City of Charlotte, North Carolina Municipal Forest Resource Analysis

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Technical Report to:
Don McSween, City Arborist
Engineering and Property Managment, Landscape Management
Charlotte, North Carolina

—November 2005—





Center for
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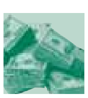
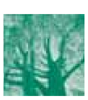
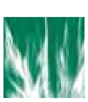
Areas of Research:


Investment Value


Energy Conservation


Air Quality


Water Quality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Mission Statement

We conduct **research** that demonstrates new ways in which **trees add value** to your community, converting results into **financial** terms to assist you in stimulating more **investment in trees.**

CITY OF CHARLOTTE, NORTH CAROLINA
MUNICIPAL FOREST RESOURCE ANALYSIS

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Executive Summary

Charlotte, a vibrant Southern city appreciated for its rich history and cultural wealth, maintains trees as an integral component of the urban infrastructure (*Figure 1*). Research indicates that healthy trees can lessen impacts associated with the built environment by reducing stormwater runoff, energy consumption, and air pollutants. Trees improve urban life, making Charlotte a more enjoyable place to live, work, and play, while mitigating the city's environmental impact. Over the years, the people of Charlotte have invested millions of dollars in their municipal forest. The primary question that this study asks is whether the accrued benefits from Charlotte's municipal forest justify the annual expenditures?

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information on the tree resource:

- Structure (species composition, diversity, age distribution, condition, etc.)
- Function (magnitude of annual environmental and esthetic benefits)
- Value (dollar value of benefits minus management costs)
- Management needs (sustainability, planting, maintenance)

Resource Structure

Based on the city's tree inventory, there are 85,146 publicly managed trees along the streets in Charlotte. However, the city maintains approximately 120,000 trees, some of which remain to be inventoried. This assessment focuses on trees that have been inventoried, and may therefore understate the full extent and benefit of Charlotte's entire municipal forest.

There is approximately one public tree for every seven residents, and these public trees shade approximately 0.75% of the city. Charlotte's streets

Figure 1—Trees frame Charlotte's Old City Hall and shade the lawn of the Old City Hall Park. Public trees in Charlotte provide the citizens of the city with great benefits, improving air quality, sequestering carbon dioxide, reducing stormwater runoff and beautifying the city. The trees of Charlotte return $3.25 in benefits for every $1 spent on tree care.

are stocked at 23% of capacity, with room, theoretically, for an additional 400,000 trees.

The inventory contains 215 tree species with willow oak and crapemyrtle as the dominant species. Willow oaks account for almost 17% of all street trees and provide 40% of all benefits. No other species approaches the significance of willow oak. Though crapemyrtle represents 14% of the population, it provides only 1.8% of the benefits.

The age structure of Charlotte's municipal tree population is similar to the "ideal" in having a high proportion (37%) of young trees (0–6 inch diameter at breast height or 4.5 ft above the ground [DBH]) and fewer mature and old trees. However, the majority of young trees are small species. As the larger trees in the population age and die and are replaced with small-stature trees, the level of benefits afforded to the city is likely to decline significantly. To reverse this trend, adequate space for large trees, both below and aboveground, must be planned early in the development process.

Resource Function and Value

The ability of Charlotte's municipal trees to intercept rain—thereby reducing stormwater runoff—is substantial, estimated at 28 million cubic ft annually, or $2.1 million. Citywide, the average tree intercepts 2,461 gallons of stormwater annually, valued at $24 per tree.

Electricity saved annually in Charlotte from both shading and climate effects of trees totals 7,658 MWh ($581,212) and annual natural gas saved totals 31,815 Mbtu ($332,789) for a total energy cost savings of $914,000 or $11 per tree.

Citywide, annual carbon dioxide (CO_2) sequestration and emission reductions due to energy savings by public trees are 10,860 tons and 3,235 tons, respectively. CO_2 released during decomposition and tree-care activities is relatively low (859 tons). Net CO_2 reduction is 13,237 tons, valued at $198,500 or $2.33 per tree.

