the canopy coverage equals 100% of the Project Area at project outset, the credits projected in the Clustered Quantification Tool may be issued. If canopy coverage is below 100% of the Project Area, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 100%. This credit issuance requires validation by the Registry and third-party verification.

2.3. Area Reforestation Quantification Method

We provide first an overview of Project Operator requirements for using the Area Reforestation Quantification Method. This is followed by a detailed description of the Area Reforestation Quantification Method, including guidance.

2.3.1 Overview

To quantify the CO_2 for area reforestation projects, Project Operators may choose one of two methods – local data or a forest ecosystem approach using the USDA Forest Service General Technical Report (GTR), with its biometric data and allometrics for 51 forest ecosystems in regions of the U.S. (Smith et al., 2006). In this GTR method, the forecasted amount of CO_2 stored at 26-years is the product of the amount of TC and the CO_2 Index (CI, t CO_2 per acre).

More detail on both of these methods – use of local data or use of the U.S. Forest Service GTR tables – follows this summary.

A. After Planting

Project Operators must use local data or the GTR tables to demonstrate projected carbon storage by Year 26. In addition, Project Operators must provide maps of the site, with boundaries, as well as a map showing the site within a larger context of land area, such as within a neighborhood, city, or region.

Project Operators must also document the planting through the following templates provided by the Registry:

- Project Design Document, including maps or other items to meet eligibility requirements
- Ownership or Eligibility to Receive Potential Credits

- Attestation of Planting, with supporting documentary evidence of planting such as invoices and event photos
- Attestation of Planting Affirmation, signed by a participating organization attesting to the planting
- Attestation of Additionality
- Attestation of No Double Counting and No Net Harm
- Imaging of the Project Area showing trees planted

Here is guidance for the imaging required after planting:

Projects must document the planting through photos or imaging. Select points and take geo-coded photos that when taken together capture the newly planted trees in the project area. If site is rectilinear, take a photo at each of the corners. If the site is large, take photos at points along the perimeter looking into the project area. If necessary to capture the trees, take photos facing each of the cardinal directions while standing in the middle of the project area. If site is nonrectilinear, identify critical points along property boundaries and take photographs at each point facing in towards the middle of the site. Next, take photographs from the middle of the project area facing out at each cardinal direction. This credit issuance requires validation by the Registry and third-party verification.

B. At Year 4

Project Operators must either conduct a physical tree count using plots or use imaging to determine canopy coverage at Year 4. More detail is contained on both of these following this summary.

If the canopy coverage equals or exceeds 2.8% (400 trees per acre with an average canopy area of 3.14 square feet per tree (2-foot diameter of canopy) is 2.8% of an acre), then the credits projected in the Area Reforestation Quantification Tool may be issued. If canopy coverage is below 2.8%, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 2.8%. This credit issuance requires validation by the Registry and third-party verification.

C. At Year 6

Project Operators must either conduct a physical tree count using plots or use imaging to determine canopy coverage at Year 6. More detail is contained on both of these following this summary.

If the canopy coverage equals or exceeds 11.5% (400 trees per acre with an average canopy area of 12.56 square feet per tree (4-foot diameter of canopy) is 11.5% of an acre), then the credits projected in the Area Reforestation Quantification Tool may be issued. If canopy coverage is below 11.5%, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 11.5%. This credit issuance requires validation by the Registry and third-party verification.

D. Year 14

Project Operators must either conduct a physical tree count using plots or use imaging to determine canopy coverage at Year 6. More detail is contained on both of these following this summary.

If the canopy coverage equals or exceeds 46% (400 trees per acre with an average canopy area of 50 square feet per tree (8-foot diameter of canopy) is 46% of an acre), then the credits projected in the Area Reforestation Quantification Tool may be issued. If canopy coverage is below 46%, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 46%. This credit issuance requires validation by the Registry and third-party verification.

E. Year 26

Project Operators must either conduct a physical tree count using plots or use imaging to determine canopy coverage at Year 26. More detail is contained on both of these following this summary.

If the canopy coverage equals 100% of the Project Area at project outset, the credits projected in the Clustered Quantification Tool may be issued. If canopy coverage is below 100% of the Project Area, then the number of credits issued is reduced by the same percentage as the canopy coverage falls below 100%. This credit issuance requires validation by the Registry and third-party verification.

2.3.2 Full Description of Area Reforestation Quantification Method

The Area Reforestation method seeks to accomplish two main goals – create a dynamic forest ecosystem and generate canopy over parcels or properties greater than 5 acres and some cases over dozens or hundreds of acres. Examples are projects to convert agricultural land to forest or reforestation of natural areas.

To accomplish these goals, the area reforestation method requires that trees are planted closely together, using a diverse palette of species and size, with relatively high expected mortality. Mortality is not the central measure of success of area reforestation, because certain species and trees are expected to out-compete others. Recruitment often occurs that results in mature trees that were not planted by the Project Operator.

The amount of CO_2 stored after 26-years by planted project trees is based on the anticipated amount of tree canopy area (TC). The forecasted amount of CO_2 stored at 26-

years is the product of the amount of tree canopy (TC) and the CO_2 Index (CI, t CO_2 per acre). This approach recognizes that forest dynamics for area reforestation projects are different than for street trees or parks projects. In many cases, native species are planted close together and early competition results in high mortality and rapid canopy closure. The Single Tree Method and the Clustered Method, which are based on the biometrics of open-growing urban trees, do not adequately describe biomass distribution among closely spaced trees and the dynamic changes in CO_2 stored in dead wood and understory vegetation as a forest stand matures.

City Forest Credits (referred to as the Registry) issues credits at five times during a 26-year area reforestation project. Assuming compliance with all Protocol requirements and third-party verification, the Registry issues credits based on projected CO_2 storage over the 26-year project duration. The Registry issues 10% of projected credits after planting, 30% of projected credits at Year 4, and 30% of projected credits at Year 6 after planting, and 10% of projected credits at Year 14 after planting. At the end of the project, in year 26, the Project Operator will receive credits for all CO_2 stored, minus credits already issued. A 5% Reversal Pool Account deduction is applied at each issuance of credits, with these funds going into a program-wide pool to insure against catastrophic loss of trees (unavoidable reversals).

To quantify the CO_2 for these kinds of area reforestation projects, Project Operators may choose one of two methods – local data or a forest ecosystem approach using the USDA Forest Service General Technical Report (GTR), with its biometric data and allometrics for 51 forest ecosystems in regions of the U.S. (Smith et al., 2006). In this GTR method, the forecasted amount of CO_2 stored at 26-years is the product of the amount of TC and the CO_2 Index (CI, t CO_2 per acre).

