i-Tree
Ecosystem Analysis

Town of Abingdon

Urban Forest Effects and Values
February 2012

Virginia Tech
College of Natural Resources
and Environment

Forest Resources
& Environmental
Conservation
at Virginia Tech

Acknowledgements

Authors:

Eric Wiseman, Ph.D.
Department of Forest Resources and Environmental Conservation, Virginia Tech

Jamie King
Department of Forest Resources and Environmental Conservation, Virginia Tech

Report layout and content adapted from the automated report generated by i-Tree Eco assessment software and authored by the i-Tree Development Team.

Inquiries on this report should be addressed to the lead author at pwiseman@vt.edu.

GIS and Planning Support:

Jen McKee
Department of Forest Resources and Environmental Conservation, Virginia Tech

Mason Patterson
Department of Forest Resources and Environmental Conservation, Virginia Tech

Field Inventory Team:

Andrew Benjamin, Jordan Endahl, Jamie King, and Michael Webb
Department of Forest Resources and Environmental Conservation, Virginia Tech

Funding:

This project was made possible through support from the Virginia Department of Forestry and the USDA Forest Service – Urban and Community Forestry Program.

Technical Support:

We thank Eric Kuehler with the USDA Forest Service Southern Research Station and Al Zelaya with the Davey Tree Expert Company for their assistance with field data processing. We also want to thank the Town of Abingdon staff along with Kevin Sigmon (Town Arborist) for providing GIS data and facilitating access to public property for field data collection. We are also grateful for the cooperation of numerous citizens and businesses that permitted access to their properties for field data collection.

Disclaimer:

Information about urban forest structure, function, and value in this report includes estimates based on statistical sampling, which has an associated margin of error. Therefore, all results should be interpreted with caution. To facilitate reading, statistical error rates are not reported for all forest attributes and model outputs in the main report.

Summary

Trees provide a long list of ecologic and economic benefits that improve environmental conditions and human well-being. Trees in urban settings are especially important. Understanding an urban forest's structure, function, and value can promote management decisions that will improve human health and environmental quality. An assessment of the urban forest in the Town of Abingdon, Virginia was conducted during 2011 using i-Tree Eco sampling protocols and analysis tools. Data from 73 field plots located throughout Abingdon in three land-use classes (Industry and Business, High-Density Residential, and Low-Density Residential) were analyzed using the Urban Forest Effects (UFORE) model developed by the U.S. Forest Service, Northern Research Station.

Key findings

- Number of trees: 204,020 (SE: 46,931)
- Tree canopy cover: 23% (SE: 0.58)
- Most common tree species: black locust, tulip-poplar, and tree-of-heaven
- Percentage of trees less than 6" trunk diameter: 62%
- Carbon storage: 55,800 tons (valued at $1.03 million)
- Annual gross carbon sequestration: 1,430 tons (valued at $26,400)
- Annual avoided carbon emissions: 42 tons (valued at $773)
- Annual pollution removal: 36 tons (valued at $258 thousand)
- Annual building energy savings: $317,000
- Structural value of trees: $253 million (SE: 53 million)

Ton: short ton (U.S.) (2,000 lbs)
Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation
Carbon sequestration: the removal of carbon dioxide from the air by plants through photosynthesis
Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree)
Monetary values ($) reported in US Dollar throughout report except where noted
SE: standard error of the total

Table of Contents

Assessment Methods

UFORE Model and Field Measurements

UFORE is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure (e.g., species composition, tree health, leaf area, etc.) and its numerous effects[5], including:

- Amount of pollution removed hourly by the urban forest and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter <10 microns (PM_{10}).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power plants.
- Structural value of the forest as well as the value for air pollution removal and carbon storage and sequestration.
- Potential impact of infestations by Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.

In the Town of Abingdon, 73 one-tenth-acre plots were sampled using a stratified random sampling method across three land use types: industry and business (11 plots), high density residential (50 plots), and low density residential (12 plots). Plots were assigned proportionate to tree canopy cover and land area within each stratum based on existing canopy data and land use zoning. Plots on both public and private property were assessed. All field data were collected during the 2011 leaf-on season to properly assess tree canopies. At each field plot, two to four crew members collected data on ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings[11].

To calculate current **carbon storage**, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations[12]. To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

To estimate the gross amount of **carbon sequestered annually**, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (year x) to estimate tree diameter and carbon storage in year x+1.

Air pollution removal estimates were derived from calculated hourly tree-canopy resistances for ozone, sulfur dioxide, and nitrogen dioxide based on a hybrid of big-leaf and multi-layer canopy deposition models[13,14]. As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[15,16] that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50 percent re-suspension rate of particles back to the atmosphere[17]. Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values[27,28,29].

Seasonal effects of trees on **residential building energy use** were calculated based on procedures described in the literature[4] using distance and direction of trees from residential structures, tree height, and tree condition data.

Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers[8], which uses tree species, diameter, condition, and location information[18].

For modeling and analysis of urban forest structure, function, and value, Abingdon’s human population was set at 8,191 as estimated by the U.S. Census Bureau in 2010 (http://quickfacts.census.gov/qfd/states/51/5100148.html).

Structure of Abingdon's Urban Forest

Tree Characteristics of the Urban Forest

The urban forest of Abingdon comprises about 204,000 trees with a tree canopy cover of about 23 percent (see Appendix III for comparable values from other cities). The three most common tree species are black locust (~11 percent), tulip-poplar (~9 percent), and tree-of-heaven (~6 percent) as shown in Figure 1. There were 52 unique taxa of woody plants catalogued in the field survey. A complete listing of tree abundance by species and land use is provided in Appendix I. The overall tree density in Abingdon averages about 40 trees per acre, which is comparable to other localities along the East Coast (Appendix III). Among the land use strata, the highest tree densities occur in Low Density Residential lands followed by Industry and Business lands and High Density Residential lands (Fig. 2). Trees that have diameters less than 6-inches constitute about 62 percent of the tree population (Fig. 3), which suggests that there are plentiful young trees to help sustain forest cover into the future.