Charlotte's public trees reduce the levels of ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and small particulate matter (PM_{10}) in the air by 85,950 lbs each year. Although most tree species in Charlotte provide net air quality benefits, the high BVOC emissions of willow oaks result in a slightly negative net effect on air quality in Charlotte, valued as a cost to the city of $36,270.

The estimated total annual benefits associated with aesthetics, property value increases, and other less tangible benefits are approximately $2.76 million or $32 per tree.

Annual benefits total $5.9 million and average $69 per tree. Willow oaks produce the highest level of benefits among street trees ($166 per tree, 40% of total benefits). On a per tree basis, water oaks are a close second, providing an average of $150 per tree. However, because they represent only 1% of the population, they provide only 2.3% of the benefits. Species providing the least benefits on an individual tree basis include crapemyrtle ($8), American holly ($8), and privet ($7).

Charlotte spends approximately $1.8 million maintaining its 85,000 public trees, or $21 per tree. Expenditures for infrastructure repairs account for about one-third of total costs. Pruning and tree and stump removal represent another one-third.

Charlotte's municipal trees are a valuable asset, providing approximately $4.1 million or $48 per tree ($7/capita) in net annual benefits to the community. Over the years, Charlotte has invested millions in its urban forest. Citizens are now receiving a substantial return on that investment—**trees are returning $3.25 in benefits for every $1 spent on tree care**. Charlotte's benefit–cost ratio of 3.25 exceeds those reported for Glendale, AZ (2.41), Fort Collins, CO (2.18), Cheyenne, WY (2.09), Minneapolis, MN (1.57) and Berkeley, CA (1.37). Continued investment in management and careful consideration of the future structure of the urban forest are critical to insuring that residents continue to receive a high return on their investment.

Resource Management Needs

Charlotte's municipal trees are a dynamic resource. Managers of this resource and the community alike can take pride in knowing that municipal trees do improve the quality of life in Charlotte; the resource, however, is fragile and needs constant care to maximize and sustain the benefits through the foreseeable future. Achieving resource sustainability requires that Charlotte:

- Plant large species where conditions are suitable to maximize benefits.
- Continue to diversify the mix of tree species planted to guard against catastrophic losses due to storms, pests or disease.
- Sustain benefits by investing in intensive maintenance of mature trees to prolong their functional lifespans.
- Develop a strong young-tree-care program that includes regular watering, staking adjustment, and inspection and pruning on at least a four-year cycle.
- Evaluate and test strategies to prevent and reduce sidewalk repair costs associated with tree roots.
- Insure adequate space for large trees in new developments by revising street design standards. Encourage the use of structural soils where appropriate. Where possible, locate power lines belowground.
- Review and revise parking lot shade guidelines and the adequacy of current ordinances to preserve and protect large trees from development impacts.

These recommendations build on a history of civic commitment to tree management that has put the city on course to provide an urban forest resource that is both functional and sustainable. As Charlotte continues to grow, it must also continue to invest in its tree canopy. This is no easy task, given financial constraints and trends toward increased development that put trees at risk. The challenge ahead is to better integrate the green infrastructure with the gray infrastructure. This can be achieved by including green space and trees in the planning phase of development projects, providing adequate space for trees, and designing and maintaining plantings to maximize net benefits over the long term. By acting now to implement these recommendations, Charlotte will benefit from a more functional and sustainable urban forest in the future.

Figure 2—Stately trees line a residential street in an established Charlotte neighborhood.

Chapter One—Introduction

Charlotte is a vibrant Southern city, appreciated for its rich history and cultural wealth. Trees are maintained as an integral component of the city infrastructure; in fact, Charlotte is known to residents as the "City of Trees" (*Figure 2*). The city's Engineering and Property Management's Engineering Services Division actively manages more than 120,000 trees along streets. The City believes that the public's investment in stewardship of the urban forest produces benefits that far outweigh the costs to the community. Investing in Charlotte's green infrastructure makes sense economically, environmentally, and socially (*Figure 3*).

