Method for
Calculating Carbon Sequestration by Trees in Urban and Suburban Settings

VOLUNTARY REPORTING of GREENHOUSE GASES

April 1998

U.S. Department of Energy
Energy Information Administration

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INTRODUCTION

This document presents a method for calculating the amount of carbon sequestered by trees planted individually in urban and suburban settings. It is intended for use by participants in the Voluntary Reporting of Greenhouse Gases Program, who intend to submit either Form EIA-1605 or EIA-1605EZ to the U.S. Department of Energy's Energy Information Administration. This simplified method can be used by those who have no formal background in forestry.

This method is appropriate only for calculating carbon sequestration by individual ("open grown") trees, such as trees typically planted along streets, in yards, and in parks. Do not use it for calculating carbon sequestration by densely planted trees, as in typical afforestation or reforestation projects where large numbers of trees are planted closely together on one or more acres of land. A separate set of tables designed to assist in calculating per-acre carbon sequestration are available upon request from the Voluntary Reporting of Greenhouse Gases Program by calling 1-800-803-5182.

A further limitation of this method is that it only estimates the greenhouse gas emission benefit associated with the carbon sequestered directly by trees planted. Trees planted adjacent to buildings can significantly reduce cooling and heating needs by providing shade during summer and acting as windbreaks during winter. These reductions in energy consumption result in reduced carbon dioxide emissions, a greenhouse gas. These emission reductions must be calculated separately.

To produce a simplified, easy-to use method, broad assumptions have been made regarding sequestration and mortality rates and site characteristics for a few groupings of tree species. As a result, this method may yield less precise results than a more tailored approach, which takes into account a larger number of the unique characteristics of the planting sites and trees involved in a project. Thus, you should use this method only if it is infeasible to generate estimates based on surveys and direct measurements of the specific trees and planting sites involved in the project.

To use this method, you need to know the species, year planted, and age of the trees when planted. The age of the tree is the most problematic of these items. The tables included for estimating sequestration were designed for reporters who have planted ordinary, nursery-raised trees, typically sold in 15-gallon containers or balled and burlapped. Such "standard" trees are usually approximately one inch in diameter at 4.5 feet above the ground when planted. For the purposes of this method, age is measured from the time the tree is planted. Therefore, standard-sized trees are designated as age 0 when planted. Although this method is easiest to use if your trees were planted at this age, it can be used for trees planted at any age.

The remainder of this document includes the following:

- a worksheet for summarizing calculations of carbon sequestration;
- instructions for performing these calculations, including survival factors (to account for mortality) and sequestration rates;
- worksheet entries for a sample project; and
- instructions for calculating sequestration for non-standard trees (i.e., trees that are younger or older than age 0 when planted).

INSTRUCTIONS

The following worksheet (page 5) is provided for summarizing your calculations of annual carbon sequestration for tree planting projects in urban or suburban areas. Use a separate worksheet for each year you are reporting carbon sequestration. (The Voluntary Reporting of Greenhouse Gases Program is accepting information for 1991 through 1997 for the reporting period ending on July 1, 1998.) Complete the worksheet columns as follows:

Column A — Species Characteristics: List each distinct species of tree included in the project by year. List trees of a different age separately even if they are of the same species (e.g., list one-year-old red cedars on a separate row from two-year-old red cedars). If you are unsure of the name of a species, list it as "Unknown." If the exact age of a tree(s) is unknown, an approximation is acceptable. A list of common tree species is provided in Table 1. Note that each species listed is characterized by type (hardwood or conifer) and growth speed (slow, moderate, or fast). These characteristics will be used subsequently in selecting appropriate survival and sequestration rates. For each species and age category, enter letter codes in the respective columns for tree type (H = hardwood, C = conifer) and growth rate (S = Slow, M = Moderate, F = Fast). If you know whether the trees are hardwoods or conifers, but do not know the exact species (or the species is not included in Table 1), assume the trees have a moderate growth rate. If you do not know whether the species is a hardwood or conifer, assume that it is a hardwood of moderate growth rate.