A. Local Data

A Project Operator may apply to the Registry to quantify the projected CO_2 storage from local data for tree growth that more accurately reflects CO_2 storage than the GTR tables. If a Project Operator has local data for 26-year-old stands like those planted, it can submit that data to the Registry. The Registry retains sole discretion to determine the applicability of that data to the planting project of the Project Operator.

B. USDA Forest Service General Technical Report (GTR) Tables

A Project Operator may alternatively choose to use the USDA Forest Service General Technical Report (GTR), with its biometric data and allometrics for 51 forest ecosystems in regions of the U.S. (Smith et al., 2006). The GTR tables provide carbon stored per hectare for each of six pools as a function of stand age. We used values for 25-year old stands for afforestation projects, because the sites contain little carbon in down dead wood and forest floor material at the time of planting. Data used to derive the 51 forest ecosystem tables came from U.S. Forest Inventory and Assessment plots. More information on methods used to prepare the tables can be found in Smith et al. (2006). The value from the applicable table, for total non-soil carbon stock for age 25 (or other source approved by the registry) is the CO_2 Index (CI).

Project Operators determine their forest type and select the type from their region in the GTR tables. Project Operators then utilize the carbon totals for year 25 from the tables. If a project is planted on an area that has been tilled to grow crops for at least three of ten years before tree planting, then soil carbon may be claimed.

C. Soil Carbon Sequestration

- If a project converts land from tillage, the project may receive credit for increasing soil carbon sequestration. If a project does not convert land from tillage, the project shall not receive credit for soil carbon sequestration. To receive soil carbon credits, the project must document a history of cropping in at least three of the 10 years preceding initiation of the project. Options for documenting tillage include cropping records, crop subsidy payment receipts, and historical aerial photos showing cropping.

- Following the United Nations Framework Convention on Climate Change, Intergovernmental Panel on Climate Change (IPCC) afforestation/reforestation methodological tool “Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities, Version 01,” projects that are on sites that are productive enough to grow trees and that stop tillage are assumed to gain more than the IPCC’s maximum creditable amount of soil carbon of 16 tC/ha, which is 23.7 tCO2e/acre over the 25 year life of the sequestration project.

- When a project converts agricultural land to forest and makes no change in the demand for agricultural products, the project creates pressure to bring other lands into agriculture. Economists call the rate that other resources are increased to serve a supply the “price elasticity of supply.” The average price elasticity of supply of agricultural land in the U.S. is calculated by Barr et al. (2010) to be 0.018, which is 1.8%. To account for this expected conversion of some other land to agriculture, and assuming that land brought into agriculture loses the same amount of carbon that soil taken out of agriculture regains, the Registry deducts 1.8% of the IPCC creditable amount of carbon gain. As a result, projects that convert land from tillage to trees may count 23.3 tCO_2e per acre of soil carbon gain as a result of the project over the 25-year life of the project.

After conversions from Carbon to CO_2, **the CO_2 Index (CI) is tons CO_2 per acre of tree canopy (TC) and the forecasted amount of CO_2 stored after 26-years is the CI x TC.** This is the value from which the Registry will issue credits.

If a Project Operator feels that the GTR table applicable to its project does not reflect accurate CO_2 storage for that project, they may apply to the Registry for use of a different GTR table in a more accurate way. Here is a non-exhaustive list of factors the Registry will consider in any requests to deviate from the GTR values:

- Soils
- Precipitation
- Climate information for the area
- Site productivity
- Local measurements of growth
- Proximity to the border of another region

D. Guidance on Numbers of Trees per Acre to Plant

To determine how many trees to plant, the Project Operator must estimate what mortality of planted seedlings it will have. With professional tree planters, quality planting stock, growing conditions conducive to growth, and little animal damage, planting at 10’ by 10’ spacing (436 trees per acre) often results in more than 400 trees per acre surviving at Year 6.

In harsh site conditions, or planting at the wrong time of year, or not keeping seedlings cool and moist, or not planting with good contact between roots and soil, mortality of 30-50% is common. Planting by volunteer planters, or in sites with high animal browsing, can result in mortality greater than 80-90%. The Registry recommends having someone with tree planting expertise manage the acquisition of planting stock and manage the planting process.

E. Methods for Determining Canopy Cover Growth or Tree Survival, and Progress Standards for Issuance of Credits at Years 4 and 6

Project Operators may choose one of two methods for determining canopy or tree survival – the Canopy Cover Growth Method or the Trees Per Acre Method

i. Canopy Cover Growth Method

- Project Operator provides images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).

- Imaging from Google Earth with leaf-on may be used. Project Operators will calculate the percent of canopy cover from the Google Earth imaging

- Project Operator can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. i-Tree Canopy will supply you with the standard errors.

- If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.

- Progress Requirements for Issuance of Credits in Years 4, 6, and 14:

  - At Year 4, projects must show canopy coverage of at least 2.8% of the Project Area (400 trees per acre with an average canopy area of 3.14 square feet per tree (2-foot diameter of canopy) is 2.8% of an acre)

  - At Year 6, projects must show canopy coverage of at least 11.5% of the Project Area (400 trees per acre with an average canopy area of 12.56 square feet per tree (4-foot diameter of canopy) is 11.5% of an acre)

  - At Year 14, projects must show canopy coverage of at least 46% of the Project Area (400 trees per acre with an average canopy area of 50 square feet per tree (8-foot diameter of canopy) is 46% of an acre)

Note, if projects exceed these Progress Requirements, they will not receive credits early or out of schedule. If projects fail to meet the Progress Requirements, they will either not be eligible to request credits until they meet the Progress Requirements or they will receive credits reduced by the same percentage as their canopy coverage is below the Progress Requirement percentages above.

ii. Trees Per Acre Method

- Select 60 plots within the Project Area. This can be done using i-Tree Canopy and downloading plot center coordinates, or by travelling to the Project Area, choosing a random starting point, and walk a grid that locates at least 60 plots within the project area, well distributed across the Project Area. If locating the plots in the field, record the coordinates of each plot center. The Registry can provide examples of methods for determining the grid spacing and doing a random start.