Research indicates that healthy city trees can mitigate impacts associated with urban environs: polluted stormwater runoff, poor air quality, high levels of energy for heating and cooling buildings, and heat islands. Healthy public trees increase real estate values, provide neighborhood residents with a sense of place, and foster psychological health. Street and park trees are associated with other intangibles, too, such as increasing community attractiveness for tourism and business and providing wildlife habitat and corridors. The urban forest makes Charlotte a more enjoyable place to live, work and play, while mitigating the city's environmental impact.

In an era of decreasing public funds and rising costs, however, there is a need to scrutinize public expenditures that are often viewed as "nonessential," such as planting and maintaining street and park trees. Although the current program has demonstrated its economic efficiency, questions remain regarding the need for the level of service presently provided. Hence, the primary question that this study asks is whether *the accrued benefits from Charlotte's urban trees justify the annual expenditures?*

In answering this question, information is provided to do the following:

- Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for Charlotte's urban forest.
- Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.

Figure 3—Trees enliven a downtown square in Charlotte.

- Highlight the relevance and relationship of Charlotte's municipal tree resource to local quality of life issues such as environmental health, economic development, and psychological health.
- Provide quantifiable data to assist in developing alternative funding sources through utility purveyors, air quality districts, federal or state agencies, legislative initiatives, or local assessment fees.

This report consists of six chapters and two appendices:

Chapter One—Introduction: Describes the purpose of the study.

Chapter Two—Charlotte's Municipal Tree Resource: Describes the current structure of the street tree resource.

Chapter Three—Costs of Managing Charlotte's Municipal Trees: Details management expenditures for publicly managed trees.

Chapter Four—Benefits of Charlotte's Municipal Trees: Quantifies the estimated value of tangible benefits and calculates net benefits and a benefit–cost ratio.

Chapter Five—Management Implications: Evaluates relevancy of this analysis to current programs and describes management challenges for street tree maintenance.

Chapter Six—Conclusions: Final word on the use of this analysis.

Appendix A—Tree Distribution: Lists species and numbers of trees in the population of street trees.

Appendix B—Describes procedures and methodology for calculating structure, function, and value of the urban tree resource.

References—Lists publications cited in the study.

Chapter Two—Charlotte's Municipal Tree Resource

Charlotte has long been known to residents as the "City of Trees." Carved out of a native oak-chestnut forest, the city retains the flavor of its Piedmont natural history with many native trees including willow oak, red maples, loblolly pines, and dogwoods among its most common street tree species. Charlotte has many landmark trees that are distinctive because of their size, form, or history. The city's trees add character, beauty, and serenity to neighborhoods and commercial areas.

Tree Numbers

The Charlotte street tree inventory was begun in 2001 and included 85,146 trees at the time of this study. The inventory concentrated on areas with high maintenance street trees. Although the total street tree population is estimated to be 120,000, this assessment focuses on trees the 85,146 trees that were inventoried. Therefore, it may understate the full extent and benefit of Charlotte's entire municipal forest.

Charlotte's street tree population is dominated by deciduous trees (86% of the total; *Table 1*). A significant proportion of these are small trees; only about 40% of the public trees are species that will eventually grow to be large (>40 ft). Because big trees provide more shade, pollutant uptake, CO_2 sequestration, and rainfall interception than small trees, the low number of large-growing trees and high percentage of small-stature trees (41%) is of some concern.