Column B — Tree Age: Enter the age of the trees in the year for which you are calculating sequestration (the reporting year). Tree age is measured from the time of planting and assumes that trees are planted at a standard size, defined as a tree in a 15-gallon container or a balled and burlapped tree. Nursery-raised trees are typically planted at this size, which is designated as age 0 for the purposes of this method. For example, if you planted a standard-sized tree in 1994, its age in the 1995 reporting year would be 1. If the exact age of a tree(s) is unknown, an approximation is acceptable. If you planted trees that were smaller or larger than this standard size, refer to p. 12 for instructions on determining age.

Column C — Number of Age 0 Trees Planted: Enter the total number of trees of this species and age category originally planted as part of the project. *If the trees were <u>not</u> the standard size (age 0) when planted, you will need to adjust the number of trees planted to reflect a difference in mortality. For example, if you planted 100 trees smaller than the standard size, a fraction—say 15 percent—of the trees might be expected to die before reaching the standard size or age 0. This method requires you to estimate the number of trees surviving to the standard size—in this case 85—and estimate sequestration for these trees. This number is referred to as the <u>effective</u> number of trees planted. See the instructions on p. 13 to make the necessary adjustment.*

Column D — Survival Factor: Enter the survival factor from Table 2 for the tree species. Leave this column blank if you know (or can otherwise estimate) the number of trees surviving at the end of the reporting year. It is necessary to account for mortality, since a fraction of the trees planted inevitably die in each succeeding year. The ideal method for determining the number of trees surviving is to conduct a census of the trees planted. Alternatively, you can estimate survival based on the specifics of your project. If either of these approaches are infeasible, you may use the standard survival factors for urban trees provided in Table 2. However, participant-estimated survival factors are preferable (if accurate) because the survival factors in Table 2 were developed from a survey of a limited number of scientific studies of urban tree mortality in a small number of U.S. cities, the results of which may or may not approximate the specifics of your project.

Column E — Number of Surviving Trees: Enter the number of trees surviving *at the end* of the reporting year in question. If you do not know or cannot otherwise estimate this number, multiply the original number of trees planted (Column C) by the survival factor (Column D). For example, for fast-growing conifers in the year in which they were planted (age 0), the survival factor would be 0.873, that is 87.3 percent of the trees originally planted are expected to survive to the end of the first year. For the same trees that are age 1 (i.e., trees that were planted in the year prior to that for which sequestration is being calculated), the survival factor would be 0.798. Retain fractions of trees.

Note: If the number of trees in a subset falls below 0.5, assume all of the trees originally planted have died and no carbon has been sequestered in the reporting year. (Provided the estimated number of trees surviving is greater than 0.5, then the probability that one tree survived and sequestered carbon is greater than 50 percent.)

Column F — Annual Sequestration Rate: Enter the annual sequestration rate from Table 2 for the species and age category of the trees during the reporting year in question.

Column G — Carbon Sequestered: Multiply the number of trees surviving (Column E) by the annual sequestration rate (Column F) and enter the resulting number in Column G. Repeat the above process for each species and age category. Sum all of the annual carbon sequestration totals for each species and age category and enter the total in the lower right-hand corner of the table. This is the total amount of carbon sequestered by the project in the reporting year in question.

Note 1: These steps must be repeated using a separate worksheet for each year for which you are reporting.

Note 2: To report in units of carbon dioxide instead of, or in addition to, carbon, multiply the total in Column G by 3.67. To report in short tons instead of pounds, divide by 2000.

Note 3: The amount sequestered is entered under the Emission Reduction or Sequestration column on the EZ form, or as Annual Increase in Schedule II, Section 8, Part III of the Long Form.

The section following Table 2 presents an example worksheet for an urban tree planting project (see p. 11).

