Urban Forest Management Quantification Guidance

April 2019

Abbreviations and Acronyms

C	Carbon
CAL FIRE	California Department of Forestry and Fire Protection
CH_4	Methane
CO_2	Carbon dioxide
CRT	Climate Reserve Tonne
DBH	Diameter at Breast Height
FIA	Forest Inventory and Analysis Program of the U.S. Forest Service
GHG	Greenhouse gas
GIS	Geographical Information System
ISO	International Organization for Standardization
KML	Keyhole Markup Language
N_2O	Nitrous oxide
PDD	Project Design Document
PIA	Project Implementation Agreement
Reserve	Climate Action Reserve
RPF	Registered Professional Forester (California only)
SSR	Source, sink, or reservoir
UFM	Urban forest management
UFMPP	Urban Forest Management Project Protocol
USFS	United States Forest Service
VOC	Volatile Organic Compound

Capitalized terms throughout this Quantification Guidance document are defined in the Glossary of the Urban Forest Management Project Protocol Version 1.1.

1 Introduction

This document provides guidance for quantifying an Urban Forest Management (UFM) offset project's Carbon Stocks,[1] both for purposes of estimating a project's baseline as well as providing ongoing estimates of project Carbon Stocks throughout the Project Life. This guidance document addresses important monitoring and quantification requirements. The specific monitoring objectives are to provide estimates of carbon inventories within the Project Area for purposes of calculating credits generated.

2 Reporting Metrics for Urban Forest Carbon Pools

Only Standing Live and Dead Trees can be included in quantifying UFM Project baselines and project estimates.

For standardized reporting, all estimates of forest Carbon Stocks must be provided in terms of tonnes (metric) of CO_2-equivalent (CO_2e) on a project and a per acre basis. Unless otherwise required in the referenced biomass equations, the following conversion formulae shall be used:

Table 2.1. Unit Conversions

Base Unit	Conversion		Final Unit
Biomass	.5 * biomass		Carbon
Carbon	3.667 * carbon		CO_2e
Kilograms	Kilograms/1000	=	Metric Tons (MT) or Tonnes
Tons	0.90718474 * tons		Metric Tons (MT) or Tonnes
Hectares	0.404686 * hectares		Acres
Square Feet	Square Feet/43560		Acres

The Project Area must be defined during the initial Reporting Period. Once defined, the Project Area may only be modified through agreement with the Climate Action Reserve (Reserve). Modification of the Project Area may impact the baseline, analysis of legal requirements affecting the Project Area, and other aspects of UFM Projects.

3 Methodologies for Estimating Current and Historical CO_2e in Urban Forest Management Projects

UFM Projects require a representation of the project's carbon inventory in the past and at the Project Commencement Date. The approach to estimating CO_2e for UFM Projects includes deriving a measurement of the canopy area within the Project Area, which are applied to ratio estimators to produce an estimate of CO_2e for the project.

Ratio estimators represent a relationship between CO_2e in standing trees and canopy cover, providing the ability to estimate the CO_2e in standing trees across the Project Area as a function of the project's overall canopy cover. Ratio estimators can be developed from ground-based plots in which all trees in the plots are measured for variables that enable calculation of CO_2e estimates and canopy cover within the plot. This enables a ratio of CO_2e per unit area of canopy cover to be derived that can be applied to a measurement or estimate of canopy cover throughout the Project Area.

[1] Capitalized terms are defined in the Urban Forest Management Project Protocol Version 1.1.

Default ratio estimators, based on published values from field studies, are available on the Reserve's Urban Forest Project webpage. Default ratio estimators are organized by Assessment Area, which are defined geographic areas available on the Reserve's Urban Forest Project webpage[2] in the format of a map file and also as a reference table. Project Operators may use the default values published for their relevant Assessment Area(s). The reference table includes information on the study used to develop the ratio estimator for each Assessment Area. This table will be updated as new studies and data become available. Projects determine which Assessment Area(s) their project falls in based on a geographic comparison. Project Operators must initiate their project using the most current version of the default values and must maintain these values for the project crediting period.

The Reserve will also allow Project Operators to use their own project-specific ratio estimators developed through ground-based sampling of trees, if they choose not to use the published default ratio estimators. Site visits are required for projects developing project-specific ratio estimators to verify the plot measurements and development of the estimators.

There are two general approaches to developing estimates of CO_2e in UFM Projects, depending on whether a project uses default ratio estimators or develops project-specific ratio estimators. These general approaches have the following steps, all of which are described in more detail in this document:

Table 3.1. Quantification Steps

Using Default Ratio Estimators	Using Project-Specific Ratio Estimators
1. Determine the Assessment Area(s) applicable to the Project Area – see Section 3.1.1	1. Stratify the Project Area as needed – see Section 3.2
2. Select the correct default ratio estimator – see Section 3.1.2	2. Allocate and sample project plots – see Section 3.2.1
3. Develop a measurement or estimate of the canopy cover within the Project Area – see Section 3.3	3. Develop a ratio estimator based on the CO_2e estimates resulting from the sampling process (by stratum, if stratified) – see Sections 3.2.2-3.2.4
4. Multiply the default ratio estimator by the canopy cover measurement or estimate to expand the CO_2e estimate to the Project Area – see Section 3.4	4. Develop a measurement or estimate of the canopy cover within the Project Area (by stratum, if stratified) – see Section 3.3
5. Develop a measurement or estimate of the canopy cover within the Project Area for the baseline year – see Section 3.5.1	5. Multiply the ratio estimator by the canopy cover measurement or estimate to expand the CO_2e estimate to the strata level (if stratified), or to the Project Area (if not stratified) – see Section 3.4
6. Follow step 4 above using the baseline canopy cover estimate and develop the baseline trend line – see Section 3.5.2	6. Sum the estimates of CO_2e for each stratum (if stratified) to expand the estimate to the Project Area – see Section 3.4
	7. Develop a measurement or estimate of the canopy cover within the Project Area for the baseline year (by stratum, if stratified) – see Section 3.5.1
	8. Follow steps 5 and 6 above for the baseline canopy cover estimate and develop the baseline trend line – see Section 3.5.2

[2] http://www.climateactionreserve.org/how/protocols/urban-forest/

After the above steps are completed, the project and baseline carbon estimates for the given Reporting Period will be used to calculate CRTs, per the protocol.

3.1 Using Default Ratio Estimators

The cities and Urban Areas in the Reserve's UFM Assessment Area data file that have been discretely sampled[3] to develop ratio estimators are referred to as Sampled Cities for purposes of UFM Protocol. For Urban Areas and cities that do not have discrete data, default ratio estimators were developed and scaled to the U.S. by applying the most conservative ratio estimator from Sampled Cities to its corresponding Assessment Area.