Table 1*—Street tree percentages by mature size class and tree type.*

Tree type	Large	Medium	Small	Total
Deciduous	37.3	12.0	37.0	86.3
Broadleaf evergreen	0.1	0.9	4.2	5.2
Conifer	4.6	3.9	0.0	8.5
Total	42.0	16.8	41.2	100.0

Species Richness, Composition And Diversity

The tree population in Charlotte includes 215 different species—four times the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey of street tree populations in 22 U.S. cities. The mild climate of the Piedmont and the great variety of native trees play a role in this species richness.

The predominant street tree species are willow oak (*Quercus phellos*, 16.7%), crapemyrtle (*Lagerstroemia* spp., 14.1%), pear (*Pyrus* spp., 7.6%), red maple (*Acer rubrum*, 6.5%) and dogwood (*Cornus florida*, 5.3%) (*Table 2*). In Charlotte, the percentages of both willow oak and crapemyrtle exceed the general rule that no single species should represent more than 10% of the population and no genus more than 20% (Clark et al. 1997).

Dominance of this kind is of concern because of the impact that storms, drought, disease, pests, or other stressors can have on the urban forest. Although willow oaks and crapemyrtles are generally not susceptible to pests and disease, nonnative fungi and insects have caused serious unexpected damage to other species in the past. It should be noted that crapemyrtles will not be planted in as large numbers as they have been. They are on the city's list of trees that are not recommended and can only be planted with approval of the Urban Forestry staff (City of Charlotte, 2002).

Species Importance

Importance values (IV) are particularly meaningful to managers because they indicate a community's reliance on the functional capacity of particular species. For this study, IV takes into account not only total numbers, but canopy cover and leaf area, providing a useful comparison to the total population distribution.

Importance value (IV), a mean of three relative values, can, in theory, range between 0 and 100, where an IV of 100 implies total reliance on one species and an IV of 0 suggests no reliance. Street tree populations with one dominant species (IV>25%) may have low maintenance costs due to the efficiency of repetitive work, but may still incur large

Table 2—*Most abundant street tree species in order of predominance by DBH class and tree type.*

Species	DBH Class (in)										
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	%
Broadleaf Deciduous Large											
Willow oak	458	1,127	2,514	2,397	1,656	1,902	2,124	1,262	809	14,249	16.7%
Sugar maple	243	768	1,134	569	190	58	11	-	3	2,976	3.5%
Silver maple	54	128	549	634	406	189	59	16	6	2,041	2.4%
Sweetgum	165	175	454	495	334	155	51	11	4	1,844	2.2%
Water oak	30	83	180	201	121	105	88	49	27	884	1.0%
BDL OTHER	581	1,573	3,171	2,165	1,121	600	355	125	91	9,782	11.5%
Total	1,531	3,854	8,002	6,461	3,828	3,009	2,688	1,463	940	31,776	37.3%
Broadleaf Deciduous Medium											
Red maple	483	1,140	2,512	1,057	330	161	32	2	4	5,721	6.7%
Unknown tree	113	301	267	192	52	31	10	1	-	967	1.1%
BDM OTHER	536	1,080	1,181	485	171	49	19	5	-	3,526	4.1%
Total	1,132	2,521	3,960	1,734	553	241	61	8	4	10,214	12.0%
Broadleaf Deciduous Small											
Common crapemyrtle	5,154	4,813	1,569	326	104	26	5	1	2	12,000	14.1%
Pear	251	695	3,044	2,251	172	17	2	1	-	6,433	7.6%
Flowering dogwood	784	1,702	1,830	213	21	1	1	3	2	4,557	5.4%
Plum	381	689	952	363	78	10	1	-	-	2,474	2.9%
Apple	109	378	433	85	10	2	-	-	1	1,018	1.2%
Dogwood	289	346	247	65	5	-	-	-	-	952	1.1%
Callery pear	27	196	250	384	39	-	-	-	-	896	1.1%
Yoshino flowering cherry	38	148	375	247	60	18	7	1	-	894	1.1%
BDS OTHER	600	773	652	206	32	5	6	-	-	2,274	2.7%
Total	7,633	9,740	9,352	4,140	521	79	22	6	5	31,498	37.0%
Broadleaf Evergreen Large	12	10	14	22	15	5	6	1	1	86	0.1%
Broadleaf Evergreen Medium	62	137	304	182	45	12	9	4	-	755	0.9%
Broadleaf Evergreen Small											
American holly	229	531	165	40	7	1	-	-	-	973	1.1%
Privet	327	425	155	15	4	1	1	-	-	928	1.1%
BES OTHER	371	777	378	112	8	3	2	1	-	1,652	1.9%
Total	927	1,733	698	167	19	5	3	1	-	3,553	4.2%
Conifer Evergreen Large											
Shortleaf pine	14	41	263	583	206	26	3	-	-	1,136	1.3%
Loblolly pine	54	86	196	342	180	51	10	-	-	919	1.1%
CEL OTHER	123	235	471	608	294	88	29	5	1	1,854	2.2%
Total	191	362	930	1,533	680	165	42	5	1	3,909	4.6%
Conifer Evergreen Medium											
Eastern red cedar	221	442	774	467	131	29	5	-	-	2,069	2.4%
CEM OTHER	366	424	364	86	15	2	1	-	-	1,258	1.5%
Total	587	866	1,138	553	146	31	6	-	-	3,327	3.9%
Conifer Evergreen Small	1	3	5	1	2	2	-	1	-	15	0.0%
Palm Medium	-	-	1	-	-	-	-	-	-	1	0.0%
Palm Small	-	3	9	-	-	-	-	-	-	12	0.0%
Citywide Total	12,076	19,229	24,413	14,793	5,809	3,549	2,837	1,489	951	85,146	100.0%