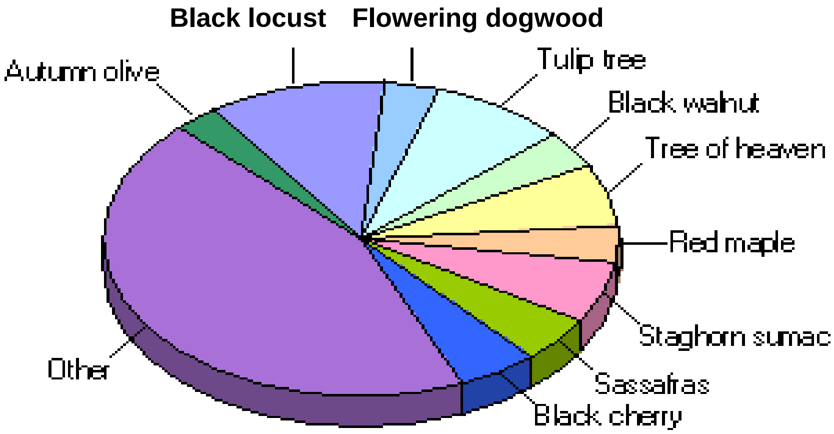

Figure 1. Tree species composition (percent of total) in Town of Abingdon

Urban forests are composed of a mix of native and exotic tree species. Thus, urban forests often have higher species diversity than surrounding native landscapes. High species diversity helps minimize forest vulnerability to species-specific pests and disorders, but may also pose a risk to forest health if exotic species are invasive plants that can potentially out-compete and displace native species. In Abingdon, about 74 percent of the trees are species native to North America, while 65 percent are native to the state (Fig. 4). Species exotic to Virginia make up 26 percent of the population. Most of Abingdon's exotic tree species are indigenous to Asia (~17 percent of the species).

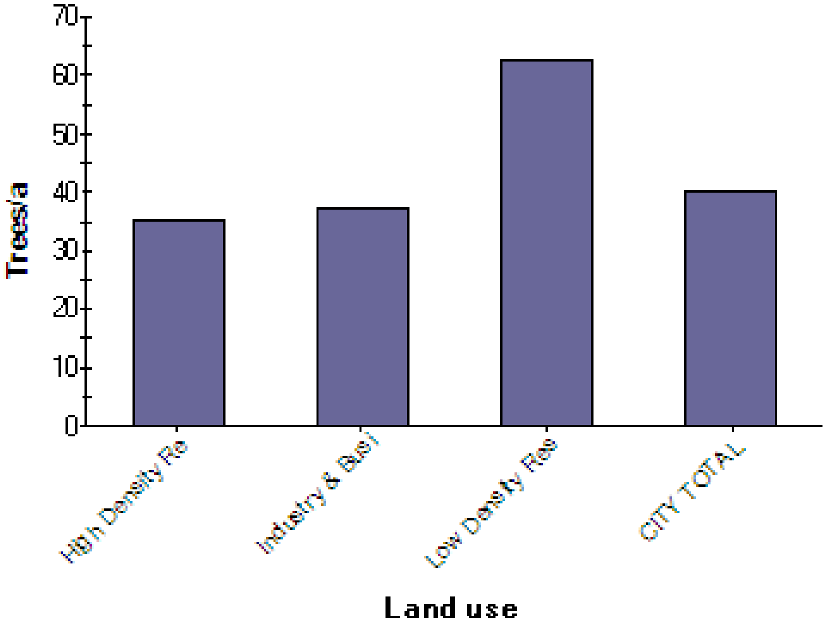

Figure 2. Trees per acre (a) in Town of Abingdon by land use

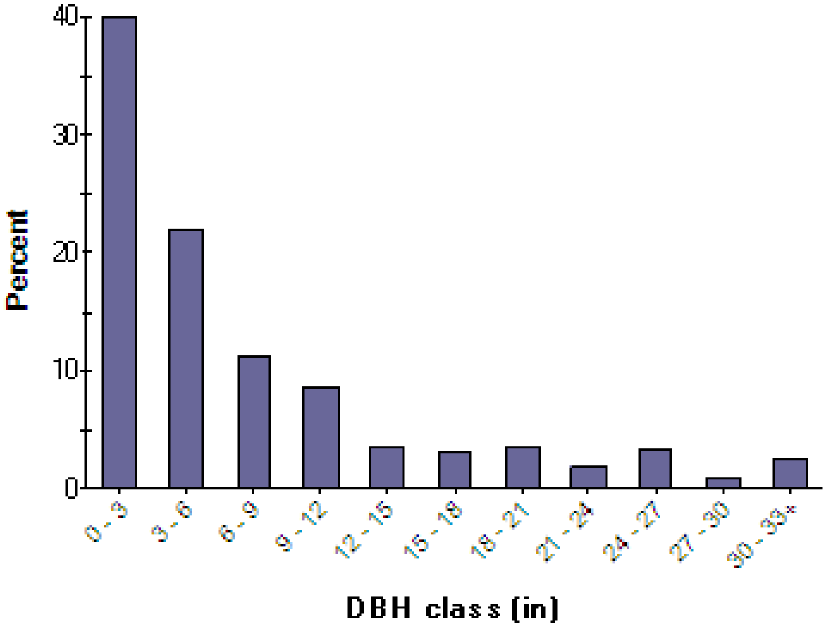

Figure 3. Trunk diameter distribution (DBH=stem diameter at 4.5 feet above ground line) of trees in Town of Abingdon.