UFM Assessment Areas include Sampled Cities and Terrestrial Ecoregions delineated by the Commission for Environmental Cooperation, an intergovernmental organization established by the North American Agreement on Environmental Cooperation. Terrestrial Ecoregions are areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. Where Sampled Cities and Terrestrial Ecoregions coincide, Sampled Cities define the Assessment Area boundaries and default ratio estimators. A complete list of Assessment Areas and its corresponding default ratio estimators (tonnes/acre) for the U.S. can be found on the Reserve's Urban Forest Project Protocol webpage. This table will be maintained and updated as new data become available.

3.1.1 Determine the Appropriate Assessment Area Applicable to the Project Area

A map layer of Assessment Areas (in .shp and .kml formats) comprised of Terrestrial Ecoregions can be found on the Urban Forest Project webpage. Project Operators can determine the appropriate Assessment Area(s) by uploading the Project Area shapefile to a mapping software and performing an analysis (such as "Intersect" in ArcGIS) with the Assessment Area layer. If a project's Assessment Area includes a Sampled City, Project Operators shall refer to map layers provided by the U.S. Census Bureau to determine geographic boundary of the Sampled City.[4]

Project Operators shall calculate the number of project acres for each Assessment Area applicable to the Project Area. If the Project Area spans multiple Assessment Areas, identify all applicable Assessment Areas. A table must be presented in the PDD that provides the data shown in Table 3.2.

[3] https://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_nowak_001.pdf.
[4] https://www.census.gov/geo/maps-data/data/tiger-geodatabases.html. "National Nation-Level Geography Geodatabase" contains Urban Area and Urban Cluster data; "National Sub-State Geography Geodatabase" contains Incorporated Places and Census Designated Places" data.

Table 3.2. Example of Assessment Area and Project Acres Required in PDD

Assessment Area	Number of Project Acres
Oakland, CA	50
Mediterranean California	35
Marine West Coast Forests	65
Total	150

3.1.2 Select the Correct Default Ratio Estimator

Use the table of Assessment Areas and its corresponding default ratio estimators (Table 3.2) to select the default ratio estimator that corresponds with the Assessment Area(s) applicable to your Project Area. If the Project Area spans multiple Assessment Areas, identify all applicable default ratio estimators. A table must be presented in the PDD that provides the data shown in Table 3.3.

Table 3.3. Example of Assessment Area, Project Acres, and Ratio Estimator Required in PDD

Assessment Area	Number of Project Acres	Default Ratio Estimator (t CO_2e/acre)
Oakland, CA	50	78
Mediterranean California	35	68
Marine West Coast Forests	65	65

3.2 Developing and Using Project-Specific Ratio Estimators

3.2.1 Allocating and Sampling Project Plots

Project Operators opting to develop their own ratio estimators must maintain a ground-based Project Inventory. Project Operators must select between one of two methods for establishing sample points. Method 1 is based on a systematic approach to locating points. Method 2 is based on a random approach to locating points. The following sub-steps from either Method 1 or Method 2 are required to develop the ratio estimators:

Method 1 – Systematic Allocation of Points

1. A grid of points spaced equally at 100 feet spacing across the Project Area must be created within the GIS map of the Project Area. Each point shall be attributed with latitude, longitude, and a unique identifier that is established in a sequential order within a database. Individual points will be selected from this set of points to serve as the basis for random sample locations of standing trees. A map of the point location and each stratum (if stratifying) must be included within the PDD. Only points that have trees on them are subject to random selection. Plots without trees may be dismissed prior to random selection of the plots or dismissed as part of the random selection process.

2. The points shall be grouped into sets within a database based on the stratum they are associated with, if applicable.

3. A subset of points shall be randomly selected from the sets of stratum/point combinations for sampling. Project Operators must provide a description of the random methodology used to select a subset of points. Alternatively, the Reserve provides the following suggested methodology:

A list must be included in the PDD that displays the sets of points at the Project Area level, or with their corresponding stratum, if stratifying. Randomization shall be conducted by organizing the plots in separate lists in Microsoft Excel following the below steps; this should be done for each stratum, if stratifying.

A field shall be added and identified as plot/urban class number. A sequential value (1-n) shall be assigned to each plot. The Microsoft Excel function ‘randbetween’ shall be used with a minimum value of 1 and a maximum value set as the total number of plots in the Project Area, or in each stratum, if stratifying. In a separate added field, the order of random selection shall be identified until all the plots are assigned a random value or a minimum of 100 plots are assigned a random value (whichever comes first). In the event a plot is selected more than once, the value assigned to the plot shall be the value of the first time it was selected.

Method 2 – Random Allocation of Points

1. The U.S. Forest Service’s i-Tree Canopy[5] tool can be used as the basis of selecting random plot locations. The tool has additional utility in its ability to calculate canopy area (described below). The i-Tree Canopy tool will place randomized points within a user-defined area (Project Area). Project Operators must establish a minimum of 100 points, or a point for every 10 acres (whichever is smaller), in each of the strata initially. This step will likely result in more than the needed points being established in some strata. It is important to maintain the order of the location of the points as they must be visited in the field in the sequential order for each urban forest class. As in the first method, only those plots that have canopy area on them are subject to random selection. Other plots may be dismissed from the random selection process.

The subset of sample points randomly selected in either of the two methods above is to be installed as fixed radius plots. The size of the radius from the plot center (from the point coordinates) is 37.25 feet (1/10th acre) or 24 feet (1/24th acre). Project Operators may explain and justify an alternative plot radius in the PDD. The radius must be consistently applied throughout the Project Life. Only the random plots selected need to be installed (and measured).

Project Operators must apply reasonable diligence to sample the selected random plots as they are ordered. Reasonable diligence means the Project Operator has contacted the landowner, either through written or oral (telephone or onsite) media. Certain randomly selected points may be impossible to sample due to safety or accessibility and therefore must be rejected, as in cases where permission to trespass is not granted, either explicitly or indirectly through inadequate communication. Project Operators must wait a minimum of 10 days following the posting of letters to make a claim of inadequate communication, in the event the landowner fails to follow up with the Project Operator. A communication log with the landowner must also be maintained, detailing the phone calls and/or physical correspondence used to communicate.

Additionally, many points may not have any standing trees associated with them. Since the purpose of the sample plots is to develop a relationship between CO_2e and urban forest canopy, points with no trees within the radius described above should be rejected. When a plot is

[5] https://canopy.itreetools.org/

rejected for any reason, the reason for the rejection (e.g., lack of standing trees) must be noted in a sampling log and included in the PDD. For verification purposes, Project Operators must document the rationale for rejecting plots prior to selecting the next random plot in their list. In the event of plot rejection, the Project Operator shall select the next numerical point (1, 2, 3…) in the plot list as a potential plot for measuring. In the event a successive plot is a plot that was already selected randomly, the Project Operator shall continue to the next plot (1, 2, 3…) in the plot list. Any additional plots rejected over the Project Life must be noted in a project log and submitted with the annual monitoring report. The rejected plot log must be available for verification oversight.

Plot centers must be monumented so they can be relocated for future measurement or for verification. Monumenting plot locations so that they are available for re-measurement and/or verification can be challenging. GPS coordinates must be recorded for each plot at, or offset from, the plot center. Since GPS coordinates will only partially assist in relocating the plot center due to accuracy of GPS, additional navigational devices are necessary. It is recommended that, where possible, an object or marking be placed at plot center that is highly resistant to environmental features, including weather, animals, and fire.