- Mark each plot center with flagging, with the plot number written on the flagging. For a circular plot with 11.78' radius measured horizontally from plot center (not slope distance). This 11.78' radius makes a 1/100 acre plot.
- Count the number of live trees on the plot, counting only tree species that typically will reach 6" DBH by age 26 under the conditions present within the project area.
- Calculate the average number of trees per plot. Multiply the average number of trees per plot by 100. This is the average number of trees per acre present on the project.
- Divide the number of trees per acre on the Project Area by 400. This is the fraction canopy cover expected to be achieved by age 26.
- Multiply the fraction canopy cover expected to be achieved by age 26 by the live tree carbon stock (in metric tons of carbon per acre) at age 26 from the appropriate afforestation table in US Forest Service GTR NE-343. This is the carbon stock expected to be present at age 26. Multiply this expected carbon stock by 3.67 to calculate the expected carbon stock in metric tons CO_2e per acre.
- Report to the Registry:
    - The method used to locate plot centers.
    - Plot center coordinates.
    - Plot data, specifically the number of trees on each plot, by plot.
    - The average number of trees per acre calculated from plot data.

To count as fully stocked, at Year 6 (after five years of growth since planting) the project must have 400 surviving trees per acre of species that typically will reach 6" DBH by age 26 under the conditions present within the project area.

If 200-400 trees per acre are surviving at Year 6, predicted carbon sequestration is adjusted by multiplying the predicted carbon stock for full stocking at age 26 times the fraction (live trees per acre divided by 400). If the project has fewer than 200 trees per acre at Year 6, the CFC "single tree" quantification tool should be used.

F. Quantification at Year 26

- Project Operator may calculate Trees Per Acre as described in Section 2.3.2E above, or
- Project Operator may provide images of the Project Area from any telemetry, imaging, remote sensing, i-Tree Canopy, or UAV service, such as Google Earth and estimate the area in tree canopy cover (acres).
    - Projects can use i-Tree Canopy and point sampling to calculate canopy cover. Using i-Tree Canopy, continue adding points until the standard error of the estimate for both the tree and non-tree cover is less than 5%. I-Tree Canopy will supply you with the standard errors.

- If tree canopy cover is determined using another approach, such as image classification, a short description of the approach should be provided, as well as the QA/QC measures that were used. A tree cover classification accuracy assessment should be conducted, as with randomly placed points, and the percentage tree cover classification accuracy reported.
- Project Operator calculates total CO2 storage at Year 26 as follows:
    - Multiply the CI (carbon index times the acres of TC (tree canopy) in the Project Area.

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Part Two - Scientific Basis for Carbon and Co-Benefit Quantification and Source Materials

Ecoservices provided by trees to human beneficiaries are classified according to their spatial scale as global and local (Costanza 2008) (citations for Part Two are listed in References). Removal of carbon dioxide (CO_2) from the atmosphere by urban forests is global because the atmosphere is so well-mixed it does not matter where the trees are located. The effects of urban forests on building energy use is a local-scale service because it depends on the proximity of trees to buildings.

To quantify these and other ecoservices City Forest Credits (CFC) has relied on peer-reviewed research that has combined measurements and modeling of urban tree biomass, and effects of trees on building energy use, rainfall interception, and air quality. CFC has used the most current science available on urban tree growth in its estimates of CO_2 storage (McPherson et al., 2016a). CFC's quantification tools provide estimates of co-benefits after 25 years in Resource Units (i.e., kWh of electricity saved) and dollars per year. Values for co-benefits are first-order approximations extracted from the i-Tree Streets (i-Tree Eco) datasets for each of the 16 U.S. reference cities/climate zones (https://www.itreetools.org/tools/i-tree-eco) (Maco and McPherson, 2003). Modeling approaches and error estimates associated with quantification of CO_2 storage and co-benefits have been documented in numerous publications (see References below) and are summarized here.

1. Scientific Basis for Carbon Dioxide Quantification

Estimates of stored (amount accumulated over many years) and sequestered CO_2 (i.e., net amount stored by tree growth over one year) are based on the U.S. Forest Service's recently published technical manual and the extensive Urban Tree Database (UTD), which catalogs urban trees with their projected growth tailored to specific geographic regions (McPherson et al. 2016a, b). The products are a culmination of 14 years of work, analyzing more than 14,000 trees across the United States. Whereas prior growth models typically featured only a few species specific to a given city or region, the newly released database features 171 distinct species across 16 U.S. climate zones. The trees studied also spanned a range of ages with data collected from a consistent set of measurements. Advances in statistical modeling have given the projected growth dimensions a level of accuracy never before seen. Moving beyond just calculating a tree's diameter or age to determine expected growth, the research incorporates 365 sets of tree growth equations to project growth.

Users select their climate zone from the 16 U.S. climate zones (Fig. 1). Calculations of CO_2 stored are for a representative species for each tree-type that was one of the predominant street tree species per reference city (Peper et al., 2001). The "Reference city" refers to the city selected for intensive study within each climate zone (McPherson, 2010). About 20 of the most abundant species were selected for sampling in each reference city. The sample was stratified into nine diameter at breast height (DBH) classes (0 to 7.6, 7.6 to 15.2, 15.2 to 30.5, 30.5 to 45.7, 45.7 to 61.0, 61.0 to 76.2, 76.2 to 91.4, 91.4 to 106.7, and >106.7 cm). Typically 10 to 15 trees per DBH class were randomly chosen. Data were collected for 16 to 74 trees in total from each species. Measurements included: species name, age, DBH [to the nearest 0.1 cm (0.39 in)], tree height [to the nearest 0.5 m (1.64 ft.)], crown height [to the nearest 0.5 m (1.64 ft.)], and crown diameter in two directions [parallel and perpendicular to nearest street to the nearest 0.5 m (1.64 ft.)]. Tree age was determined from local residents, the city's urban forester, street and home construction dates, historical planting records, and aerial and historical photos.