URBAN FORESTRY CARBON SEQUESTRATION WORKSHEET

(Calculate each reporting year on a separate worksheet; photocopy if more than one sheet is required)

Reporting year: 19___

A. Species Characteristics (Refer to Table 1)			B. Tree Age	C. Number of Age 0 Trees Planted	D. Survival Factor (Refer to Table 2)	E. Number of Surviving Trees (C x D)	F. Annual Sequestration Rate (lbs./tree) (Refer to Table 2)	G. Carbon Sequestered (lbs) (E x F)
Name	**Tree Type** (H or C)	**Growth Rate** (S, M, or F)						
Total Pounds of Carbon Sequestered								
Total Pounds of Equivalent CO2 Sequestered							**X 3.67**	
Equivalent CO2 Sequestered in Short Tons							**/2000**	

Table 1. Common Urban Tree Species

Species	Type	Growth Rate	Species	Type	Growth Rate
Ailanthus, *Ailanthus altissima*	H	F	Maple, bigleaf, *Acer macrophyllum*	H	S
Alder, European, Alnus glutinosa	H	F	Maple, Norway, *Acer platanoides*	H	M
Ash, green, Fraxinus pennsylvanica	H	F	Maple, red, *Acer rubrum*	H	M
Ash, mountain, American,*Sorbus americana*	H	M	Maple, silver, *Acer saccharinum*	H	M
Ash, white, *Fraxinus americana*	H	F	Maple, sugar, *Acer saccharum*	H	S
Aspen, bigtooth, *Populus grandidentata*	H	M	Mulberry, red, *Morus rubra*	H	F
Aspen, quaking, *Populus tremuloides*	H	F	Oak, black, *Quercus velutina*	H	M
Baldcypress, *Taxodium distichum*	C	F	Oak, blue, *Quercus douglasii*	H	M
Basswood, American, *Tilia americana*,	H	F	Oak, bur, *Quercus macrocarpa*	H	S
Beech, American, *Fagus grandifolia*	H	S	Oak, California black, *Quercus kelloggii*	H	S
Birch, paper (white), *Betula papyrifera*	H	M	Oak, California White, *Quercus lobata*	H	M
Birch, river, *Betula nigra*	H	M	Oak, canyon live, *Quercus chrysolepsis*	H	S
Birch, yellow, *Betula alleghaniensis*	H	S	Oak, chestnut, *Quercus prinus*	H	S
Boxelder, *Acer negundo*	H	F	Oak, Chinkapin, *Quercus muehlenbergii*	H	M
Buckeye, Ohio, *Aesculus glabra*	H	S	Oak, Laurel, *Quercus laurifolia*	H	F
Catalpa, northern, *Catalpa speciosa*	H	F	Oak, live, *Quercus virginiana*	H	F
Cedar-red, eastern, *Juniperus virginiana*	C	M	Oak, northern red, *Quercus rubra*	H	F
Cedar-white, northern, *Thuja occidentalis*	C	M	Oak, overcup , *Quercus lyrata*	H	S
Cherry, black, *Prunus serotina*	H	F	Oak, pin, *Quercus palustris*	H	F
Cherry, pin, *Prunus pennsylvanica*	H	M	Oak, scarlet, *Quercus coccinea*	H	F