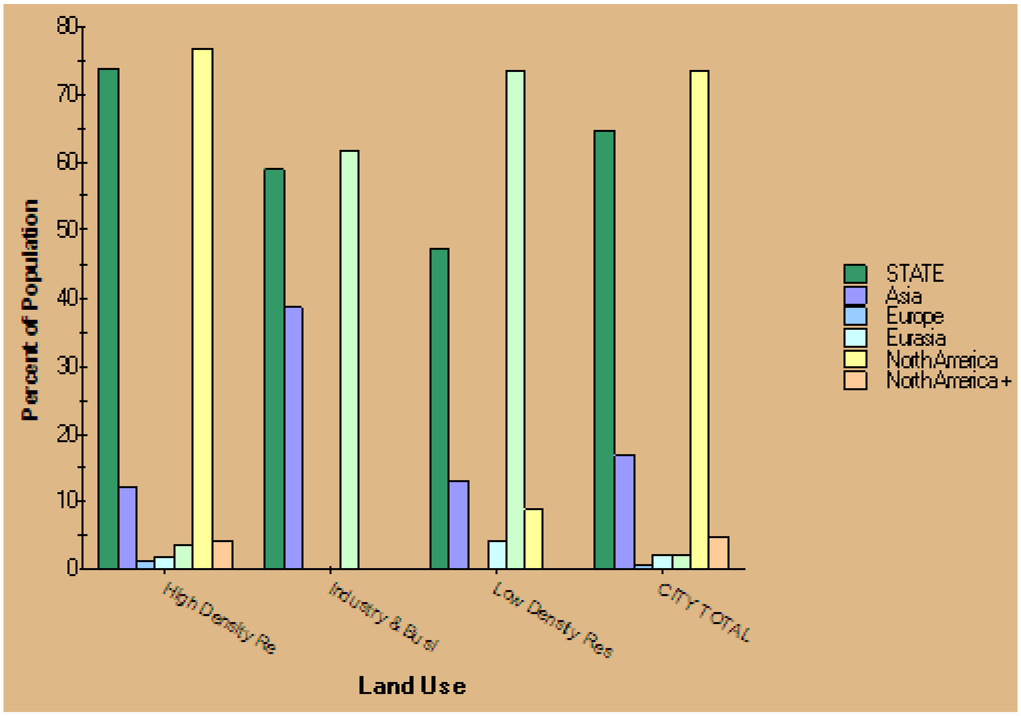

Figure 4. Species composition of live trees in Town of Abingdon by geographic origin

"North America +" = native to North America and at least one other continent except South America

Urban Forest Cover and Leaf Area

Tree canopy covers about 23 percent of Abingdon's land area. Many tree benefits are directly proportional to the amount of healthy leaf surface area. In Abingdon, the three most dominant tree species in terms of leaf area are tulip-poplar, sugar maple, and silver maple (Table 1). Along with red maple, sugar maple and silver maple account for nearly 25 percent of leaf area. Importance Value (IV) is a metric that documents species dominance by summing relative abundance and relative leaf area for each tree species. An IV over 10 may indicate that an urban forest is over-reliant on a particular species for structural and functional benefits, depending on the local ecosystem. Abingdon's ten most important species are listed in Table 1 below. Five tree species have IVs exceeding 10, lead by tulip-poplar with the highest IV at 20.7.

The two most dominant ground cover types in Abingdon are grass (43 percent) and wild grass (20 percent) as shown in Figure 5. The three impervious ground cover classes (Building, Cement, and Tar) make up 24 percent of total ground cover. Ground space permissible for tree planting (not covered by impervious surface and free of overhead obstructions such as existing tree canopy and utility lines) exists on about 52 percent of the land area, which suggests high potential for increasing Abingdon's tree canopy cover.

Table 1. Ten most important tree species in City of Charlottesville. Importance Value (IV) is the sum of relative abundance and relative leaf area.

Species Name	*Percent of Population*	*Percent of Leaf Area*	*Importance Value (IV)*
Tulip tree	8.7	12.0	20.7
Black locust	11.1	4.7	15.9
Red maple	3.8	7.8	11.6
Black cherry	5.0	6.0	11.0
Sugar maple	2.1	8.5	10.7
Silver maple	1.6	7.9	9.5
Black walnut	3.7	5.4	9.1
Tree of heaven	6.4	1.4	7.7
Eastern white pine	2.8	4.5	7.3
Staghorn sumac	6.2	0.4	6.6

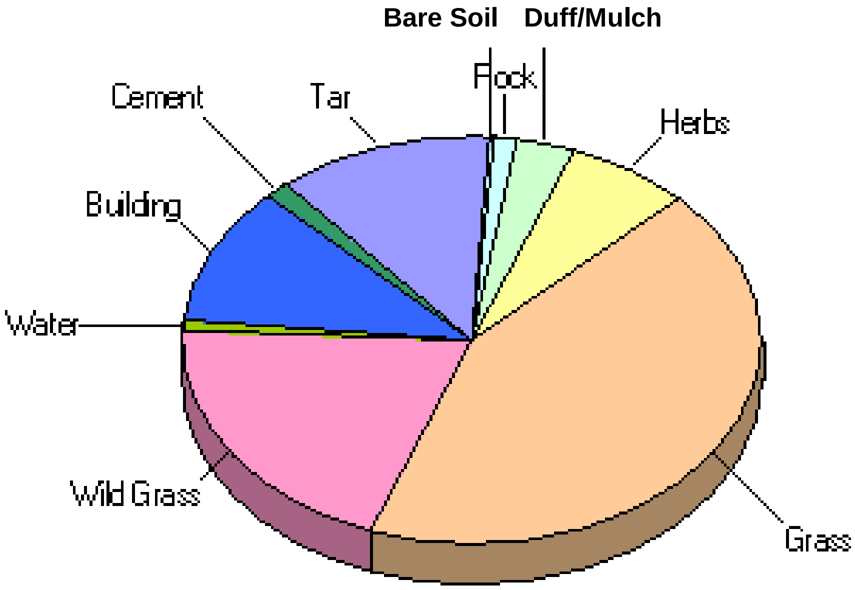

Figure 5. Ground cover composition (percent of total) in Town of Abingdon.

Structural and Functional Values of Abingdon's Urban Forest

Overview of Urban Forest Values

Urban forests have monetary value as structural assets much like any other infrastructure found in a municipality. This value is commonly calculated based on the cost that would be incurred to replace existing trees with trees of similar type and size. In addition, the carbon stored in woody tree parts has structural value as a carbon offset resource. Urban forests also have monetary value as functional assets based on the ecosystem services that they provide. These services (carbon sequestration, air pollution removal, and energy conservation) are rendered through tree interactions with the natural and built environment and may have positive or negative value depending on the nature of these interactions.