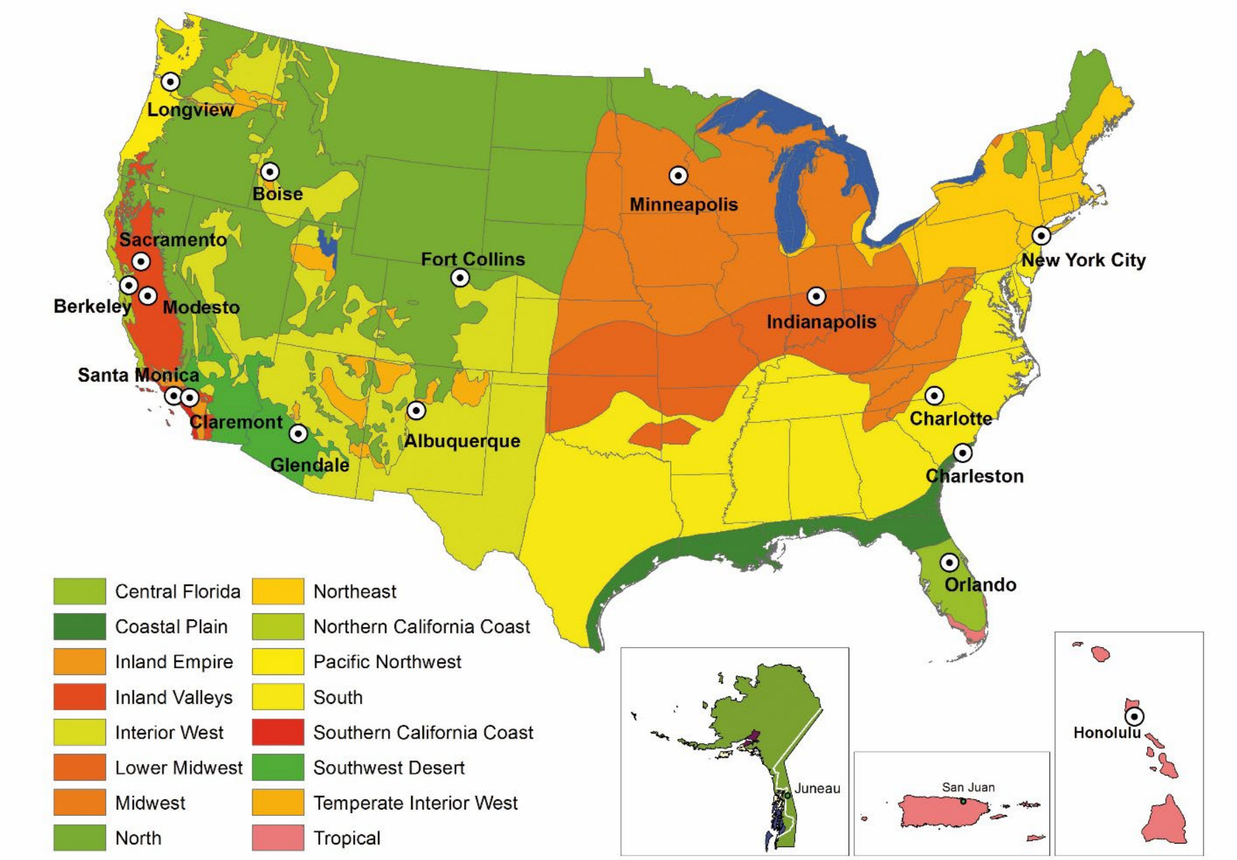

Figure 1. Climate zones of the United States and Puerto Rico were aggregated from 45 Sunset climate zones into 16 zones. Each zone has a reference city where tree data were collected. Sacramento, California was added as a second reference city (with Modesto) to the Inland Valleys zone. Zones for Alaska, Puerto Rico and Hawaii are shown in the insets (map courtesy of Pacific Southwest Research Station).

1.1 Species Assignment by Tree-Type

Representative species for each tree-type in the South climate zone (reference city is Charlotte, NC) are shown in Table 1. They were chosen because extensive measurements were taken on them to generate growth equations, and their mature size and form was deemed typical of other trees in that tree-type. Representative species were not available for some tree-types because none were measured. In that case, a species of similar mature size and form from the same climate zone was selected, or one from another climate zone was selected. For example, no Broadleaf Evergreen Large (BEL) species was measured in the South reference city. Because of its large mature size, *Quercus nigra* was selected to represent the BEL tree-type, although it is deciduous for a short time. *Pinus contorta*, which was measured in the PNW climate zone, was selected for the CES tree-type, because no CES species was measured in the South.

Table 1. Nine tree-types and abbreviations. Representative species assigned to each tree-type in the South climate zone are listed. The biomass equations (species, urban general broadleaf [UGB], urban general conifer [UGC]) and dry weight density (kg/m^3) used to calculate biomass are listed for each tree-type.

Tree-Type	Tree-Type Abbreviation	Species Assigned	DW Density	Biomass Equations
Brdlf Decid Large (>50 ft)	BDL	*Quercus phellos*	600	*Quercus macrocarpa* [1.]
Brdlf Decid Med (30-50 ft)	BDM	*Pyrus calleryana*	600	UGB [2.]
Brdlf Decid Small (<30 ft)	BDS	*Cornus florida*	545	UGB [2.]
Brdlf Evgrn Large (>50 ft)	BEL	*Quercus nigra*	797	UGB [2.]
Brdlf Evgrn Med (30-50 ft)	BEM	*Magnolia grandiflora*	523	UGB [2.]
Brdlf Evgrn Small (<30 ft)	BES	*Ilex opaca*	580	UGB [2.]
Conif Evgrn Large (>50 ft)	CEL	*Pinus taeda*	389	UGC [2.]
Conif Evgrn Med (30-50 ft)	CEM	*Juniperus virginiana*	393	UGC [2.]
Conif Evgrn Small (<30 ft)	CES	*Pinus contorta*	397	UGC [2.]
[1.] from Lefsky, M., & McHale, M.,2008. [2] from Aguaron, E., & McPherson, E. G., 2012				

1.2 Calculating Biomass and Carbon Dioxide Stored

To estimate CO_2 stored, the biomass for each tree-type was calculated using urban-based allometric equations because open-growing city trees partition carbon differently than forest trees (McPherson et al., 2017a). Input variables included climate zone, species, and DBH. To project tree size at 25-years after planting, we used DBH obtained from UTD growth curves for each representative species.

Biomass equations were compiled for 26 open-grown urban trees species from literature sources (Aguaron and McPherson, 2012). General equations (Urban Gen Broadleaf and Urban Gen Conifer) were developed from the 26 urban-based equations that were species specific (McPherson et al., 2016a). These equations were used if the species of interest could not be matched taxonomically or through wood form to one of the urban species with a biomass equation. Hence, urban general equations were an alternative to applying species-specific equations because many species did not have an equation.

These allometric equations yielded aboveground wood volume. Species-specific dry weight (DW) density factors (Table 1) were used to convert green volume into dry weight (7a). The urban general equations required looking up a dry weight density factor (in Jenkins et al. 2004 first, but if not available then the Global Wood Density Database). The amount of belowground biomass in roots of urban trees is not well researched. This work assumed that root biomass was 28% of total tree biomass (Cairns et al., 1997; Husch et al., 2003; Wenger, 1984). Wood volume (dry weight) was converted to C by multiplying by the constant 0.50 (Leith, 1975), and C was converted to CO_2 by multiplying by 3.667.