However, the placement of a monument at plot center is not feasible in Urban Areas under most circumstances. Therefore, monumented plot locations should include identifying features that can be used to triangulate to the plot center using distance and compass bearing measurements. Care should be used to ensure features are selected that are likely to endure up to 10 years. This might include building corners, fire hydrants, street signs, etc. Notes should clearly describe the feature being used as well as distance and bearing data. A minimum of two navigational features are required. It is recommended that the features be separated by at least 20 degrees to plot center.

Measurement standards and data requirements on each plot are outlined in Table 3.4.

Table 3.4. Measurement Standards for Urban Forest Sample Plots

<table>
<tr><th colspan="3">For Each Plot</th></tr>
<tr><th>Attribute</th><th colspan="2">Description</th></tr>
<tr><td>Date of Plot Visit</td><td colspan="2">Day/Month/Year</td></tr>
<tr><td>Latitude of Plot Center</td><td colspan="2">From GPS</td></tr>
<tr><td>Longitude of Plot Center</td><td colspan="2">From GPS</td></tr>
<tr><td rowspan="3">Navigational Feature 1</td><td>Description of a resilient feature that can be used to help relocate plot center in the future. Features might include manhole covers, building corners, street signs, etc.</td><td>(Fire hydrant, street sign, building corner, etc.)</td></tr>
<tr><td>Distance from feature to plot center</td><td>Feet</td></tr>
<tr><td>Azimuth from feature to plot center</td><td>Degrees</td></tr>
<tr><td rowspan="3">Navigational Feature 2</td><td>Description of a resilient feature that can be used to help relocate plot center in the future. Features might include manhole covers, building corners, street signs, etc.</td><td>(Fire hydrant, street sign, building corner, etc.)</td></tr>
<tr><td>Distance from feature to plot center</td><td>Feet</td></tr>
<tr><td>Azimuth from feature to plot center</td><td>Degrees</td></tr>
<tr><td>Stratum</td><td colspan="2">If applicable, enter the Urban Class Code or user-defined stratum associated with the plot.</td></tr>
</table>

Plot Number	Enter the plot number for the plot
Inventory Personnel	Enter the initials of the inventory technicians responsible for measuring and recording data on the plot.

Measure all canopy area and all trees within a fixed 1/10th or 1/24th acre radius (radius = 37.25 feet or 24 feet, respectively) according to guidance below.

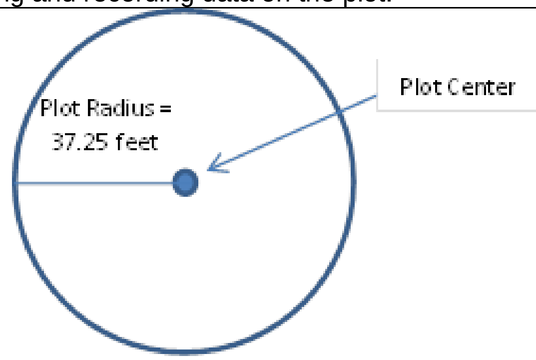
Radial measurements need to be corrected for horizontal distances:

1/10th acre fixed plot:

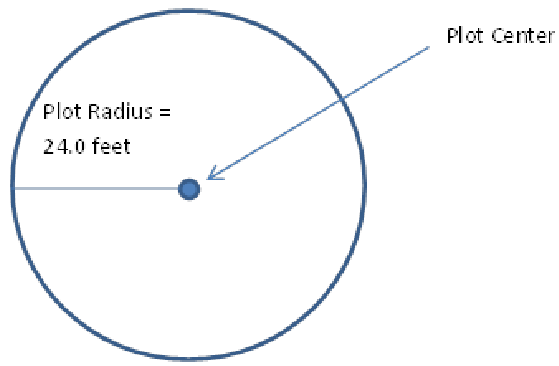
Slope %	5	10	15	20	25
Adj. Radius	37.30	37.44	37.67	37.99	38.40
Slope %	30	35	40	45	50
Adj. Radius	38.89	39.47	40.12	40.85	41.65
Slope %	55	60	65	70	75
Adj. Radius	42.51	43.44	44.43	45.47	46.56
Slope %	80	85	90	95	100
Adj. Radius	47.70	48.89	50.11	51.38	52.68

1/24th acre fixed plot:

Slope %	5	10	15	20	25
Adj. Radius	24.03	24.12	24.27	24.48	24.74
Slope %	30	35	40	45	50
Adj. Radius	25.06	25.43	25.85	26.32	26.83
Slope %	55	60	65	70	75
Adj. Radius	27.39	27.99	28.63	29.30	30.00
Slope %	80	85	90	95	100
Adj. Radius	30.73	31.50	32.29	33.10	33.94



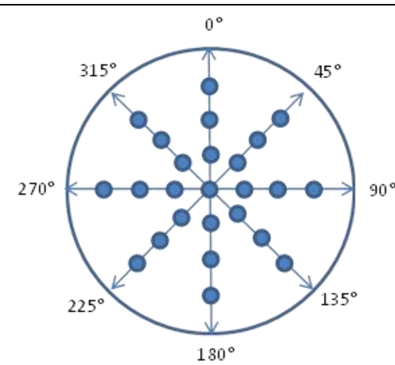
1/10th acre fixed plot



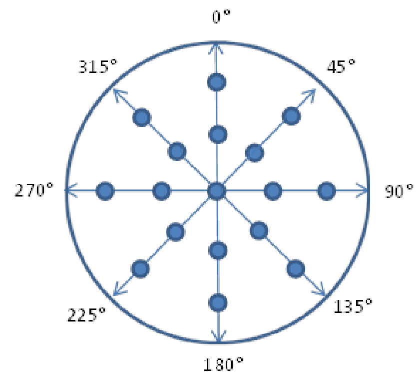
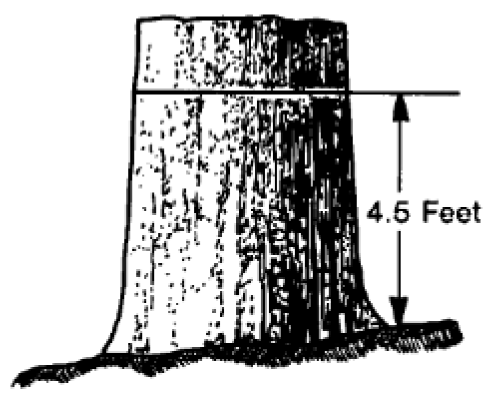
1/24th acre fixed plot:

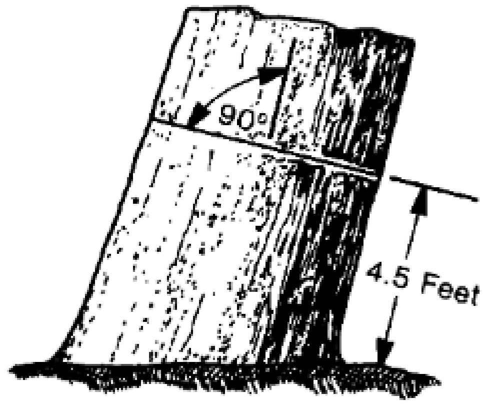
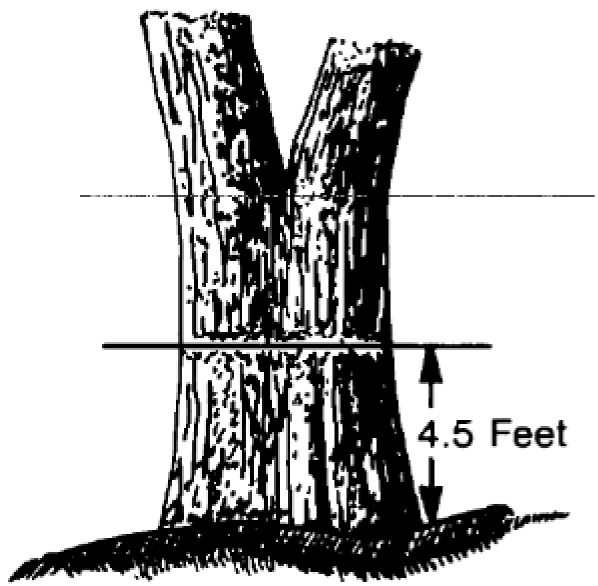
To determine canopy area, use a sighting tube at plot center and at 10 feet, 20 feet, and (if using a 1/10th acre plot) 30 feet from plot center on the compass bearings shown to determine a canopy 'hit' or canopy 'miss'.

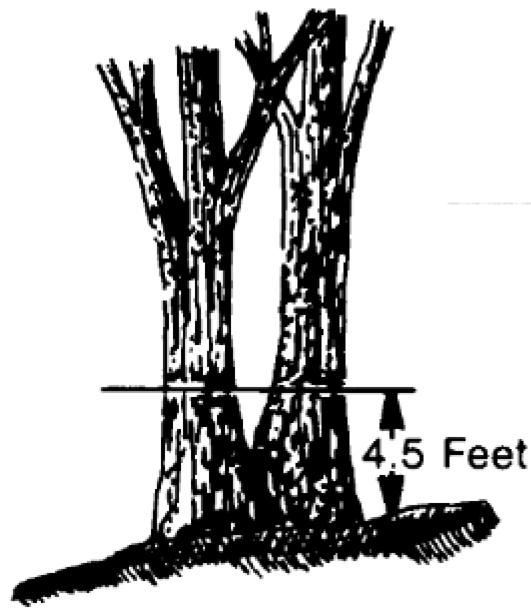
Multiply the sum of the hits by 4 to estimate the canopy cover percentage within the plot.



1/10th acre plot

	 **1/24th acre plot**
For Each Tree	
Attribute	**Description**
Tree Number	Trees are assigned a number 1 to X starting from 0 degrees (North) and generally proceeding clockwise. The numbering convention facilitates the relocation and the verification of the trees.
Species	Enter the species code for each species on the plot. The species code can be found for each species in the corresponding biomass equation reference document. The species code is based on the first two letters of the genus and the first two letters of the species for any given species.
DBH	Measure and record Diameter at Breast Height (DBH) of all trees 3" DBH and greater to the nearest inch on every tree using a diameter tape and wrapping the tree at a height of 4.5 feet from the base of the tree on the uphill side. 

	 Forked trees above DBH are counted as one tree. Forked trees below DBH are counted as two trees (or however many forked stems exist). Add minimum DBH to be included.  One tree

<table>
<tr><td></td><td>

Two trees

Images via FSH 2409.12 USDA Forest Service Timber Cruising Handbook</td></tr>
<tr><td>Total Height</td><td>Measure of total height (height from base of tree to top) of each tree to the nearest foot.</td></tr>
<tr><td>Growth Condition</td><td>An attribute of ‘Open’ or ‘Closed’ must be assigned to each tree according to the description below:
<table>
<tr><th>Class</th><th>Description</th></tr>
<tr><td>O</td><td>An open attribute is assigned to trees growing in non-natural settings. Tree species may be a variety of native and non-native species. Most often, trees exist in areas where disturbance of natural areas and conversion to another land use has occurred.</td></tr>
<tr><td>C</td><td>A closed attribute is assigned to trees growing in natural settings. Trees present are characteristic of the species diversity and structure in forested areas typically found outside the Urban Area.</td></tr>
</table></td></tr>
<tr><td>Vigor</td><td>For each tree, provide a rating of the tree’s apparent vigor. Determination of vigor based on consideration of color of foliage, crown proportion and appearance, retention of leaves/needles, appearance of apical growth, length between growth whorls, and presence of cavities and fungal growth. The code is assigned based on the following classes:
<table>
<tr><th>Code</th><th>Description*

*Based on conditions present during growing periods. Professional judgment need be applied if sampling conducted outside of growing periods.</th></tr>
</table></td></tr>
</table>

	1	**Excellent** – Tree exhibits high level of vigor and no barriers (soil, light, etc.) to continued vigor. No decay or broken branches are observed.
	2	**Good** – Tree exhibits high level of vigor and some minor barriers (soil, light, etc.) to continued vigor. No decay or broken branches are observed.
	3	**Fair** – Tree appears generally healthy. Barriers (soil, light, etc.) affect the tree's vigor. Tree's crown may be smaller proportionally than in healthier trees. Decay and/ or broken branches, if observed, are not likely to have negative impacts in the short term.
	4	**Poor** – Tree appears notably unhealthy, as determined by reduced crown, presence of decay and/or broken branches and/or significant barriers to future growth. Observed problems have high likelihood of being rectified through management of said tree and trees surrounding it.
	5	**Critical –** Tree appears notably unhealthy, as determined by reduced crown, presence of decay and/or broken branches and/or significant barriers to future growth. Observed problems have low likelihood of being rectified through management of said tree and trees surrounding it.
	6	**Dying –** Tree is unhealthy. Minimal live crown is present; portions of bark may be missing and/or substantial levels of broken stems and branches. Tree may exhibit advanced decay. No further investment in restoring the tree to a higher vigor is deemed worthwhile.
	7	**Dead –** No live material is observed in the tree. Trees with this attribute will be used to quantify SSR3 – Standing Dead Wood.
Defect – Bottom 1/3	For each portion of the tree (based on total height), provide an ocular estimate of the portion of tree that is missing (as a percentage of the section) as the result of breakage or cavities.	
Defect – Middle 1/3		
Defect – Top 1/3		
Decay Class	Decay Class	Description of Condition of Standing Dead Wood
	1	All limbs and branches are present; the top of the crown is still present; all bark remains; sapwood is intact with minimal decay; heartwood is sound and hard.
	2	There are few limbs and no fine branches; the top may be broken; a variable amount of bark remains; sapwood is sloughing with advanced decay; heartwood is sound at base but beginning to decay in the outer part of the upper bole.
	3	Only limb stubs exist; the top is broken; a variable amount of bark remains; sapwood is sloughing; heartwood has advanced decay in upper bole and is beginning at the base.
	4	Few or no limb stubs remain; the top is broken; a variable amount of bark remains; sapwood is sloughing; heartwood has advanced decay at the base and is sloughing in the upper bole.
	5	No evidence of branches remains; the top is broken; less than 20 percent of the bark remains; sapwood is gone; heartwood is sloughing throughout.