The structural and functional values of an urban forest tend to increase with an increase in the number and size of healthy trees[6]. However, inappropriate species selection, improper tree placement, and tree neglect can diminish both structural and functional values.

The structural value of Abingdon's urban forest exceeds $250 million. The most valuable species in Abingdon's urban forest is tulip-poplar at nearly $47 million (Fig. 6). The ten most valuable species alone have a combined value of over $187 million. A summary of annual functional values are shown below and summarized in the subsequent sections of this report.

<u>Structural values of trees in Abingdon's urban forest:</u>

- Structural value: $253 million
- Carbon storage: $1.03 million

<u>Functional values of trees in Abingdon's urban forest (annual basis):</u>

- Carbon sequestration (removal): $26.4 thousand
- Pollution removal: $258 thousand
- Energy savings and carbon emission reductions: $317 thousand

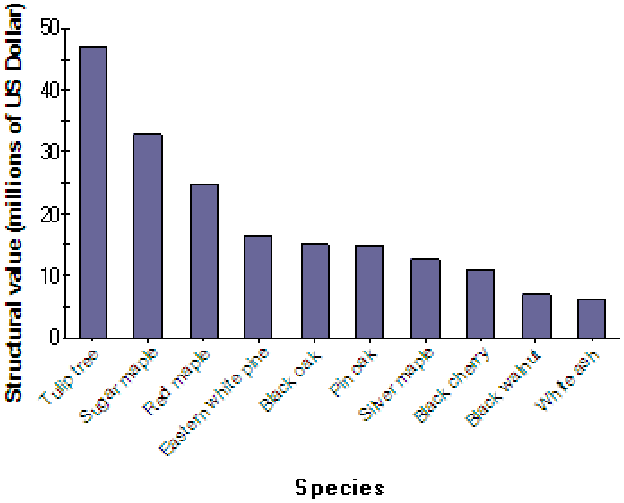

Figure 6. Structural value of the ten most valuable tree species in Town of Abingdon.

Carbon Storage and Sequestration

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering (removing) atmospheric carbon (as carbon dioxide through photosynthesis) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants[3].

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered increases with the size and health of the trees. The gross sequestration of Abingdon's trees is about 1,430 tons of carbon per year with an associated value of $26,400. Net carbon sequestration (accounting for losses from carbon dioxide release through tree respiration) in Abingdon's urban forest is about 1,230 tons annually. Tulip-poplar sequesters the most carbon annually (~175 tons), which accounts for about 14% of all sequestered carbon in the urban forest (Fig. 7).

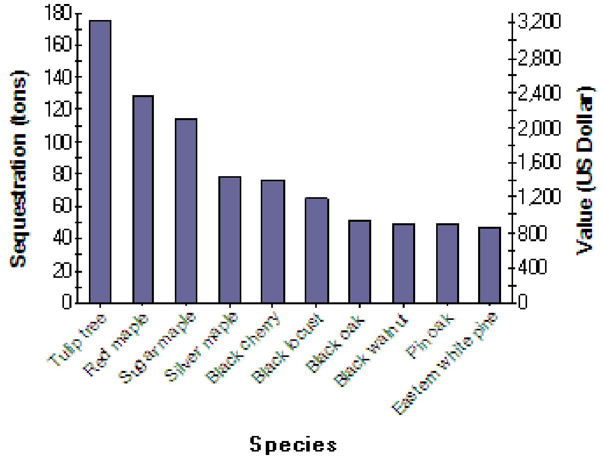

Figure 7. Annual carbon sequestration quantity and value for top ten tree species in Abingdon

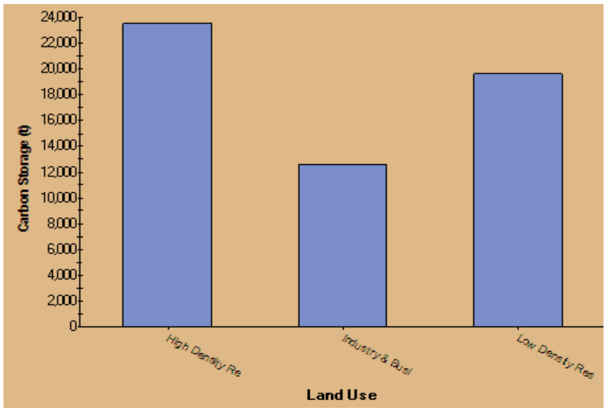

Figure 8. Carbon storage in Abingdon's urban forest by land use

As trees grow, they accumulate carbon as wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Abingdon are estimated to store 55,800 tons of carbon, which is valued at $1.03 million (Fig. 8). Of all the species sampled, silver maple stores the most carbon (~20% of the total; data not shown).

Air Pollution Removal by Urban Trees

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damaged landscape plants and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by directly removing pollutants from the air, reducing ambient air temperature, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds (VOCs) that can contribute to ground-based ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation overall despite VOC emissions[1].

Pollution removal by trees in Abingdon was estimated using field data and recent pollution and weather data available. Pollution removal is greatest for ozone (O_3) as shown in Figure 9. It is estimated that Abingdon's trees remove 36 tons of air pollution (CO, NO_2, O_3, PM_{10}, and SO_2) per year with an associated value of $258 thousand (based on estimated national median externality costs associated with pollutants[2]).