costs if decline, disease, or senescence of the dominant species results in large numbers of removals and replacements. When IVs are more evenly dispersed among five to ten leading dominant species the risks of a catastrophic loss of a single dominant species are reduced. Of course, suitability of the dominant species is an important consideration. Planting short-lived or poorly adapted species can result in short rotations and increased long-term management costs.

The 20 most abundant street tree species listed in *Table 3* constitute 74% of the total street tree population, 80% of the total leaf area, and 77% of total canopy cover, for an IV value of 76.9. As *Table 3* illustrates, because of the limited number of large trees in the city as a whole, Charlotte is relying on the functional capacity of willow oaks even more than their population numbers suggest. Though the species accounts for 17% of all public trees, because of the trees' relatively large size, the amount of leaf area and canopy cover they provide is even greater, increasing their importance value to 38 when all components are considered. This makes them more than six times more significant than the next species. In contrast, small trees tend to have lower importance values than their population numbers would suggest. Although crapemyrtles make up 14% of the population, their IV is only 5.8.

Street Tree Stocking Level

Charlotte's citizens are becoming concerned about the state of their urban forest (Henderson 2005). A recent report noted that Mecklenburg County, one of the fastest growing metropolitan areas in the United States, lost 22% of its tree cover between 1984 and 2001 (American Forests 2003). Although the inventory on which our study is based is not complete and did not sample empty street-tree planting sites in Charlotte to determine stocking level, stocking can be estimated based on total street miles and the city's estimate of 120,000 trees. Assuming there are 2,522 linear miles of streets in Charlotte (McSween 2005), on average there are 48 street trees per street mile. A fully stocked city

Table 3—*Importance values (IV) indicate which species dominate the population due to their numbers and size.*