Cottonwood, eastern, *Populus deltoides*	H	M	Oak, swamp white, *Quercus bicolor*	H	M
Crabapple, *Malus* spp.	H	M	Oak, water, *Quercus nigra*	H	M
Cucumbertree, *Magnolia acuminata*	H	F	Oak, white, *Quercus alba*	H	S
Dogwood, flowering, *Cornus florida*	H	S	Oak, willow, *Quercus phellos*	H	M
Elm, American, *Ulmus americana*	H	F	Pecan, *Carya illinoensis*	H	S
Elm, Chinese, *Ulmus parvifolia*	H	M	Pine, European black, *Pinus nigra*	C	S
Elm, rock, *Ulmus thomasii*	H	S	Pine, jack, *Pinus banksiana*	C	F
Elm, September, *Ulmus serotina*	H	F	Pine, loblolly, *Pinus taeda*	C	F
Elm, Siberian, *Ulmus pumila*	H	F	Pine, longleaf, *Pinus palustris*	C	F
Elm, slippery, *Ulmus rubra*	H	M	Pine, ponderosa, *Pinus ponderosa*	C	F
Fir, balsam, *Abies balsamea*	C	S	Pine, red, *Pinus resinosa*	C	F
Fir, Douglas, Pseudotsuga menziesii	C	F	Pine, Scotch, *Pinus sylvestris*	C	S
Ginkgo, *Ginkgo biloba*	H	S	Pine, shortleaf, *Pinus echinata*	C	F
Hackberry, *Celtis occidentalis*	H	F	Pine, slash, *Pinus elliottii*	C	F
Hawthorne, *Crataegus* spp.	H	M	Pine, Virginia, *Pinus virginiana*	C	M
Hemlock, eastern, *Tsuga canadensis*	C	M	Pine, white eastern, *Pinus strobus*	C	F
Hickory, bitternut, *Carya cordiformis*	H	S	Poplar, yellow, *Liriodendron tulipifera*	H	F
Hickory, mockernut, *Carya tomentosa*	H	M	Redbud, eastern, *Cercis canadensis*	H	M
Hickory, shagbark, *Carya ovata*	H	S	Sassafras, *Sassafras albidum*	H	M
Hickory, shellbark, Carya laciniosa	H	S	Spruce, black, *Picea mariana*	C	S
Hickory, pignut, *Carya glabra*	H	M	Spruce, blue, *Picea pungens*	C	M
Holly, American, *Ilex opaca*	H	S	Spruce, Norway, *Picea abies*	C	M
Honeylocust, *Gleditsia triacanthos*	H	F	Spruce, red, *Picea rubens*	C	S
Hophornbeam, eastern, *Ostrya virginiana*	H	S	Spruce, white, *Picea glauca*	C	M
Horsechestnut, common, *Aesculus hippocastanum*	H	F	Sugarberry, *Celtis laevigata*	H	F
Kentucky coffeetree, *Gymnocladus dioicus*	C	F	Sweetgum, *Liquidambar styraciflua*	H	F
Linden, little-leaf, *Tilia cordata*	H	F	Sycamore, *Platanus occidentalis*	H	F
Locust, black, *Robinia pseudoacacia*	H	F	Tamarack, *Larix laricina*	C	F
London plane tree *Platanus_X_acerifolia*	H	F	Walnut, black, *Juglans nigra*	H	F
Magnolia, southern, *Magnolia grandifolia*	H	M	Willow, black, *Salix nigra*	H	F