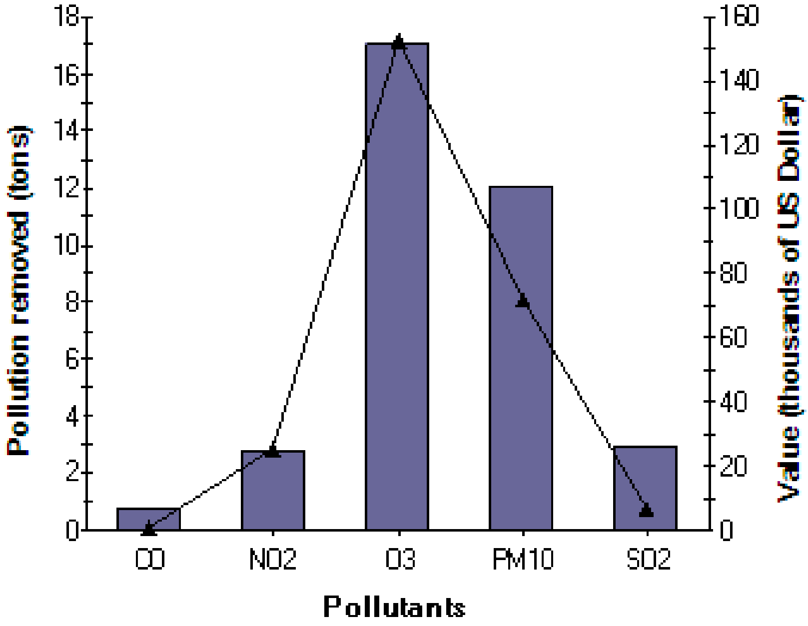

Figure 9. Pollution removal (bars) and associated monetary value (line) for trees in Town of Abingdon

Trees and Building Energy Use

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space conditioned residential buildings[4].

Based on 2002 prices, trees in Abingdon are estimated to reduce energy-related costs from residential buildings by $316 thousand annually (Tables 2 and 3). Trees also provide an additional $773 in value[5] by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 42 tons of carbon emissions).

Table 2. Annual energy conservation and carbon avoidance due to trees near residential buildings. Note: negative numbers indicate an increased energy use or carbon emission.

	Heating	*Cooling*	*Total*
MBTU¹	2,321	n/a	2,321
MWH²	30	2,681	2,711
Carbon avoided (tons)	41	1	42

¹One million British Thermal Units
²Megawatt-hour

Table 3. Annual savings¹ in residential energy expenditure during heating and cooling seasons. Note: negative numbers indicate a cost due to increased energy use or carbon emission.

	Heating ($)	*Cooling ($)*	*Total ($)*
MBTU²	28,455	n/a	28,455
MWH³	3,183	284,454	287,637
Carbon avoidance	755	18	773

¹Based on state-wide energy costs for Virginia.
²One million British Thermal Units
³Megawatt-hour

Potential Pest Impacts

Various insects and diseases can infest trees, potentially killing trees and reducing the health, value, and sustainability of the urban forest. As pests tend to have differing tree hosts, the potential risk of each pest will differ. Four exotic pests were analyzed for their potential impact (Fig. 10): Asian longhorned beetle (ALB), gypsy moth (GM), emerald ash borer (EAB), and Dutch elm disease (DED).

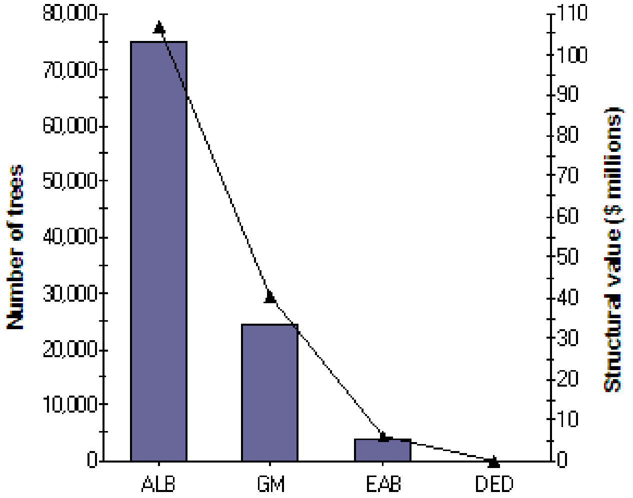

Figure 10. Susceptible trees (bars) and potential structural value loss (line) by pest for Town of Abingdon's urban forest

The Asian longhorned beetle (ALB)[7] is an insect that bores into and kills a wide range of hardwood tree species. ALB poses a threat to about 37 percent of Abingdon's urban forest, which represents a potential loss of $107 million in structural value of the urban forest.

The gypsy moth (GM)[8] caterpillar is an insect that feeds on many tree species, causing widespread defoliation and tree death if outbreak conditions persist over several years. This pest threatens about 12 percent of the tree population, representing a potential loss of $40.4 million in structural value.

Emerald ash borer (EAB)[9] is a wood-boring insect has killed thousands of native ash trees in parts of the United States. EAB has the potential to affect about 2 percent of Abingdon's tree population ($6.25 million in potential structural value loss).

American elm, one of the most important street trees in the twentieth century, has been devastated by the Dutch elm disease (DED)[10]. Since the 1930s, DED has killed over 50 percent of the native elm population in the United States. Although American elms are known to inhabit Abingdon, there was no measurable vulnerability to DED in terms of potential loss of trees or their structural value in this assessment.