Species	No. of trees	% of total trees	Leaf area (ft^2)	% of total leaf area	Canopy cover (ft^2)	% of total canopy cover	Importance value
Willow oak	14,249	16.7	140,572,992	58.4	20,987,252	39.9	38.3
Common crapemyrtle	12,000	14.1	1,006,628	0.4	1,462,545	2.8	5.8
Pear	6,433	7.6	5,595,279	2.3	3,031,806	5.8	5.2
Red maple	5,721	6.7	12,295,888	5.1	3,056,378	5.8	5.9
Flowering dogwood	4,557	5.4	1,004,284	0.4	1,040,083	2.0	2.6
Sugar maple	2,976	3.5	5,118,775	2.1	1,935,952	3.7	3.1
Plum	2,474	2.9	926,422	0.4	736,722	1.4	1.6
Eastern red cedar	2,069	2.4	880,952	0.4	641,371	1.2	1.3
Silver maple	2,041	2.4	6,743,083	2.8	2,163,244	4.1	3.1
Sweetgum	1,844	2.2	6,112,161	2.5	1,257,242	2.4	2.4
Shortleaf pine	1,136	1.3	1,804,780	0.8	795,108	1.5	1.2
Apple	1,018	1.2	149,974	0.1	306,200	0.6	0.6
American holly	973	1.1	78,497	0.0	120,386	0.2	0.5
Dogwood	952	1.1	183,836	0.1	194,410	0.4	0.5
Privet	928	1.1	53,486	0.0	96,305	0.2	0.4
Loblolly pine	919	1.1	1,800,926	0.7	606,339	1.2	1.0
Callery pear	896	1.1	853,154	0.4	446,314	0.9	0.8
Yoshino flowering cherry	894	1.1	530,958	0.2	407,196	0.8	0.7
Water oak	884	1.0	6,606,427	2.7	1,150,031	2.2	2.0
Total	62,964	73.9	192,318,499	80	40,434,884	76.9	76.9

would have one tree on each side of the street every 50 feet or 211 trees per street mile. By this measure, Charlotte's street tree stocking level is 23%, and there is room, theoretically, for as many as another 400,000 trees. The actual number of street tree planting sites may be significantly less due to inadequate planting spaces, presence of privately owned trees, and utility conflicts. Charlotte's stocking level compares favorably with Cheyenne, WY (12%), and Glendale, AZ (9%), but is significantly less than Bismarck (37%) and the mean stocking level for 22 U.S. cities (38.4%) (McPherson et al. 2005; McPherson and Rowntree 1989).

Street Trees Per Capita

Calculations of street trees per capita are important in determining how well-forested a city is. Assuming a human population of 597,308 and a tree population of 120,000 (McSween 2005), Charlotte's number of street trees per capita is 0.20—approximately one tree for every five people—significantly below the mean ratio of 0.37 reported for 22 U.S. cities (McPherson and Rowntree 1989).

Age Structure

The distribution of ages within a tree population influences present and future costs as well as the flow of benefits. An uneven-aged population allows managers to allocate annual maintenance costs uniformly over many years and assures continuity in overall tree-canopy cover. An ideal distribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

The overall age structure for street trees in Charlotte appears quite similar to the ideal (*Figure 4*). Closer examination, however, shows that the results differ greatly by species. Willow oak shows a very flat distribution across DBH classes with a very high percentage of old trees, including nearly 30% with a DBH above 30 inches. It also appears that few new willow oaks have been planted recently (11% in the 0–6 inch DBH class). Crapemyrtle, in contrast, is very heavily weighted toward small trees, with 83% in the smallest DBH class.

Trends in tree planting in Charlotte can be estimated from the age distribution of species. Silver maple is well represented, even over-represented, in the mature and old classes with twice the percentage of trees as is desired in the mature age class (18–30 inch DBH; 30% vs. 15%). Most of these trees were planted by developers over 30 years ago or by individual homeowners without permission. Very few new silver maples have been planted recently (only 8% in the 0–6 inch DBH class); in fact, this species is now prohibited by the City Tree Ordinance because its roots cause infrastructure damage and it is prone to storm damage (City of Charlotte 2002).

Red maple has a reasonable distribution in the older classes above 12 inches, but is very heavily weighted towards younger trees (44% with DBH 6–12 inches compared to the desired 25%). Recently, there has been a reduction in the number of new red maples planted (youngest class, 0–6 inches, 29%), perhaps due to their susceptibility to trunk cankers and crown dieback.