1.2.1 Error Estimates and Limitations

The lack of biometric data from the field remains a serious limitation to our ability to calibrate biomass equations and assign error estimates for urban trees. Differences between modeled and actual tree growth adds uncertainty to CO_2 sequestration estimates. Species assignment errors result from matching species planted with the tree-type used for biomass and growth calculations. The magnitude of this error depends on the goodness of fit in terms of matching size and growth rate. In previous urban studies the prediction bias for estimates of CO_2 storage ranged from -9% to +15%, with inaccuracies as much as 51% RMSE (Timilsina et al., 2014). Hence, a conservative estimate of error of ± 20% can be applied to estimates of total CO_2 stored as an indicator of precision.

2. Scientific Bases for Co-Benefit Calculations

2.1 Co-Benefit: Energy Savings

Trees and forests can offer energy savings in two important ways. In warmer climates or hotter months, trees can reduce air conditioning bills by keeping buildings cooler through reducing regional air temperatures and offering shade. In colder climates or cooler months, trees can confer savings on the fuel needed to heat buildings by reducing the amount of cold winds that can strip away heat.

Energy conservation by trees is important because building energy use is a major contributor to greenhouse gas emissions. Oil or gas furnaces and most forms of electricity generation produce CO_2 and other pollutants as by-products. Reducing the amount of energy consumed by buildings in urban areas is one of the most effective methods of combatting climate change. Energy consumption is also a costly burden on many lowincome families, especially during mid-summer or mid-winter. Furthermore, electricity consumption during mid-summer can sometimes over-extend local power grids leading to rolling brownouts and other problems.

Energy savings are calculated through numerical models and simulations built from observational data on proximity of trees to buildings, tree shapes, tree sizes, building age classes, and meteorological data from McPherson et al. (2017) and McPherson and Simpson (2003). The main parameters affecting the overall amount of energy savings are crown shape, building proximity, azimuth, local climate, and season. Shading effects are based on the distribution of street trees with respect to buildings recorded from aerial photographs for each reference city (McPherson and Simpson, 2003). If a sampled tree was located within 18 m of a conditioned building, information on its distance and compass bearing relative to a building, building age class (which influences energy use) and types of heating and cooling equipment were collected and used as inputs to calculate effects of shade on annual heating and cooling energy effects. Because these distributions were unique to each city, energy values are considered first-order approximations.

In addition to localized shade effects, which were assumed to accrue only to trees within 18 m of a building, lowered air temperatures and windspeeds from increased neighborhood tree cover (referred to as climate effects) can produce a net decrease in demand for winter heating and summer cooling (reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances). Climate effects on energy use, air temperature, and wind speed, as a function of neighborhood canopy cover, were estimated from published values for each reference city. The percentages of canopy cover increase were calculated for 20-year-old large, medium, and small trees, based on their crown projection areas and effective lot size (actual lot size plus a portion of adjacent street and other rights-of-way) of 10,000 ft^2 (929 m^2), and one tree on average was assumed per lot. Climate effects were estimated by simulating effects of wind and air-temperature reductions on building energy use.

In the case of urban Tree Preservation Projects, trees may not be close enough to buildings to provide shading effects, but they may influence neighborhood climate. Because these effects are highly site-specific, we conservatively apply an 80% reduction to the energy effects of trees for Preservation Projects.

Energy savings are calculated as a real-dollar amount. This is calculated by applying overall reductions in oil and gas usage or electricity usage to the regional cost of oil and gas or electricity for residential customers. Colder regions tend to see larger savings in heating and warmer regions tend to see larger savings in cooling.

2.1.1 Error Estimates and Limitations

Formulaic errors occur in modeling of energy effects. For example, relations between different levels of tree canopy cover and summertime air temperatures are not well-researched. Another source of error stems from differences between the airport climate data (i.e., Los Angeles International Airport) used to model energy effects and the actual climate of the study area (i.e., Los Angeles urban area). Because of the uncertainty associated with modeling effects of trees on building energy use, energy estimates may be accurate within ± 25 percent (Hildebrandt & Sarkovich, 1998).

2.2 Co-Benefit: Rainfall Interception

Forest canopies normally intercept 10-40% of rainfall before it hits the ground, thereby reducing stormwater runoff. The large amount of water that a tree crown can capture during a rainfall event makes tree planting a best management practice for urban stormwater control.

City Forest Credits uses a numerical interception model to calculate the amount of annual rainfall intercepted by trees, as well as throughfall and stem flow (Xiao et al., 2000). This model uses species-specific leaf surface areas and other parameters from the Urban Tree Database. For example, deciduous trees in climate zones with longer "in-leaf" seasons will tend to intercept more rainfall than similar species in colder areas shorter foliation periods. Model results were compared to observed patterns of rainfall interception and found to be accurate. This method quantifies only the amount of rainfall intercepted by the tree crown, and does not incorporate surface and subsurface effects on overland flow.

The rainfall interception benefit was priced by estimating costs of controlling stormwater runoff. Water quality and/or flood control costs were calculated per unit volume of runoff controlled and this price was multiplied by the amount of rainfall intercepted annually.

2.2.1 Error Estimates and Limitations

Estimates of rainfall interception are sensitive to uncertainties regarding rainfall patterns, tree leaf area and surface storage capacities. Rainfall amount, intensity and duration can vary considerably within a climate zone, a factor not considered by the model. Although tree leaf area estimates were derived from extensive measurements on over 14,000 street trees across the U.S. (McPherson et al., 2016a), actual leaf area may differ because of differences in tree health and management. Leaf surface storage capacity, the depth of water that foliage can capture, was recently found to vary threefold among 20 tree species (Xiao & McPherson, 2016). A shortcoming is that this model used the same value (1 mm) for all species. Given these limitations, interception estimates may have uncertainty as great as ± 20 percent.

2.3 Co-Benefit: Air Quality

The uptake of air pollutants by urban forests can lower concentrations and affect human health (Derkzen et al., 2015; Nowak et al., 2014). However, pollutant concentrations can be increased if the tree canopy restricts polluted air from mixing with the surrounding atmosphere (Vos et al., 2013). Urban forests are capable of improving air quality by lowering pollutant concentrations enough to significantly affect human health. Generally, trees are able to reduce ozone, nitric oxides, and particulate matter. Some trees can reduce net volatile organic compounds (VOCs), but others can increase them through natural processes. Regardless of the net VOC production, urban forests usually confer a net positive benefit to air quality. Urban forests reduce pollutants through dry deposition on surfaces and uptake of pollutants into leaf stomata.