Appendix I. Tree count and structural value by land use and tree species

		Number of Trees		Structural Value ($)	
Land Use	**Species**	**Value**	**SE**	**Value**	**SE**
High Density Res	Tulip tree	16,172	10,633	36,653,230	29,069,672
High Density Res	Black locust	15,469	12,218	2,001,984	1,602,340
High Density Res	Flowering dogwood	6,328	3,125	3,083,728	2,072,963
High Density Res	Red maple	6,328	3,432	17,564,555	9,025,014
High Density Res	Eastern white pine	5,625	4,954	16,462,397	12,595,391
High Density Res	Privet spp	5,625	4,416	733,064	548,800
High Density Res	Black cherry	4,922	2,247	6,420,510	4,647,977
High Density Res	Black tupelo	4,219	3,569	2,948,311	2,883,719
High Density Res	Black walnut	4,219	2,950	6,744,501	5,042,919
High Density Res	Sourwood	4,219	3,116	238,587	184,082
High Density Res	Sweet cherry	4,219	3,569	265,666	238,614
High Density Res	Yew spp	4,219	3,569	4,983,719	4,932,504
High Density Res	Leyland cypress	3,516	3,513	2,499,823	2,498,045
High Density Res	White oak	3,516	3,513	4,850,811	4,847,361
High Density Res	Pawpaw	2,813	2,810	2,406,659	2,404,947
High Density Res	Sugar maple	2,813	2,208	8,588,983	6,044,073
High Density Res	Callery pear	2,109	1,558	2,302,944	1,759,862
High Density Res	Common privet	2,109	1,192	84,011	51,189
High Density Res	Eastern red cedar	2,109	2,108	325,733	325,501
High Density Res	Sassafras	2,109	2,108	3,006,541	3,004,403
High Density Res	Boxelder	1,406	983	35,596	25,054
High Density Res	Eastern redbud	1,406	1,405	841,308	840,710
High Density Res	Norway spruce	1,406	1,405	1,369,700	1,368,726
High Density Res	Tree of heaven	1,406	1,405	42,368	42,337
High Density Res	White mulberry	1,406	983	3,073,791	2,991,060
High Density Res	American basswood	703	703	83,975	83,915
High Density Res	American beech	703	703	146,041	145,937
High Density Res	Apple spp	703	703	721,179	720,666
High Density Res	Autumn olive	703	703	221,773	221,616
High Density Res	Black oak	703	703	7,093,466	7,088,420
High Density Res	Chinese chestnut	703	703	1,970,042	1,968,640
High Density Res	Crabapple	703	703	785,548	784,989
High Density Res	Lagerstroemia spp	703	703	49,686	49,651
High Density Res	Northern white cedar	703	703	31,641	31,618
High Density Res	Shagbark hickory	703	703	40,708	40,679
High Density Res	Siberian elm	703	703	1,893,612	1,892,265
High Density Res	Silver maple	703	703	7,936,829	7,931,183
High Density Res	White ash	703	703	6,103,947	6,099,605
High Density Res	**Total**	**118,828**	**32,197**	**154,606,967**	**45,974,689**

Industry & Business	Tree of heaven	11,569	11,562	537,896	537,570
Industry & Business	Black locust	5,785	3,926	2,433,309	1,826,120
Industry & Business	Black walnut	3,305	2,532	352,466	342,389
Industry & Business	Boxelder	2,479	1,771	3,103,171	3,097,888
Industry & Business	Carolina ash	2,479	2,478	136,452	136,370
Industry & Business	Silver maple	2,479	2,478	4,745,708	4,742,835
Industry & Business	Black cherry	1,653	1,108	*	*
Industry & Business	Callery pear	826	826	39,130	39,106
Industry & Business	Laurel espada	826	826	39,130	39,106
Industry & Business	Pin oak	826	826	139,456	139,371
Industry & Business	Sassafras	826	826	54,872	54,839
Industry & Business	Sugar maple	826	826	9,093,706	9,088,202
Industry & Business	**Total**	**33,881**	**22,985**	**20,675,297**	**14,163,439**
Low Density Res	Staghorn sumac	12,642	12,633	797,523	796,987
Low Density Res	Sassafras	6,693	6,688	412,042	411,765
Low Density Res	Autumn olive	5,205	5,202	450,733	450,430
Low Density Res	Black cherry	3,718	2,998	4,646,746	4,117,574
Low Density Res	Apple spp	2,231	1,600	2,905,406	1,974,128
Low Density Res	Balsam fir	2,231	2,229	2,813,934	2,812,042
Low Density Res	Holly spp	2,231	1,600	227,402	191,304
Low Density Res	Black locust	1,487	1,002	48,569	38,749
Low Density Res	Black oak	1,487	1,486	7,831,146	7,825,878
Low Density Res	Osage orange	1,487	1,486	75,194	75,143
Low Density Res	Red maple	1,487	1,002	7,255,926	7,171,694
Low Density Res	Tulip tree	1,487	1,002	10,335,860	7,968,318
Low Density Res	Eastern red cedar	744	743	1,790,596	1,789,392
Low Density Res	Fire thorn	744	743	64,522	64,479
Low Density Res	Flowering dogwood	744	743	23,639	23,623
Low Density Res	Kousa dogwood	744	743	35,213	35,189
Low Density Res	Norway maple	744	743	1,286,159	1,285,294
Low Density Res	Pear spp	744	743	33,452	33,429
Low Density Res	Pin oak	744	743	14,583,726	14,573,917
Low Density Res	Sugar maple	744	743	15,052,446	15,042,322
Low Density Res	Sweetgum	744	743	645,806	645,371
Low Density Res	Table mountain pine	744	743	5,945,477	5,941,478
Low Density Res	White ash	744	743	11,155	11,147
Low Density Res	Yoshino flowering cherry	744	743	624,024	623,605
Low Density Res	**Total**	**51,311**	**25,250**	**77,896,695**	**21,769,280**
CITY TOTAL	**Total**	**204,020**	**46,931**	**253,178,959**	**52,803,187**

*Dead trees have no structural value.

Appendix II. Relative Tree Effects

The urban forest in Town of Abingdon provides benefits that include carbon storage, carbon sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions[19], average passenger automobile emissions[20], and average household emissions[21].

Carbon storage is equivalent to:
- Amount of carbon emitted in Town of Abingdon in 410 days
- Annual carbon (C) emissions from 33,500 automobiles
- Annual C emissions from 16,800 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 3 automobiles
- Annual carbon monoxide emissions from 12 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 176 automobiles
- Annual nitrogen dioxide emissions from 117 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 4,260 automobiles
- Annual sulfur dioxide emissions from 72 single-family houses

Particulate matter less than 10 micron (PM_{10}) removal is equivalent to:
- Annual PM10 emissions from 32,100 automobiles
- Annual PM10 emissions from 3,100 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Town of Abingdon in 11 days
- Annual C emissions from 900 automobiles
- Annual C emissions from 400 single-family houses

Note: estimates above are partially based on the user-supplied information on human population total for study area.