3.2.2 Calculating Canopy Cover Area for Each Plot

The tree canopy shall be measured as shown in Table 3.4 above. The percent canopy cover estimate derived from the plot shall be averaged across all plots (within a given stratum if the Project Area is stratified) to determine the average percentage canopy cover for the Project Area (or for each stratum). The resulting percentage should be multiplied by the acreage in the Project Area (or given stratum) to determine the final canopy cover estimate in acres, and then converted to square feet using the conversion factor in Section 2.

3.2.3 Calculating Above- and Below-Ground Carbon

CO_2e shall be calculated for each tree using the appropriate biomass equations provided by the Reserve on the Urban Forest Project Protocol website. Trees in natural forest stands within the Project Area should refer to the biomass equations approved for use with the current version of the Forest Project Protocol. The biomass equations enable calculation of CO_2e for the above-ground portion of trees, using the units of conversion provided in Section 2. It is assumed that the below-ground portion of the trees contains 26% of the carbon of the above-ground portion. The calculated carbon value of the above-ground portion of all trees shall therefore be multiplied by 1.26 (including trees in natural forest stands). This should be done for all trees in Project Area (including natural forest stands). The resulting value represents the total carbon in the above and below-ground portions of the tree.

Both standing live trees and standing dead trees may be missing portions of the tree as the result of physical and biological disturbances. Tree biomass needs to be adjusted for missing parts to produce an improved estimate of the tree's biomass. Calculating CO_2e in standing dead trees raises additional challenges since they may be in stages of decay such that density equations in standard biomass equations for live trees do not provide an accurate estimate. The guidance in this section provides a standardized method to account for biomass adjustments for defect and decay.

The first step is to estimate the gross biomass in the tree as if it were whole, using the biomass equations provided on the Reserve's Urban Forest Project Protocol webpage (or Forest Project Protocol webpage for natural forest stands). The tree's biomass is then adjusted based on the tree's 'net' biomass and adjusted density estimates for standing dead trees. To standardize such adjustments, the tree is divided into four parts: top, middle, bottom (visually estimating the original disposition of the above-ground portion of the tree when it was alive and vigorous), and the below-ground portion. The below-ground portion must be calculated as 26% of the gross above-ground portion of the tree. It is assumed that the below-ground portion is intact and complete. The standardized percentages assumed to be in each above-ground portion of the tree are shown in Table 3.5.

Table 3.5. Assumed Percentages of Biomass in Each Above-Ground Portion of the Tree

Tree Portion	Percent of Above-Ground Tree Biomass
Top 1/3	10%
Middle 1/3	30%
Bottom 1/3	60%

An ocular estimate is made of the portion remaining in each above-ground section of the tree during field sampling, as described in Table 3.4. Deductions from gross biomass (or gross volume) are made for anything that reduces the tree's gross biomass, including breakage and cavities. The percentage remaining in each third is then multiplied by the respective assumed percentage of the tree biomass indicated in Table 3.5 to determine the weighted percentage remaining in each above-ground section. These weighted percentages are then summed and multiplied by the gross above-ground biomass estimate for the tree to calculate the net above-ground biomass remaining in the tree. The gross below-ground and net above-ground biomass estimates are then summed to estimate the net biomass for the entire tree.

For standing dead wood, the tree's density must be adjusted to account for the varying states of decay in the remaining portion of the tree. Because standing dead wood does not have the same density as a live tree, a density reduction must be applied. Standing dead wood may fall into five decay classes, which must be recorded during the field sampling. The five decay classes, described in Table 3.4, are qualitative, based on the physical characteristics of the dead tree.[6]

The density identified for each species in the biomass equations must be modified for decay classes 2 to 5 using the reduction factors displayed in Table 3.6.[7] Trees in decay class 1 do not require modification their density.

Table 3.6. Average Density Reduction Factors for Standing Dead Wood for Hardwoods and Softwoods by Decay Class

Softwoods		Hardwoods	
Decay Class	**Reduction Factor**	**Decay Class**	**Reduction Factor**
2	1.0	2	0.8
3	0.92	3	0.54
4	0.55	4	0.43
5	0.29	5	0.22

An example of field data that has all the required elements for calculating the standing dead tree's CO_2e is shown in Table 3.7

Table 3.7. Example: Data Attributes Needed to Calculate CO_2e in Standing Dead Trees

Tree Number	Species Code	DBH (inches)	Height* (feet)	Growth Condition	Vigor	Percent Remaining			Decay Class
						Top 1/3 of Tree	Middle 1/3 of Tree	Bottom 1/3 of Tree	
1	UGEC (urban general conifer)	16	95	O	7 - Dead	0%	50%	100%	3

The density of the tree must be adjusted based on its decay class. The first step is to calculate the tree's biomass as if the tree were a normal tree to determine the tree's gross biomass. Net

[6] USDA 2007, Woundenberg et al., 2010.
[7] Harmon et al, 2011. Differences between standing and downed dead tree wood density reduction factors: A comparison across decay classes and tree species. Res. Pap. NRS-15. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 40 p.

biomass is determined by multiplying the gross biomass of the tree by the reduction factor displayed in Table 3.6. An example is provided in Table 3.8.

Table 3.8. Example: Adjusting Biomass Calculation for Decay Using Density Adjustment Factors

Tree Gross Biomass	Density Reduction Based on Decay	Net Biomass
(tonnes CO_2e) (assumed)	(from Table 3.6 for a softwood with a decay class '3')	(tonnes CO_2e) (assuming tree is whole)
0.100	0.92	0.092

As an example of the application of the biomass deductions for missing sections of the tree, using the data from Table 3.7 above, a tree (assuming normal form) with a net biomass of 0.092 CO_2e tonnes would be further adjusted to a net biomass for the missing portions of the tree as shown in Table 3.9.

Table 3.9. Example: Calculating Net Biomass in a Tree

Tree Portion	Percent of Tree Biomass	Gross Biomass	Percent Remaining in Tree	Net Biomass
	(from Table 3.56)	(tonnes CO_2e) Percent of tree biomass **x** tree biomass adjusted for density (Table 3.87)	(from example in Table 3.79)	(tonnes CO_2e) Percent remaining in tree **x** gross biomass
Top 1/3	10%	10% **x** 0.092 **=** 0.0092	0%	0.00000
Middle 1/3	25%	25% **x** 0.092 **=** 0.023	50%	0.00115
Bottom 1/3	65%	65% **x** 0.092 **=** 0.0598	100%	0.0598
Total Biomass				0.0713

Tree CO_2e values calculated per the process described above shall be summed for each plot and multiplied by 10 or 24 (according to whether 1/10th or 1/24th acre plots are used) to establish a per-acre estimate from each plot. Plot values shall be averaged across all plots (within a given stratum if the Project Area is stratified) to determine the average CO_2e per acre for the Project Area (or for each stratum).