A numerical model calculated hourly pollutant dry deposition per tree at the regional scale using deposition velocities, hourly meteorological data and pollutant concentrations from local monitoring stations (Scott et al., 1998). The monetary value of tree effects on air quality reflects the value that society places on clean air, as indicated by willingness to pay for pollutant reductions. The monetary value of air quality effects were derived from models that calculated the marginal damage control costs of different pollutants to meet air quality standards (Wang and Santini 1995). Higher costs were associated with higher pollutant concentrations and larger populations exposed to these contaminants.

2.3.1 Error Estimates and Limitations

Pollutant deposition estimates are sensitive to uncertainties associated with canopy resistance, resuspension rates and the spatial distribution of air pollutants and trees. For example, deposition to urban forests during warm periods may be underestimated if the stomata of well-watered trees remain open. In the model, hourly meteorological data from a single station for each climate zone may not be spatially representative of conditions in local atmospheric surface layers. Estimates of air pollutant uptake may be accurate within ± 25 percent.

2.4 Conclusion

Our estimates of carbon dioxide storage and co-benefits reflect an incomplete understanding of the processes by which ecoservices are generated and valued (Schulp et al., 2014). Our choice of co-benefits to quantify was limited to those for which numerical models were available. There are many important benefits produced by trees that are not quantified and monetized. These include effects of urban forests on local economies, wildlife, biodiversity and human health and well-being. For instance, effects of urban trees on increased property values have proven to be substantial (Anderson & Cordell, 1988). Previous analyses modeled these “other” benefits of trees by applying the contribution to residential sales prices of a large front yard tree (0.88%) (McPherson et al., 2005). We have not incorporated this benefit because property values are highly variable. It is likely that co-benefits reported here are conservative estimates of the actual ecoservices resulting from local tree planting projects.

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Part Three - Illustrative Summary of Quantification Steps using the Single Tree Quantification Tools

This section summarizes the steps in three Single Tree Tools used to quantify carbon storage in tree planting projects. These steps are set out in instructions on each sheet of the Single Tree Quantification Tools. The steps will be much clearer to many readers when viewed within the spreadsheets rather than read here without tables, fields, and inputs. The next section of this Appendix – entitled Quantification Methods and Examples – gives screen shots of the spreadsheets with explanatory text.

1. Steps for Single Tree Initial Credit Quantification after Planting

1) For each planting site, collect this information
    a. Unique site number
    b. Unique tree number (may be several tree numbers at same site if remove & replace)
        i. Tree species planted
        ii. Date planted
    c. Tree number removed
        i. Date removed
    d. GPS coordinates (lat/long)
    e. Notes
2) Photograph tree site or provide imaging of sufficient resolution to discern individual trees
    a. If using photographs, take photos at the four outer corners of each site, and also at 50 foot intervals on diagonal lines running between corners
    b. Include time stamp and GPS coordinates
3) The Tool will deduct 20% for mortality and 5% for the program-wide Reversal Pool Account and then show projected CO_2e storage and Credits
    a. The Project Operator can request to use an alternative value for the 20% mortality reduction. Justification for the value must be provided to the Registry based on historic mortality data for projects with similar species, planting stock, site quality and management regime.

2. Steps for the Single Tree Management Credit Quantification Used at Years 4 and 6

1) Collect the planting data described in initial credit quantification above, specifically,
    a. Unique site number
    b. Unique tree number (may be several tree numbers at same site if remove & replace)
        i. Tree species planted
        ii. Date planted

c. GPS coordinates (lat/long)
d. Notes

2) Use the Sample Size Calculator that we provide and the Stored CO_2 per Tree Look-Up Table to determine the number of tree sites to sample. We define a "tree site" as the location where a project tree was planted, and use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.
3) Randomly sample tree sites collecting data on species, status (alive, dead, removed, replaced).
4) With this sampled data, the Tool will then calculate projected CO_2 storage and credits, and will set those out for Years 4 and 6, along with quantified Co-Benefits.

3. Steps for the Single Tree Final Quantification Used at Year 14 and 26

1) Collect the planting data described in initial credit quantification above, or use the data already collected, specifically,
   a. Unique site number
   b. Unique tree number (may be several tree numbers at same site if remove & replace)
      i. Tree species planted
      ii. Date planted
   c. GPS coordinates (lat/long)
   d. Notes
2) Use the Sample Size Calculator that we provide and the Stored CO_2 per Tree Look-Up Table to determine the number of tree sites to sample. We define a "tree site" as the location where a project tree was planted, and use the term "site" instead of "tree" because some planted trees may no longer be present in the sites where they were planted.
3) Randomly sample tree sites collecting data on species, status (alive, dead, removed, replaced), diameter at breast height (dbh) (to nearest inch), and photo of tree site (may be with or without the tree planted) with geocoded location and date.
4) Fill in the table provided showing the number of live trees sampled in each 1" dbh class by tree-type.
5) Combine data from the step 5 table with the CO_2 Stored by DBH Look-Up Table for your climate zone to calculate CO_2 stored by sampled trees for each tree-type.
6) Fill in the table provided showing number of sites planted, sites sampled and status of sampled tree sites by tree-type. This table calculates Extrapolation Factors.
7) Combine data from tables in step 7 (Extrapolation Factors) and step 6 to scale-up CO_2 stored from the sample to the population of trees planted.
8) Fill in the table provided to incorporate error estimates of ±15% to CO_2 stored by the entire tree population.
9) Fill in the table provided to incorporate estimates of co-benefits.

4. Quantification Examples

4.1 Data Collection for all Single Tree Quantification and Tools

At planting, Project Operators must collect the data listed below. Project Operators can update that data as the Project proceeds.

Directions
Create a data sheet with the same fields seen in the example below.
At the time of data collection soon after planting, record the following information:
-Date of data collection.
-Names of the crew that collected that data.
At the time of data collection soon after planting record the following information on each tree:
-Date planted
-Tree Id#, the unique number that coincides with each tree that was planted at the site. When each tree has just been planted, and there are not any dead or missing trees, the tree id#s will all be the same as the site#s. As trees get replaced, the list of tree id#s will increase. In the example below, site# 1 has a replacement tree planted in it, therefore what was originally tree #1 is now tree #4. If tree #4 is the next one at the project that gets replaced, that new tree will then be tree #5.
-Site Id#, a unique number assigned to each spot a tree is planted at.
-Species name (botanical name)
-Latitude and Longitude (or x and y coordinates) of where each tree is located. These data are used to accurately locate the site for remeasurement.
-Image#1, the unique number for the first image of this site.
-Image#2, the unique number for the second image of this site taken at 90 degrees to the first.