Type: H = Hardwood, C = Conifer   Growth Rate: S = Slow, M = Moderate, F = Fast

Table 2: Survival Factors and Annual Carbon Sequestration Rates for Common Urban Trees

Tree Age (yrs)	Survival Factors by Growth Rate			Annual Sequestration Rates by Tree Type and Growth Rate (lbs. carbon/tree/year)					
				Hardwood			Conifer		
	Slow	Moderate	Fast	Slow	Moderate	Fast	Slow	Moderate	Fast
0	0.873	0.873	0.873	1.3	1.9	2.7	0.7	1.0	1.4
1	0.798	0.798	0.798	1.6	2.7	4.0	0.9	1.5	2.2
2	0.736	0.736	0.736	2.0	3.5	5.4	1.1	2.0	3.1
3	0.706	0.706	0.706	2.4	4.3	6.9	1.4	2.5	4.1
4	0.678	0.678	0.678	2.8	5.2	8.5	1.6	3.1	5.2
5	0.658	0.658	0.658	3.2	6.1	10.1	1.9	3.7	6.4
6	0.639	0.639	0.644	3.7	7.1	11.8	2.2	4.4	7.6
7	0.621	0.621	0.630	4.1	8.1	13.6	2.5	5.1	8.9
8	0.603	0.603	0.616	4.6	9.1	15.5	2.8	5.8	10.2
9	0.585	0.589	0.602	5.0	10.2	17.4	3.1	6.6	11.7
10	0.568	0.576	0.589	5.5	11.2	19.3	3.5	7.4	13.2
11	0.552	0.564	0.576	6.0	12.3	21.3	3.8	8.2	14.7
12	0.536	0.551	0.563	6.5	13.5	23.3	4.2	9.1	16.3
13	0.524	0.539	0.551	7.0	14.6	25.4	4.6	9.9	17.9
14	0.512	0.527	0.539	7.5	15.8	27.5	4.9	10.8	19.6
15	0.501	0.516	0.527	8.1	16.9	29.7	5.3	11.8	21.4
16	0.490	0.504	0.516	8.6	18.1	31.9	5.7	12.7	23.2
17	0.479	0.493	0.505	9.1	19.4	34.1	6.1	13.7	25.0
18	0.469	0.483	0.495	9.7	20.6	36.3	6.6	14.7	26.9
19	0.459	0.472	0.484	10.2	21.9	38.6	7.0	15.7	28.8
20	0.448	0.462	0.474	10.8	23.2	41.0	7.4	16.7	30.8
21	0.439	0.452	0.464	11.4	24.4	43.3	7.9	17.8	32.8
22	0.429	0.442	0.454	12.0	25.8	45.7	8.3	18.9	34.9
23	0.419	0.433	0.445	12.5	27.1	48.1	8.8	20.0	37.0
24	0.410	0.424	0.435	13.1	28.4	50.6	9.2	21.1	39.1
25	0.401	0.415	0.426	13.7	29.8	53.1	9.7	22.2	41.3
26	0.392	0.406	0.417	14.3	31.2	55.6	10.2	23.4	43.5
27	0.384	0.398	0.409	15.0	32.5	58.1	10.7	24.6	45.7
28	0.375	0.389	0.400	15.6	33.9	60.7	11.2	25.8	48.0
29	0.367	0.381	0.392	16.2	35.3	63.3	11.7	27.0	50.3
30	0.359	0.373	0.383	16.8	36.8	65.9	12.2	28.2	52.7
31	0.352	0.365	0.375	17.5	38.2	68.5	12.7	29.5	55.1
32	0.344	0.358	0.367	18.1	39.7	71.2	13.3	30.7	57.5
33	0.337	0.350	0.360	18.7	41.1	73.8	13.8	32.0	59.9
34	0.330	0.343	0.349	19.4	42.6	76.5	14.3	33.3	62.4
35	0.323	0.336	0.339	20.0	44.1	79.3	14.9	34.7	64.9

Table 2: Survival Factors and Annual Carbon Sequestration Rates for Common Urban Trees (Cont'd)