3.2.4 Developing Project-Specific Ratio Estimators

The average canopy cover percentage and the average CO_2e value (per-acre basis) from all measured plots shall be calculated and documented in the PDD. A ratio of CO_2e per square foot of canopy cover shall be calculated, as shown in Table 3.10. The following example includes stratification. If a project does not stratify, a single ratio estimator will be calculated.

Table 3.10. Urban Forest Class and Ratio Estimators

Stratum	Average Canopy Cover Area from Ground-Based Plots as a Proportion of the Stratum	Average CO_2e from Ground-Based Plots	Ratio Estimators	Ratio Estimators
	(ft^2/acre)	(per acre)	(CO_2e/ft^2 of canopy cover)	(CO_2e/acre of canopy cover)
Stratum I	3,485	15	0.0043042	187.49
Stratum II	5,227	20	0.0038263	166.67
Stratum III	15,246	60	0.0039355	171.43

3.3 Measuring or Estimating Current Canopy Cover in Standing Trees within the Project Area

The total canopy of trees must be measured or estimated (via sampling) for each of the UFM Assessment Areas (or stratum, if using project specific ratio estimators and stratifying) using remotely sensed data throughout the Project Area. If measured, the entire canopy cover for the Project Area will be mapped as a layer in a GIS. The data and tools used to measure the canopy area are not limited and may include a variety of remotely sensed data and automated digitizing, as well as manual digitizing. Any tools and methodologies used to develop the GIS layer of canopy will be reviewed by the verifier for statistical accuracy and appropriateness. With both measurement and sampling, a current satellite image or up-to-date remote sensing data must be used. The image should be dated within 12 months of the project commencement date and should be from a month where foliage is present and visible (spring or summer). Contact Reserve staff if no image is available.

If the canopy layer is sampled rather than measured, the sampled portion must be displayed as a layer in a GIS. The following methods are allowed for sampling canopy area:

1. Randomized points developed using the i-Tree Canopy tool derive a 'hit' or 'miss' (of tree canopy) and must be determined by the technician. The points superimposed on the Project Area allow a percentage of canopy cover, total canopy area, and confidence statistics to be calculated. If a project spans multiple Assessment Areas (or stratum, if using project specific ratio estimators and stratifying), the i-Tree estimate process should be completed separately for each Assessment Area (or stratum).

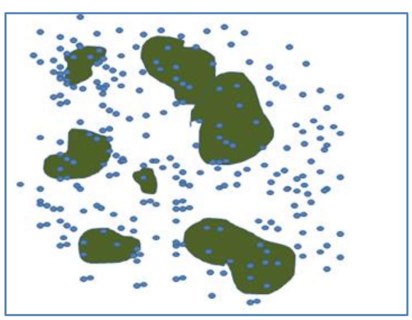


Figure 3.1. Example of Overlaying Random Points in the Project Area to Determine Canopy Percentage

2. A systematic sample can be conducted with a grid of points established in GIS and placed over the Project Area for the purposes of estimating canopy area. The Project Operator must determine the 'hit' and 'miss' of each point (in terms of being coincident with a tree crown or multiple tree crowns), which will enable a percentage of canopy cover to be determined and total canopy area to be determined (as described above). If a project spans multiple Assessment Areas (or strata, if using project specific ratio estimators and stratifying), this process should be completed separately for each Assessment Area (or stratum).

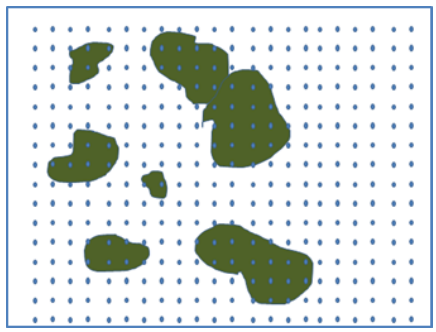


Figure 3.2. Example of Overlaying a Systematic Grid in the Project Area to Determine Canopy Percentage

3. Sampling can be conducted using remotely sensed data as a subset of the Project Area. Again, the sampling must be designed to develop estimates for each Assessment Area (or stratum) independently. The sampling must incorporate randomized strips (two parallel lines with a known distance between them to calculate area) or randomized or systematic area plots. The Project Operator must be able to calculate accurately the area within the strip or plot that is tree canopy and the area that is not tree canopy.

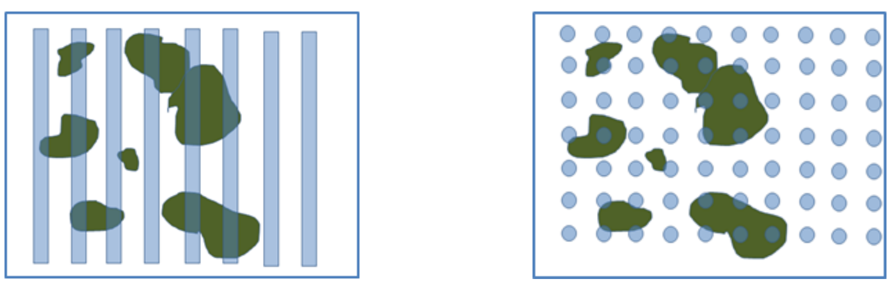


Figure 3.3. Example of Overlaying Known Area Sampling Units (Strips and Fixed Radius)

Regardless of the method utilized:

1. The points, strips, or plots must be maintained for the Project Life and be available for verification.

2. Sampling for canopy cover must continue until a confidence estimate for average canopy cover for each Assessment Area (or stratum) is achieved of no greater than +/-5% at 1 Standard Error. Regardless of the sampling method used, a list of point/plots/strips and its corresponding geographic information estimated percentage of canopy cover relative to the Project Area must be included the. For example, for projects utilizing randomized points developed using iTree Canopy, a table of cover

class, description, latitude and longitude of each point shall be included in the PDD, as well as a table of estimated percentage of canopy cover by cover class.

The Reserve does not require that a new set of random points be generated each year. The same points may be applied to an updated image. It is acceptable to augment the set of random points to maintain and/or augment the confidence in the estimate of the canopy cover estimate. However, the confidence level achieved in the first Reporting Period must be met or exceeded in future Reporting Periods.

3. A table must be presented in the PDD that provides the data shown in Table 3.11. Data shall be carried out to two decimal points. If the canopy was 100% measured, the canopy area can be entered directly into the table below. If sampled, the mean percent canopy estimate from sampling is multiplied by the area within each urban forest class to estimate the canopy area.