Example Data Collection Table

Data Collection Dates: 1/1/24 Crew:

Date Planted	Tree ID #	Species	Site ID #	Latitude	Longitude	Image #1	Image #2	Live (Orig/Replace #1/Replace #2)	Standing Dead or Vacant Site	Date Removed	Date Replaced	Notes
1/1/2021	1	*Malus ioensis*	575	33.96872	-117.344							
1/1/2021	2	*Corylus americana*	575	32.96752	-117.263							
1/1/2021	3	*Prunus americana*	575	32.87346	-116.84							

4.2 Single Tree Initial Credit Quantification and Tool

The Registry will provide the Tools that contains look-up tables and calculations built into the spreadsheet so that Project Operators can enter their project data and then walk through the sheets to quantify CO_2 and co-benefits.

4.2.1 Planting List

Directions
1) In Table 1 record the number of sites planted for each tree species.
2) If species are not listed, add them to the bottom of Table 1.

Table 1. Planting List

Scientific Name	Common Name	Tree-Type Abbreviation	No. Sites Planted
Acer ginnala	Amur maple	BDS	
Acer negundo	boxelder	BDM	
Acer nigrum	black maple	BDL	
Acer palmatum	Japanese maple	BDS	
Acer platanoides	Norway maple	BDL	
Acer rubrum	red maple	BDL	
Acer saccharinum	silver maple	BDL	
Acer saccharum	sugar maple	BDL	
Acer species	maple	BDL	
Aesculus glabra	Ohio buckeye	BDL	
Albizia julibrissin	mimosa	BDS	
Alnus species	alder	BDM	
Amelanchier laevis	serviceberry, Allegheny	BDS	11
Amelanchier spp.	serviceberry, spp.	BDS	9
Betula nigra	river birch	BDM	
Betula papyrifera	paper birch	BDL	
Betula species	birch	BDM	
Broadleaf Deciduous Large	broadleaf deciduous large	BDL	
Broadleaf Deciduous Medium	broadleaf deciduous medium	BDM	

Table 2. Summary of Planting Sites

Tree-Type	Tree-Type Abbreviation	No. Sites Planted
Brdlf Decid Large (>50 ft)	**BDL**	1823
Brdlf Decid Med (30-50 ft)	**BDM**	41
Brdlf Decid Small (<30 ft)	**BDS**	1031
Brdlf Evgrn Large (>50 ft)	**BEL**	0
Brdlf Evgrn Med (30-50 ft)	**BEM**	0
Brdlf Evgrn Small (<30 ft)	**BES**	45
Conif Evgrn Large (>50 ft)	**CEL**	0
Conif Evgrn Med (30-50 ft)	**CEM**	0
Conif Evgrn Small (<30 ft)	**CES**	0
	Total Sites Planted	2940

4.2.2 Initial Credits – Total CO_2

This sheet calculates the Credits that can be issued in Year 1. It uses a default mortality of 20%. Project Operators may adjust that mortality deduction if they demonstrate to the Registry justification based on historic mortality data for projects with similar species, planting stock, site quality and management regime. Credits issued in Years 4 and 6 will depend on mortality based on sampling of trees in those years.

Directions

Using the information you provide and background data, the tool calculates the amount of Credits that could be issued after planting (10%), at Year 4 (30%), at Year 6 (30%), at Year 14 (10%), and at Year 26 (20%) after planting. A mortality deductions (% loss) is applied to account for anticipated tree losses (Cell D6). A 5% Reversal Pool Account deduction is applied that will go into a program-wide pool to insure against catastrophic loss of trees. This tool is used to determine credits issued after planting (Intial Crediting). A different tool is used for credit issuance in Years 4 and 6. The tool in those years requires calculation of a sample and collection of data on tree status in the sample sites.

Mortality Deduction (%):	20%

Table 3. Credits are based on 10% after planting, 30% at Year 4, 30% at Year 6, 10% at Year 14, and 20% at Year 26 after planting of the projected CO_2 stored by live trees 26-years after planting. These values account for anticipated tree losses and the 5% buffer pool deduction.

						10%	30%	30%	10%	20%
	No. Sites Planted	No. Live Trees	Mortality Deduction (%)	26-yr CO_2 stored (kg/tree)	Tot. 26-yr CO_2 stored w/ losses and 5% deduction (t)	10% CO_2 (t)	30% CO_2 (t)	30% CO_2 (t)	10% CO_2 (t)	20% CO_2 (t)
BDL	1823	1458	0.20	3,978.85	5512.6	551.26	1653.78	1653.78	551.26	1102.52
BDM	41	33	0.20	2,451.33	76.1	7.61	22.92	22.92	7.61	15.28
BDS	1031	825	0.20	700.27	548.7	54.87	164.61	164.61	54.87	109.74
BEL	0	0	0.20	0.00	0.0	0.00	0.00	0.00	0.00	0.00
BEM	0	0	0.20	0.00	0.0	0.00	0.00	0.00	0.00	0.00
BES	45	36	0.20	475.12	16.2	1.62	4.87	4.87	1.62	3.25
CEL	0	0	0.20	0.00	0.0	0.00	0.00	0.00	0.00	0.00
CEM	0	0	0.20	0.00	0.0	0.00	0.00	0.00	0.00	0.00
CES	0	0	0.20	0.00	0.0	0.00	0.00	0.00	0.00	0.00
	2940	2352	0.20	7,605.57	6154.0	615.40	1846.19	1846.19	615.40	1230.79

In Table 4 the tool infers the amount of CO_2 stored after 26 years from the sample to the population of live trees. Values in column H account for anticipated tree losses and the 5% Reversal Pool Account deduction.

Table 4. Grand Total CO_2 Stored after 26 years (all live trees, includes tree losses and buffer pool deduction)

Tree-Type	No. Sites Planted	Mortality Deduction (%)	Total Live Trees After Mortality	26-yr CO_2 stored (kg/tree)	CO_2 Tot. - No Deductions (t)	Grand Total CO_2 w/ Deductions (t)
Brdlf Decid Large (>50 ft)	1823	0.20	1458	3,978.85	7,253.4	5,512.6
Brdlf Decid Med (30-50 ft)	41	0.20	33	2,451.33	100.5	76.4
Brdlf Decid Small (<30 ft)	1031	0.20	825	700.27	722.0	548.7
Brdlf Evgrn Large (>50 ft)	0	0.20	0	0.00	0.0	0.0
Brdlf Evgrn Med (30-50 ft)	0	0.20	0	0.00	0.0	0.0
Brdlf Evgrn Small (<30 ft)	45	0.20	36	475.12	21.4	16.2
Conif Evgrn Large (>50 ft)	0	0.20	0	0.00	0.0	0.0
Conif Evgrn Med (30-50 ft)	0	0.20	0	0.00	0.0	0.0
Conif Evgrn Small (<30 ft)	0	0.20	0	0.00	0.0	0.0
	2940		2352	7606	8,097.3	6,154.0

Directions

In Table 5, enter the low and high price of CO_2 in $ per tonne (t).