Tree Age (yrs)	Survival Factors by Growth Rate			Annual Sequestration Rates by Tree Type and Growth Rate (lbs. carbon/tree/year)					
				Hardwood			Conifer		
	Slow	Moderate	Fast	Slow	Moderate	Fast	Slow	Moderate	Fast
36	0.316	0.329	0.329	20.7	45.6	82.0	15.5	36.0	67.5
37	0.310	0.322	0.320	21.4	47.1	84.8	16.0	37.3	70.1
38	0.303	0.315	0.310	22.0	48.6	87.6	16.6	38.7	72.7
39	0.297	0.308	0.301	22.7	50.2	90.4	17.2	40.1	75.3
40	0.291	0.302	0.293	23.4	51.7	93.2	17.7	41.5	78.0
41	0.285	0.296	0.284	24.1	53.3	96.1	18.3	42.9	80.7
42	0.279	0.289	0.276	24.8	54.8	99.0	18.9	44.3	83.4
43	0.273	0.283	0.268	25.4	56.4	101.9	19.5	45.8	86.2
44	0.267	0.277	0.260	26.1	58.0	104.8	20.1	47.2	89.0
45	0.261	0.269	0.253	26.8	59.6	107.7	20.7	48.7	91.8
46	0.256	0.261	0.245	27.6	61.2	110.7	21.3	50.2	94.7
47	0.251	0.254	0.238	28.3	62.8	113.6	22.0	51.7	97.5
48	0.245	0.247	0.231	29.0	64.5	116.6	22.6	53.2	100.4
49	0.240	0.239	0.225	29.7	66.1	119.6	23.2	54.8	103.4
50	0.235	0.232	0.218	30.4	67.8	122.7	23.9	56.3	106.3
51	0.230	0.226	0.212	31.1	69.4	125.7	24.5	57.9	109.3
52	0.225	0.219	0.206	31.9	71.1	128.8	25.2	59.4	112.3
53	0.221	0.213	0.199	32.6	72.8	131.8	25.8	61.0	115.4
54	0.216	0.207	0.193	33.4	74.5	134.9	26.5	62.6	118.4
55	0.211	0.201	0.188	34.1	76.2	138.0	27.2	64.2	121.5
56	0.207	0.195	0.182	34.8	77.9	141.2	27.8	65.9	124.6
57	0.203	0.189	0.177	35.6	79.6	144.3	28.5	67.5	127.8
58	0.198	0.184	0.171	36.3	81.3	147.5	29.2	69.2	130.9
59	0.194	0.178	0.166	37.1	83.0	150.6	29.9	70.8	134.1

WORKSHEET ENTRIES FOR A SAMPLE PROJECT

This example illustrates how the worksheet should be used in calculating the carbon sequestered by a hypothetical tree planting project in 1995. The project involves 100 Norway maples planted in 1993, 75 Norway maples planted in 1992, 35 rock elms planted in 1989, and 437 white spruces planted in 1994. All the trees were standard, nursery-raised specimens (i.e., trees in 15-gallon containers or balled and burlapped) at the time of planting.

The following steps should be taken to complete the worksheet (see Table 3):

1. In Column A, enter each species-age category on a separate line. Note that the species Norway maple occupies two lines, since plantings of that species were made in two distinct years. Enter the appropriate letter code for tree type and growth rate.

2. In Column B, enter the age of each group of trees. The age indicated should be the number of years since planting. For example, the 35 rock elms planted in 1989 would be 6 years old in 1995 (1995 - 1989 = 6).

3. In Column C, enter the original number of trees planted for each species-age category.

4. In Column D, enter the survival factors for each species and age category as listed in Table 2. In the case of the 100 Norway maples planted in 1993, the survival factor for 2-year-old, moderate growth hardwoods is 0.736.

5. Calculate the number of trees surviving in each species-age category at the end of the reporting year by multiplying the original number of trees (Column C) by the survival factor. Enter the resulting number in Column E. For example, the surviving number of Norway maples planted in 1993 is determined by multiplying the 75 trees planted by a survival factor of 0.736, to give 73.6 trees left at the end of 1995. (Retain fractions of trees).

6. In Table 2, find the annual sequestration rate corresponding to each species-age category and enter this rate in Column F. For example, the 2 year-old Norway maples (moderate growth hardwoods) sequester carbon at a rate of 3.5 pounds per tree per year, while the 7-year-old rock elms (slow growth hardwoods) would have sequestered 3.7 pounds of carbon each.

7. For each species-age category, multiply the number of surviving trees (Column E) by the annual sequestration rate in (Column F) to obtain the amount (in pounds) of carbon sequestered in 1995. Enter the resulting number in Column G. For example, the 2-year-old Norway maples sequestered 257.6 pounds of carbon in 1995.

8. In Column G, sum all entries and enter the result on the last row of Column G. This is the total amount of carbon sequestered by this project in the 1995 reporting year (257.6 + 227.9 + 82.9 + 523.1 = 1091.5 pounds in this example). Record this number as the Annual Increase in Section 8, Part III on Form EIA-1605 or Sequestration on Form EIA-1605EZ.