Appendix III. Comparison of Urban Forests

A common question asked is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the UFORE model.

I. City totals for trees

City	*% Tree Cover*	*Number of trees*	*Carbon storage (tons)*	*Carbon Sequestration (tons/yr)*	*Pollution removal (tons/yr)*	*Pollution Value (USD)*
Calgary, Canada	7.2	11,889,000	445,000	21,422	326	1,611,000
Atlanta, GA	36.8	9,415,000	1,345,000	46,433	1,662	2,534,000
Toronto, Canada	20.5	7,542,000	992,000	40,345	1,212	6,105,000
New York, NY	21.0	5,212,000	1,351,000	42,283	1,677	8,071,000
Baltimore, MD	21.0	2,627,000	596,000	16,127	430	2,129,000
Philadelphia, PA	15.7	2,113,000	530,000	16,115	576	2,826,000
Washington, DC	28.6	1,928,000	523,000	16,148	418	1,956,000
Boston, MA	22.3	1,183,000	319,000	10,509	284	1,426,000
Woodbridge, NJ	29.5	986,000	160,000	5561.00	210	1,037,000
Minneapolis, MN	26.5	979,000	250,000	8,895	305	1,527,000
Syracuse, NY	23.1	876,000	173,000	5,425	109	268,000
Morgantown, WV	35.9	661,000	94,000	2,940	66	311,000
Moorestown, NJ	28.0	583,000	117,000	3,758	118	576,000
Jersey City, NJ	11.5	136,000	21,000	890	41	196,000
Freehold, NJ	34.4	48,000	20,000	545	21	133,000

II. Per-acre values of tree effects

City	*No. of trees*	*Carbon storage (tons)*	*Carbon sequestration (lbs/yr)*	*Pollution removal (lbs/yr)*	*Pollution Value (USD)*
Calgary, Canada	66.7	2.5	0.120	3.6	9.0
Atlanta, GA	111.6	15.9	0.550	39.4	30.0
Toronto, Canada	48.3	6.4	0.258	15.6	39.1
New York, NY	26.4	6.8	0.214	17.0	40.9
Baltimore, MD	50.8	11.5	0.312	16.6	41.2
Philadelphia, PA	25.0	6.3	0.190	13.6	33.5
Washington, DC	49.0	13.3	0.410	21.2	49.7
Boston, MA	33.5	9.0	0.297	16.0	40.4
Woodbridge, NJ	66.5	10.8	0.375	28.4	70.0
Minneapolis, MN	26.2	6.7	0.238	16.4	40.9
Syracuse, NY	54.5	10.8	0.338	13.6	16.7
Morgantown, WV	119.7	17.0	0.532	23.8	56.3
Moorestown, NJ	62.0	12.5	0.400	25.2	61.3
Jersey City, NJ	14.3	2.2	0.094	8.6	20.7
Freehold, NJ	38.5	16.0	0.437	33.6	106.6

Appendix IV. General Recommendations for Air Quality Improvement

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are[22]:

- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities[23]. Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include[24]:

Strategy	***Result***
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree canopy cover	Maintain pollution removal levels
Maximize use of low VOC-emitting tree species	Reduces ozone and carbon monoxide formation
Maintain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived tree species	Reduce long-term pollutant emissions from planting and removal
Use low maintenance tree species	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample irrigation to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive tree species	Improve tree health
Utilize evergreen trees for particulate matter capture	Year-round removal of particles

References

1. Nowak D.J. and Dwyer J.F. *Understanding the benefits and costs of urban forest ecosystems*. Handbook of Urban and Community Forestry in the Northeast. Ed. John E. Kuser. Kluwer Academics/Plenum Pub., New York. 2000. 11-22.

2. Murray, F.J.; Marsh L.; Bradford, P.A. 1994. *New York State Energy Plan, Vol. II: Issue Reports*. Albany, NY: New York State Energy Office.

3. Abdollahi, K.K.; Z.H. Ning; and A. Appeaning (eds). 2000. *Global climate change and the urban forest*. Baton Rouge, LA: GCRCC and Franklin Press. 77p.

4. McPherson, E.G. and J. R. Simpson 1999. *Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters*. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research station 237 p. http://wcufre.ucdavis.edu/products/cufr_43.pdf

5. Nowak, D.J., and D.E. Crane. 2000. *The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions*. In: Hansen, M. and T. Burk (Eds.) Integrated Tools for Natural Resources Inventories in the 21st Century. Proc. Of the IUFRO Conference. USDA Forest Service General Technical Report NC-212. North Central Research Station, St. Paul, MN. pp. 714-720. See also http://www.ufore.org.

6. Nowak, D.J.; Crane, D.E.; Dwyer, J.F. 2002. *Compensatory value of urban trees in the United States.* Journal of Arboriculture. 28(4): 194 - 199.

7. Northeastern Area State and Private Forestry. 2005. *Asian Longhorned Beetle*. Newtown Square, PA: U.S. Department of Agriculture, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/alb

8. Northeastern Area State and Private Forestry. 2005. *Gypsy moth digest*. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://na.fs.fed.us/fhp/gm

9. Northeastern Area State and Private Forestry. 2005. *Forest health protection emerald ash borer home*. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/eab/index.html

10. Northeastern Area State and Private Forestry. 1998. *How to identify and manage Dutch Elm Disease*. NA-PR-07-98. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. http://www.na.fs.fed.us/spfo/pubs/howtos/ht_ded/ht_ded.htm

11. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E. 2005. *The urban forest effects (UFORE) model: field data collection manual*. V1b. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station, 34 p. http://www.fs.fed.us/ne/syracuse/Tools/downloads/UFORE_Manual.pdf

12. Nowak, D.J. 1994. *Atmospheric carbon dioxide reduction by Chicago's urban forest*. In: McPherson, E.G.; Nowak, D.J.; Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 83-94.

13. Baldocchi, D. 1988. *A multi-layer model for estimating sulfur dioxide deposition to a deciduous oak forest canopy*. Atmospheric Environment. 22: 869-884.