None of the largest tree species are well represented in the youngest age class, while small species are over-represented, suggesting that the city has been primarily planting smaller species. Because small-stature trees provide significantly fewer benefits throughout their life span than larger species, the benefits provided to the city of Charlotte are

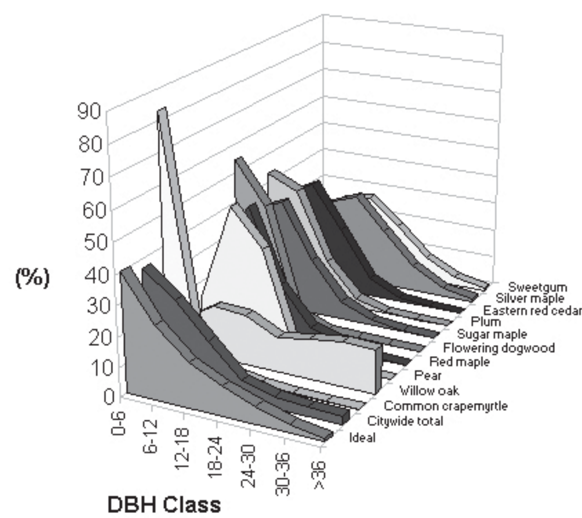

Figure 4—Relative age distribution for Charlotte's 10 most abundant street trees citywide shown with an ideal distribution.

likely to decline. There are several reasons for this trend towards smaller species:

- The city has made a concentrated effort to remove and replace trees under power lines that have been badly disfigured by severe pruning. Small-stature trees have been replanted to avoid future conflicts with power lines that are 20–25 ft aboveground.

- Charlotte is trying to reduce urban sprawl through the zoning process. Increased densities have increased conflicts between tree roots and underground utilities, resulting in loss of trees and planting of smaller species.

- It is difficult to successfully establish large species in areas that are heavily stocked with large trees because most species do not compete well for light, water and nutrients when they are young.

- Only recently have transportation planners and engineers been convinced that large trees can be located near roads without undue hazard.

Tree Condition

Tree condition indicates both how well trees are managed and how well they perform given site-specific conditions. Overall, the condition of trees in Charlotte is very good, with 95% showing no or only minor problems (*Figure 5*).

The relative performance index (RPI) of each species provides an indication of its suitability to local growing conditions, as well as its performance. A species whose trees are in average condition compared to all other species in the city has an RPI of 1.0. Species that perform better than average have an RPI greater than 1.0, and likewise, those species with below average performance have RPIs below 1.0.

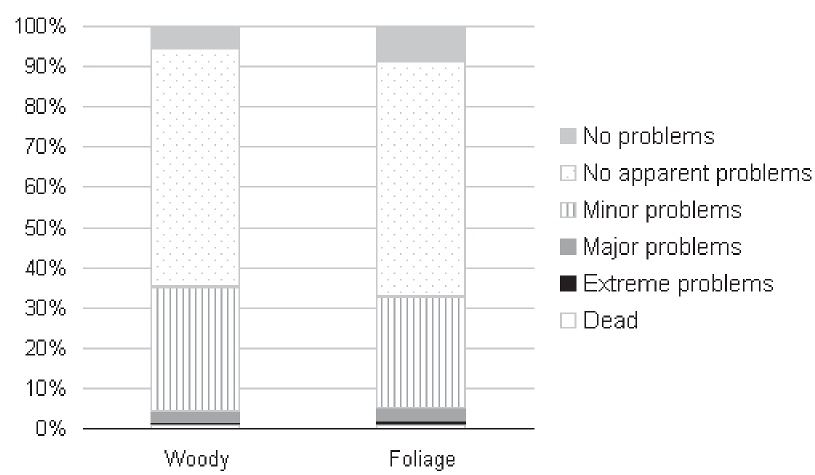

Figure 5—Condition of foliage and woody parts of street trees in Charlotte.