Table 3: Sample Urban Forestry Carbon Sequestration Worksheet

Reporting year: 19 95

A. Species Characteristics (Refer to Table 1)			B. Tree Age	C. Number of Age 0 Trees Planted	D. Survival Factor (Refer to Table 2)	E. Number of Surviving Trees (C x D)	F. Annual Sequestration Rate (lbs./tree) (Refer to Table 2)	G. Carbon Sequestered (lbs) (E x F)
Name	Tree Type (H or C)	Growth Rate (S, M, or F)						
Maple, Norway	H	M	2	100	0.736	73.6	3.5	257.6
Maple, Norway	H	M	3	75	0.706	53.0	4.3	227.9
Elm, rock	H	S	6	35	0.639	22.4	3.7	82.9
Spruce, white	C	M	1	437	0.873	381.5	1.5	572.3
Total Pounds of Carbon Sequestered								1130.7
Total Pounds of Equivalent CO2 Sequestered X 3.67								4149.67
Equivalent CO2 Sequestered in Short Tons /2000								2.07

CALCULATING SEQUESTRATION FOR NON-STANDARD TREES

The preceding method for estimating carbon sequestration was designed for trees planted at a "standard" size, defined as a tree in 15-gallon container or balled and burlapped conifer. At this size, a tree is usually approximately one inch in diameter at 4.5 feet above the ground. For the purposes of this method, age is measured from the time the tree is planted at the standard size. Therefore, standard-sized trees are designated as age 0, even though it will generally take seedlings several years to reach this size.

Trees can also be planted when they are either smaller or larger than this standard size. This section provides instructions on how to adapt the preceding method to estimate sequestration for trees that were a non-standard size when planted. The following adjustments are necessary:

1. The age of the trees planted must be normalized to that of a standard tree. This means determining the number of years that have elapsed since the trees reached (or will elapse before the trees reach) the standard size (age 0).

2. The number of trees planted must be adjusted to reflect differences in mortality. This means estimating the number of trees expected to have survived to age 0 and using this number, the *effective* number of trees planted, in subsequent calculations. (This adjustment will not be necessary if you determine the number of trees surviving by conducting a survey of the trees planted or by a method does not rely on the survival factors presented in Table 2).

The remainder of this section provides instructions for determining the year the trees reach standard size and estimating the effective number of trees planted. In addition, several examples and a sample worksheet are provided to illustrate how these adjustments are made in calculating carbon sequestration.

Normalizing Tree Age

Tables 4 and 5 estimate the ages of hardwoods and conifers, respectively, planted at different sizes. Tree age is the number of years since the tree reached standard size (or age 0). Negative relative ages indicate the number of years *before* the tree will reach age 0. For example, if you planted 100 Norway maples (hardwoods) in 10-gallon containers in 1992, the age of these trees when planted would be -2, which means they would reach age 0 two years later in 1994. The age of the trees in the 1995 reporting year would be 1.

Table 4: Relative Ages and Survival Adjustment Factors for Hardwoods

Size of Tree When Planted	Tree Age	Survival Factor
Bare Root Seedling	-6	.443
10 Gallon Container	-2	.762
15 Gallon Container	0	1.000
Balled and Burlapped	0	1.000

Estimating the Effective Number of Trees Planted

Tables 4 and 5 also provide survival factors for hardwoods and conifers, respectively. These factors are applied to the *actual* number of trees planted to determine the *effective* number of trees planted at age 0. If trees smaller than the standard size are planted, a fraction of the original trees planted would reach the standard size (i.e., survive to age 0). Hence the survival factor is less than 1 when smaller trees are planted. The opposite is true if trees larger than the standard size are planted: the effective number of standard-sized trees one would have to plant would be greater than the number of older trees actually planted in a later year. Hence the survival factors for larger trees are greater than 1. In the Norway maple example above, the effective number of trees planted is determined by multiplying the actual number of trees originally planted (100) by the survival adjustment factor for trees of age -2 (0.762) to give 76.2 trees. This information — 76.2 trees effectively planted in 1994 at age 0 — can now be used to calculate annual carbon sequestration using the worksheet in the normal manner.