Table 3.11. Example of Canopy Cover Data Required in Project Area

Assessment Area	(A) Total Area within Project Area	(B) Mean Estimate of Canopy Cover at 90% CI[1]	(C) Total Area of Tree Canopy within Project Area
	(acres)		(acres)
Oakland, CA	50	10.60%	5.30
Mediterranean California	35	17.71%	6.20
Marine West Coast Forests	65	34.89%	22.68
Total	150		34.18

[1]Enter value based on sampling. If total canopy cover area is directly measured, this step can be skipped and the final values may be reported.

In the example shown above, column B represents the canopy cover estimate derived using one of the methods described in Section 3.3 above. This is broken down by Assessment Area. The value in column A represents the total size of that Assessment Area. Column C (the total area of tree canopy within the Project Area) is generated by multiplying column A by column B. These final numbers are then used to calculate project CO_2e, as described below.

3.4 Determining the Current Project Area Estimate of CO_2e

With the total tree canopy area estimated or measured and ratio estimators selected or developed for each of the applicable Assessment Areas (or strata, if using project specific ratio estimators and stratifying), an estimate of CO_2e for the Project Area can be estimated. The ratio estimators are multiplied by the total acre of canopy cover in each Assessment Area (stratum, if using project specific ratio estimators and stratifying) and summed to determine the estimated CO_2e in the Project Area, as shown in Table 3.12.

Table 3.12. Example of Expanding Ratio estimators Based on Canopy Cover Area to Estimate Total Current CO_2e within the Project Area

Urban Forest Class	Current Estimated/Measured Canopy Cover Area (from Table 3.1112, or measured)	Ratio estimators (from Table 3.2)	Total CO_2e
	(acre)	(CO2e tonne/acre of canopy cover)	(tonnes)
Oakland, CA	5.30	78	413
Mediterranean California	6.20	68	422
Marine West Coast Forests	22.68	65	1,474
Total	34.18		2,309

3.4.1 Maintaining and Updating Project Inventories

Urban forest Project Inventories must be reported to the Reserve on an annual basis for each Reporting Period. Urban forest inventories are in constant flux due to forest growth and mortality or removal and therefore must be updated on an annual basis for reporting. The Project Inventory must be updated annually through a re-calculation of the canopy area and applying the ratio estimator that was used for the baseline analysis, as well as through the use of any field measurements that occurred since the previous Reporting Period (if the project's ratio estimators are based on field sampling and the plot data has been updated).

It is important to note that the basis of a successful verification depends on alignment (within tolerance bands defined in Section 8 of the protocol) between verifier data and Project Operator data for each randomly selected plot (selected by verifier), therefore these guidelines do not ensure successful project verification.

3.4.1.1 For Projects Using Default Ratio Estimators

It is acceptable to use the previous points used to develop the canopy area and re-evaluate them with updated imagery. It is also acceptable to use newly generated random point to develop a revised estimate on the updated imagery. The Project Operator may provide an attestation asserting that no new image update is available for the current year in which case the Reserve will accept the previous year's reported Project Inventory.

3.4.1.2 For Projects Using Project-Specific Ratio Estimators

For projects that developed their own project-specific ratio estimators, updating the field-based Project Inventory is optional. Projects may choose to apply the project-specific ratio estimators used for its initial Reporting Period for the remaining for the project's crediting period. Or, projects may choose to update the project-specific ratio estimators by updating its field-based Project Inventory at intervals determined by the Project Operator. Updates to the field-based Project Inventory will require successful full site verification prior to credit issuance. This quantification guidance provides sampling methodologies to develop urban forest inventories. Additional sampling methodologies may be added to this section as they are developed and reviewed by the Reserve.

For projects relying on ground-based inventories, plot data can be 'grown', or projected for a maximum of 10 years, after which additional field work is required to either update the plot data or establish new plots.

Since the biomass of sampled trees is determined through the use of equations that are based on diameter (breast height) and total height variables, updating plot data for forest growth can be accomplished through the use of projections of inventory data in the database that mimic the diameter and height increment of trees in the field. An additional resource document posted on the urban forest webpage provides biomass equations for urban forest projects.

The references in the resource document may be useful for Project Operators in designing an appropriate mechanism to ‘grow’ their plot data. Most references address the annual increment of diameter (DBH). Height growth also needs to be addressed to ensure the most accurate comparison of tree records in the database to actual conditions in the field. Heights can be estimated through regression analysis by comparison of measured diameters to measured heights for a given species. It is recommended that, rather than simply relying on the height estimate from the regression analysis, that Project Operators apply the height increment derived from the regression analysis to the height that was measured in the field.

In any case, plot data that is updated to reflect current conditions with the use of predicted increments of height and diameter data, as well as updates for removals, will be used during onsite verifications to compare against verifiers’ field measurements using the sequential sampling techniques described in Section 8 of the protocol. This provision ensures that plot measurements and update processes are within accuracy thresholds.

3.5 Developing the Baseline for Urban Forest Management Projects

The baseline for UFM Projects is calculated by developing a trend based on a comparison of historical estimates of standing live and dead trees – taken at two points in time, as described below - and/or a comparison of historical estimates of standing live and dead trees to current estimates.

3.5.1 Calculating the Historical Project Area Estimate of CO_2e

A historical inventory is required to develop a trend used in the development of the project baseline. The historical Project Area estimate of CO_2e is calculated using the ratio estimators along with at least two canopy cover estimates from remotely-sensed data that were produced prior to the project commencement date. This can be done by exporting the points generated in i-Tree Canopy and importing them into Google Earth where historical images are available. This may also be done in a GIS program through the use of historical aerial or satellite imagery, such as NAIP. Regardless of the image source used, historical images should be leaf-on, color images, and more recent when possible. Project Operators should aim to use historical images with a similar resolution to current aerial images of the project, wherever possible. The trend line must pass through at least two historical inventory estimates that are at least 10 years apart and with the earliest point no earlier than 1990. For instance, if a project commences in 2018, the historical estimates may be done using aerial imagery from 2005 and 2015, since the two points pre-date project commencement date, are at least 10 years apart from one another, and do not pre-date 1990.

Wherever possible, Project Operators should strive to have all points use the same image for a given year. If this is not possible, Project Operators may arrive at a historical estimate for a given year by using images that are all within 12 months of one another; the calendar year of the image(s) on which the majority of the points fall will be used as the calendar year for that historical point. For instance, if a Project Operator is calculating a historical estimate in which 25% of iTree points use a historical image dated 08/2011, and 75% of iTree points use a historical image dated 02/2012, then the date of that historical canopy estimate will be 02/2012, as this image represents the majority of the historical canopy cover estimates taken around that time. The second historical point in time must be at least 10 years apart from 02/2012 and may not pre-date 1990.

It is acceptable to either measure the entire canopy area from an earlier image or to sample the canopy area, using the method described in Section 3.3. If sampling, the same plots must be sampled for the historical canopy estimates as were used for the current project canopy estimate. The image(s) used must be available to a verifier and identified in the PDD. An example of using a historical estimate of canopy cover to expand ratio estimators in order to calculate a historical CO_2e estimate is shown in Table 3.13. Two tables showing the historical CO_2e estimate for each of the two points in time must be available in the PDD.