This table incorporates error estimates of ±15% to the high and low estimates of the total CO_2 (t) stored by the live tree population after 26 years. For planning purposes only, it calculates dollar values.

Table 5. CO_2 value

	CO_2 $ per tonne
Low	$20.00
High	$40.00

Table 6. Summary of CO2 stored after 26 years (all live trees, includes tree losses)

Tree-Type	Total CO_2 (t) at 25 years	Low $ value	High $ value
Brdlf Decid	6137.7	$122,754.07	$245,508.14
Brdlf Evgrn	16.2	$324.98	$649.97
Conif Evgrn	0.0	$0.00	$0.00
Total	6154.0	$123,079.05	$246,158.11
	CO_2 (t)	Total $	Total $
Grand Total CO_2 (t) at 25 years:	6154.0	$123,079.05	$246,158.11
High Est. with Error:	7077.0	$141,540.91	$283,081.82
Low Est. with Error:	5230.9	$104,617.20	$104,617.20

± 15% error = ± 10% formulaic ± 3% sampling ± 2% measurement

4.2.3 Co-Benefits

Using the information you provide and background data, the tool provides estimates of co-benefits after 26 years.

Table 7. Co-Benefits per year after 26 years (all live trees, includes tree losses)

Ecosystem Services	Resource Units Totals	Total $
Rainfall Interception (m3/yr)	15,342.38	$109,837.06
Air Quality (t/yr)		
O3	0.1967	$657.05
NOx	0.0316	$105.38
PM10	0.1033	$293.31
Net VOCs	0.1368	$1,131.15
Air Quality Total	0.4684	$2,186.89
Energy (kWh/yr & kBtu/yr)		
Cooling - Electricity	454,631.80	$34,506.55
Heating - Natural Gas	6,746,192.64	$65,672.38
Energy Total ($/yr)		$100,178.93
Grand Total ($/yr)		$219,120.95

4.3 Resources

The look-up tables in both examples were created from allometric equations in the Urban Tree Database, now available on-line at: http://www.fs.usda.gov/rds/archive/Product/RDS-2016-0005/. A US Forest Service General Technical Report provides details on the methods and examples of application of the equations and is available online at: http://www.fs.fed.us/psw/publications/documents/psw_gtr253/psw_gtr253.pdf.

The citations for the archived UTD and the publication are as follows.

McPherson, E. Gregory; van Doorn, Natalie S.; Peper, Paula J. 2016. Urban tree database. Fort Collins, CO: Forest Service Research Data Archive. http://dx.doi.org/10.2737/RDS-2016-0005

McPherson, E. Gregory; van Doorn, Natalie S.; Peper, Paula J. 2016. Urban tree database and allometric equations. General Technical Report PSW-253. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. http://www.fs.fed.us/psw/publications/documents/psw_gtr253/psw_gtr253.pdf

The i-Tree Canopy Tools is available online at: http://www.itreetools.org/canopy/.

Features of ten software packages for tree inventory and monitoring are evaluated in this comprehensive report from Azavea: https://www.azavea.com/reports/urban-tree-monitoring/.

4.4 Error Estimates in Carbon Accounting

Our estimates of error include 3 components that are additive and applied to estimates of total CO_2 stored:

Formulaic Error (± 10%) + Sampling Error (± 3%) + Measurement Error (± 2%)

We take this general approach based on data from the literature, recognizing that the actual error will vary for each project and is extremely difficult to accurately quantify. We limit the amount of sampling error by providing guidance on the minimum number of trees to sample in the single-tree approach and the minimum number of points to sample using i-Tree Canopy. If sample sizes are smaller than recommended these error percentages may not be valid. Project Operators are encouraged to provide adequate training to those taking measurements, and to double-check the accuracy of a subsample of tree dbh measurements and tree canopy cover classification. A synopsis of the literature and relevant sources are listed below.

4.4.1 Formulaic Error

A study of 17 destructively sampled urban oak trees in Florida reported that the aboveground biomass averaged 1201 kg. Locally-derived biomass equations predicted 1208 kg with RMSE of 427 kg. Tree biomass estimates using the UFORE-ACE (Version 6.5) model splined equations were 14% higher (1368 kg) with an RMSE that was more than 35% higher than that of the local equation (614 kg or 51%). Mean total carbon (C) storage in the sampled urban oaks was 423 kg, while i-Tree ECO over-predicted storage by 14% (483 kg C) with a RMSE of 51% (217 kg C). The CTCC under-predicted total C storage by 9% and had a RMSE of 611 kg (39%)

Result: Prediction bias for carbon storage ranged from -9% to 14%

Source: Timilsina, N., Staudhammer, C.L., Escobedo, F.J., Lawrence, A. 2014. Tree biomass, wood waste yield and carbon storage changes in an urban forest. Landscape and Urban Planning. 127: 18-27.

The study found a maximum 29% difference in plot-level CO_2 storage among 4 sets of biomass equations applied to the same trees in Sacramento, CA. i-Tree Eco produced the lowest estimate (458 t), Urban General Equations were intermediate (470 t, and i-Tree Streets was highest (590 t).

Source: Aguaron, E., McPherson, E.G. Comparison of methods for estimating carbon dioxide storage by Sacramento's urban forest. pp. 43-71. In Lal, R. and Augustin, B. (Eds.) Carbon Sequestration in Urban Ecosystems. New York. Springer.

4.4.2 Sampling Error

This error term depends primarily on sample size and variance of CO_2 stored per tree. If sample size is on the order of 80-100 sites for plantings of up to 1,000 trees, and most of the trees were planted at the same time, so the standard deviation in CO_2 stored is on the order of 30% or less of the mean, then the error is small, about 2-4%.

Source: US Forest Service, PSW Station Statistician Jim Baldwin's personal communication and sample size calculator (Sept. 6, 2016)

4.4.3 Measurement Error

In this study the mean sampling errors in dbh measurements with a tape were 2.3 mm (volunteers) and 1.4 mm (experts). This error had small effect on biomass estimates: 1.7% change (from 2.3 mm dbh) in biomass calculated from allometric equations.

Source: Butt, N., Slade, E., Thompson, J., Malhl, Y., Routta, T. 2013. Quantifying the sampling error in tree census measurements by volunteers and its effect on carbon stock estimates. Ecological Applications. 23(4): 936-943.