Example Calculations

This example project involves calculating carbon sequestration in 1995 for the following non-standard-sized trees (in addition to the 100 Norway maples planted in 1992 from the above example):

- 50 bare root black locust seedlings planted in 1989;
- 120 5-foot blue spruce trees in 1992; and
- 25 15-foot Douglas fir trees in 1991.

The effective number of trees planted at age 0 would be calculated as follows for each species-age category:

Black Locust: Table 4 indicates that the relative age of bare root (hardwood) black locust is -6, which means they would take 6 years to reach age 0. Since they were planted in 1989, they would reach age 0 in 1995. The survival adjustment factor for this tree is 0.443. Therefore, of the 50 planted in 1989, 22.2 could be expected to survive until 1995, which would be the effective number of trees planted.

Blue Spruce: Blue spruce is a moderate-growth rate conifer. According to Table 6, the age of 5-foot trees at planting would have been -1. Since they were planted in 1992, they would have reached age 0 in 1993. As the survival factor is 0.873, the effective number of trees planted at age 0 in 1993 would be 0.873 x 150 or 131.1. The trees would be age 2 in 1995.

Douglas Fir: Douglas fir is a fast-growing conifer. At 15 feet high, its age is +3. Therefore, if planted in 1991, it would have reached age 0 three years earlier in 1988. Given a survival adjustment factor of 1.416, the effective number of trees planted at age 0 in 1991 would be 25 x 1.416, or 35.4. The trees would be age 7 in 1995.

Given values for the effective number of trees planted and tree age, sequestration for 1995 can be calculated using the normal method (see Table 6).

Table 5: Relative Ages and Survival Adjustment Factors for Conifers

Growth Rate	Tree Height in Feet	Tree Age	Survival Factor
Slow	Less than 1	-6	.443
	1 - 2	-5	.507
	2 - 3	-4	.581
	3 - 4	-3	.665
	4 - 5	-2	.762
	5 - 6	-1	.873
	6 - 7	0	1.000
	7 - 8	1	1.145
	8 - 9	2	1.253
	9 - 10	3	1.416
	10 - 11	4	1.475
Moderate	1.6 or less	-4	.581
	1.6 - 3.2	-3	.665
	3.2 - 4.8	-2	.762
	4.8 - 6.4	-1	.873
	6.4 - 8.2	0	1.000
	8.2 - 9.8	1	1.145
	9.8 - 11.4	2	1.253
	11.4 - 13.0	3	1.416
	13.0 - 14.6	4	1.475
Fast	Less than 2.3	-3	.665
	2.3 - 4.6	-2	.762
	4.6 - 6.9	-1	.873
	6.9 - 9.2	0	1.000
	9.2 - 11.5	1	1.145
	11.5 - 13.8	2	1.253
	13.8 - 16.1	3	1.416
	16.1 - 18.4	4	1.475

Table 6: Sample Urban Forestry Carbon Sequestration Worksheet

Reporting year: 19 95

A. Species Characteristics (Refer to Table 1)			B. Tree Age	C. Number of Age 0 Trees Planted	D. Survival Factor (Refer to Table 2)	E. Number of Surviving Trees (C x D)	F. Annual Sequestration Rate (lbs./tree) (Refer to Table 2)	G. Carbon Sequestered (lbs) (E x F)
Name	Tree Type (H or C)	Growth Rate (S, M, or F)						
Norway maples	H	M	1	76.2	0.798	60.8	2.7	164.2
Black locust	H	F	0	22.1	0.873	19.3	2.7	52.1
Blue spruce	C	M	2	131.1	0.736	96.5	2.0	193.0
Douglas fir	C	F	7	35.4	0.630	22.3	8.9	198.5
Total Pounds of Carbon Sequestered								607.8
Total Pounds of Equivalent CO2 Sequestered							X 3.67	2230.6
Equivalent CO2 Sequestered in Short Tons							/2000	1.12