Table 3.13. Example of Expanding Ratio Estimators Based on Historical Canopy Cover Area to Estimate Historical CO_2e within the Project Area

Urban Forest Class	Ratio estimators (from Table 3.2) (tonne/acre of canopy cover)	Historic Estimated/Measured Canopy Cover Area (acre)	Total CO_2e (metric tons)
Oakland, CA	78	4.62	360
Mediterranean California	68	1.83	124
Marine West Coast Forests	65	5.45	354
		Total	838

3.5.2 Estimating the Baseline

The slope developed by plotting the two points of inventory on their respective year of reporting is continued into the future for the next 25 years beginning at the Project Start Date, and then held steady for the subsequent 75 years where legal requirements have not been modified substantially, as described below. In scenarios where the extended slope dips below zero, projects must stop the slope at zero, at which point the baseline shall be held steady at zero for the remainder of 100 years from the Project Start Date. Developing a 100-year baseline allows projects to apply the same baseline to additional crediting periods, if a project opts to the renew its crediting period after the first 25 years.

An analysis of legal requirements must accompany the baseline development. The PDD must include a full disclosure of legal requirements affecting tree management within the Project Area, as well as a narrative describing the analysis of these requirements. Any substantial change in legal requirements, including ordinances, regulations, or other legal obligations, not including legal obligations associated with the use of this protocol, that would modify the trend described above over the next 25 years must be factored into the trend line for the next 25 years or as long as stated in the legal requirements (whichever is longer). If a legal constraint that affects Carbon Stocks in the Project Area took effect during the historical period used to generate the baseline but is not reflected in the trend estimated from the comparison of historical images alone, the effects of the legal constraint must be factored into the final trend line for the 25 year project crediting period, or as long as stated in the legal requirements (whichever is longer). Modeling is conducted by projecting any carbon stored by trees obligated by the regulation forward into time. If the trend line requires modification, modeling of the trend line must be conducted by a Certified Arborist, a Certified Forester, or a Professional Forester.

Where modeling must be conducted, the baseline trend shall be defined by a straight line from the UFM Project's initial stocks to the highest point determined from baseline modeling. If the highest point is reached before year 100, the baseline will be held constant from that point until year 100. Examples of sources of legal obligations may include, but are not limited to, tree ordinances, urban forest ordinances or management plans required by law, landscaping ordinances, or other environmental regulations associated with urban development and land use change. Refer to Section 3.4.1 of the protocol for more information on requirements regarding legal requirements.

Examples of the baseline approach, assuming a project commencing in 2015, are displayed in Figure 3.4 and Figure 3.5.

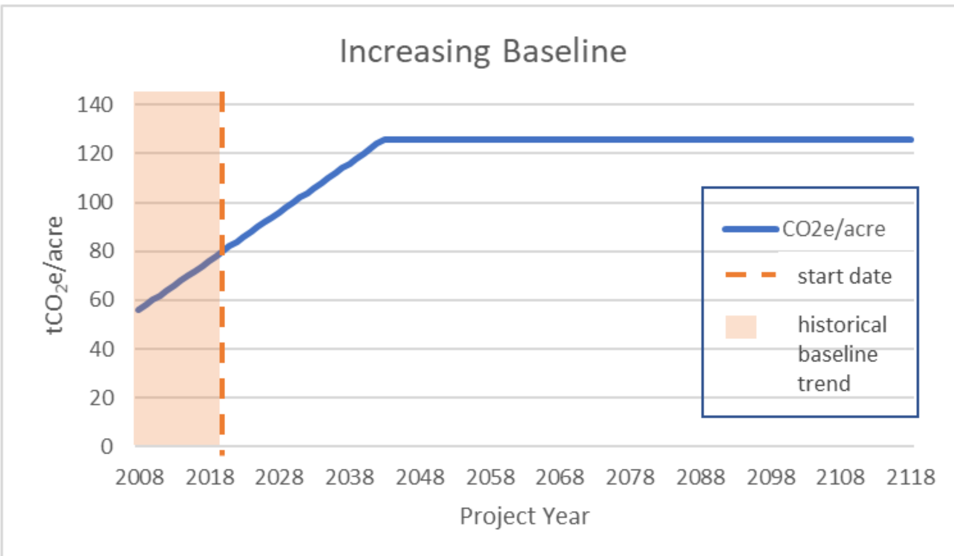


Figure 3.4. Example of Increasing Baseline Trend Extending 25 Years Beyond Current Inventory and then Static for Balance of 100 Years

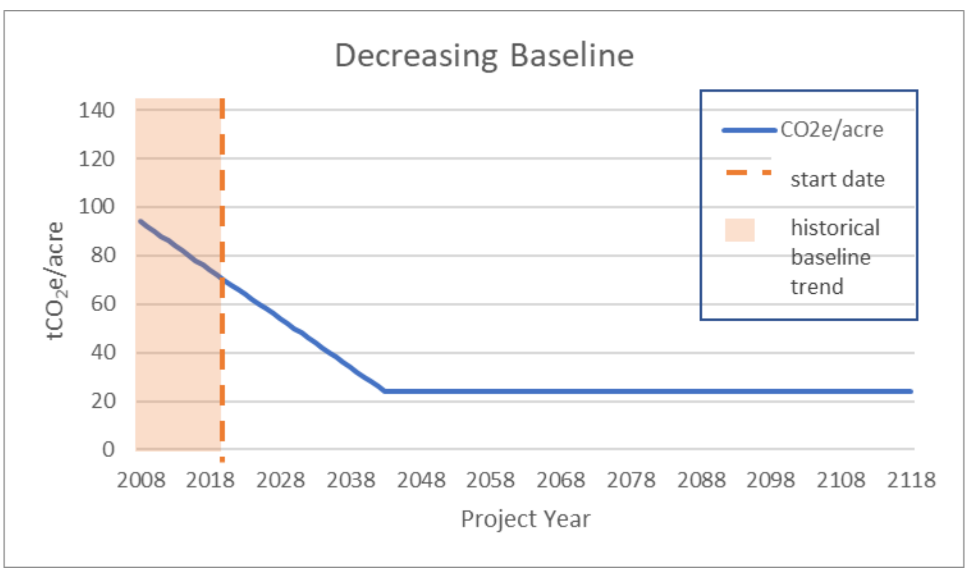


Figure 3.5. Example of Decreasing Baseline Trend Extending 25 Years Beyond Current Inventory and then Static for Balance of 100 Years

For annual reporting purposes, a project must report the CO_2e/acre in the baseline for the current vintage and determine how much this has changed from the prior year (Δ BC_{onsite}). This is compared to the change in project Carbon Stocks for the current vintage (Δ AC_{onsite}) to calculate CRTs for the Reporting Period. Refer to Section 5 and Equation 5.1 in the Urban Forest Management Project Protocol V1.1 for more information.