14. Baldocchi, D.D.; Hicks, B.B.; Camara, P. 1987. *A canopy stomatal resistance model for gaseous deposition to vegetated surfaces*. Atmospheric Environment. 21: 91-101.

15. Bidwell, R.G.S.; Fraser, D.E. 1972. *Carbon monoxide uptake and metabolism by leaves*. Canadian Journal of Botany. 50: 1435-1439.

16. Lovett, G.M. 1994. *Atmospheric deposition of nutrients and pollutants in North America: an ecological perspective*. Ecological Applications. 4: 629-650.

17. Zinke, P.J. 1967. *Forest interception studies in the United States*. In: Sopper, W.E.; Lull, H.W., eds. Forest Hydrology. Oxford, UK: Pergamon Press: 137-161.

18. Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Ibarra, M. 2002. *Brooklyn's Urban Forest*. Gen. Tech. Rep. NE-290. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 107 p. Council of Tree and Landscape Appraisers guidelines.

For more information, see Nowak, D.J., D.E. Crane, and J.F. Dwyer. 2002. *Compensatory value of urban trees in the United States*. Journal of Arboriculture. 28(4): 194-199.

19. Total city carbon emissions were based on 2003 U.S. per capita carbon emissions - calculated as total U.S. carbon emissions (Energy Information Administration, 2003, Emissions of Greenhouse Gases in the United States 2003. http://www.eia.doe.gov/oiaf/1605/ggrpt) divided by 2003 U.S. total population (www.census.gov). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

20. Average passenger automobile emissions per mile were based on dividing total 2002 pollutant emissions from light-duty gas vehicles (National Emission Trends http://www.epa.gov/ttn/chief/trends/index.html) divided by total miles driven in 2002 by passenger cars (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004).

Average annual passenger automobile emissions per vehicle were based on dividing total 2002 pollutant emissions from light-duty gas vehicles by total number of passenger cars in 2002 (National Transportation Statistics http://www.bts.gov/publications/national_transportation_statistics/2004).

Carbon dioxide emissions from automobile assumed six pounds of carbon per gallon of gasoline if energy costs of refinement and transportation are included (Graham, R.L., Wright, L.L., and Turhollow, A.F. 1992. The potential for short-rotation woody crops to reduce U.S. CO2 Emissions. Climatic Change 22:223-238.

21. Average household emissions based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household from: Energy Information Administration. Total Energy Consumption in U.S. Households by Type of Housing Unit, 2001 http://www.eia.doe.gov/emeu/recs/contents.html.

CO2, SO2, and NOx power plant emission per KWh from: U.S. Environmental Protection Agency. U.S. Power Plant Emissions Total by Year http://www.epa.gov/cleanenergy/egrid/samples.htm.

CO emission per kWh assumes 1/3 of one percent of C emissions is CO based on: Energy Information Administration. 1994 Energy Use and Carbon Emissions: Non-OECD Countries DOE/EIA-0579.

PM10 emission per kWh from: Layton, M. 2004. 2005 Electricity Environmental Performance Report: Electricity Generation and Air Emissions. California Energy Commission.

http://www.energy.ca.gov/2005_energypolicy/documents/2004-11-15_workshop/2004-11-15_03-A_LAYTON.PDF

CO2, NOx, SO2, PM10, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from: Abraxas energy consulting, http://www.abraxasenergy.com/emissions

CO2 and fine particle emissions per Btu of wood from: Houck, J.E. Tiegs, P.E, McCrillis, R.C. Keithley, C. and Crouch, J. 1998. Air emissions from residential heating: the wood heating option put into environmental perspective. In: Proceedings of U.S. EPA and Air Waste Management Association Conference: Living in a Global Environment, V.1: 373-384.

CO, NOx and SOx emission per Btu based on total emissions and wood burning (tonnes) from: Residential Wood Burning Emissions in British Columbia, 2005. http://www.env.bc.ca/air/airquality/pdfs/wood_emissions.pdf.

Emissions per dry tonne of wood converted to emissions per Btu based on average dry weight per cord of wood and average Btu per cord from: Heating with Wood I. Species characteristics and volumes. http://ianrpubs.unl.edu/forestry/g881.htm

22. Nowak, D.J. 1995. *Trees pollute? A "TREE" explains it all*. In: Proceedings of the 7th National Urban Forestry Conference. Washington, DC: American Forests. Pp. 28-30

23. Nowak, D.J. and J.F. Dwyer. 2007. *Understanding the benefits and costs of urban forest ecosystems*. In: Kuser, J. (ed.) Urban and Community Forestry in the Northeast. New York: Springer. Pp. 25-46.

24. Nowak, D.J. 2000. *The interactions between urban forests and global climate change*. In: Abdollahi, K.K., Z.H. Ning, and A. Appeaning (Eds). Global Climate Change and the Urban Forest. Baton Rouge: GCRCC and Franklin Press. Pp. 31-44.

25. Nowak, D.J., D.E. Crane and J.C. Stevens. 2006. *Air pollution removal by urban trees and shrubs in the United States*. Urban Forestry and Urban Greening. 4:115-123

26. Nowak, D.J., R.E. Hoehn, D.E. Crane, J.C. Stevens, J.T. Walton, and J. Bond. 2008. *A ground-based method of assessing urban forest structure and ecosystem services*. Arboriculture and Urban Forestry. 34(6): 347-358

27. Hirabayashi, S., C. Kroll, and D. Nowak. (2011). *Component-based development and sensitivity analyses of an air pollutant dry deposition model*. Environmental Modeling and Software 26(6): 804-816.

28. Hirabayashi, S., C. Kroll, and D. Nowak. (2011). Urban Forest Effects-Dry Deposition (UFORE-D) Model Descriptions, http://www.itreetools.org/eco/resources/UFORE-D%20Model%20Descriptions_V1_1.pdf

29. Hirabayashi, S. (2011). Urban Forest Effects-Dry Deposition (UFORE-D) Model Enhancements, http://www.itreetools.org/eco/resources/UFORE-D_enhancements.pdf