Species with higher percentages of their trees in good or better condition are likely to provide greater benefits at lower cost than species with more trees in fair or poor condition. Abundant species rated as having the best performance are American holly (*Ilex opaca*), sugar maple (*Acer saccharum*), loblolly pine (*Pinus taeda*), and red maple (*Acer rubrum*) (*Table 4*). These species are adapted to growing conditions throughout the city. Predominant species with the poorest performance include apple (*Malus* spp.) and dogwood (*Cornus* spp.).

Tree Canopy

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As canopy cover increases, so do the benefits afforded by leaf area. It is important to remember that street and park trees throughout the United States—and those of Charlotte—likely represent less than 20% of the entire urban forest (Moll and Kollin 1993). The street tree canopy in Charlotte is estimated at 1,206 acres and covers 0.73% of the city, given a city area of 165,000 acres (McSween 2005). Publicly managed street trees shade approximately 7% of streets and sidewalks.

Table 4—*Relative performance index of most common street tree species in Charlotte.*

Species	Dead	Extreme problems	Major problems	Minor problems	No apparent problems	No problems	RPI
American holly	0.31	0.00	0.77	23.43	43.17	32.32	1.11
Sugar maple	0.22	0.35	1.92	18.04	67.07	12.40	1.06
Loblolly pine	0.65	0.00	0.49	17.52	78.78	2.56	1.04
Red maple	0.28	0.56	2.89	23.19	65.13	7.95	1.03
Water oak	0.28	0.62	1.02	27.66	64.71	5.71	1.02
Common crapemyrtle	0.13	0.35	2.09	31.39	56.74	9.31	1.02
Willow oak	0.22	0.46	1.91	29.97	59.72	7.73	1.01
Eastern red cedar	0.87	0.24	1.89	27.40	63.48	6.11	1.01
Pear	0.20	0.38	2.76	29.30	60.56	6.79	1.01
Silver maple	0.44	0.64	3.21	30.25	63.74	1.71	0.99
Callery pear	0.00	0.56	2.62	33.59	63.23	0.00	0.98
Plum	2.67	0.44	2.16	25.97	68.07	0.69	0.98
Shortleaf pine	2.55	0.09	1.58	32.88	59.99	2.95	0.97
Privet	0.32	0.54	1.94	44.67	45.26	7.27	0.97
Flowering dogwood	1.25	1.38	3.57	33.82	54.90	5.08	0.97
Sweetgum	0.35	0.73	3.12	39.13	54.28	2.39	0.96
Dogwood	0.53	1.21	7.62	42.38	38.50	9.77	0.95
Apple	2.26	0.88	6.58	41.80	45.24	3.24	0.92
Yoshino flowering cherry	1.06	3.30	11.86	36.24	37.25	10.29	0.92

Land Use

The majority (77%) of public trees in Charlotte are located in front of homes and apartment buildings (*Figure 6*). Eight percent are associated with businesses, 7.5% are planted in boulevard medians, islands and parking areas, and 2% are located on the grounds of various institutions, including churches, hospitals, schools.

Maintenance Needs

Understanding species distribution, age structure, and tree condition may aid in estimating proper pruning cycles, but it is important to understand the actual pruning and maintenance needs of the city trees. Not only will this information provide clues as to whether or not pruning is adequate, but it will also indicate the level of risk and liability associated with the city's street tree population.

The city's inventory included an assessment of maintenance needs, and showed that 62% of street trees are in need of maintenance (*Table 5*). To promote continued good health and performance, 53% of the trees need routine pruning for training (8.6%), and routine pruning for large (23.1%) and small (21.4%) trees. Approximately 4% of the population requires priority pruning, usually for safety reasons. Trees requiring removal (2.2%) have severe problems, although these are not necessarily related to safety hazards. They may be dead or dy-

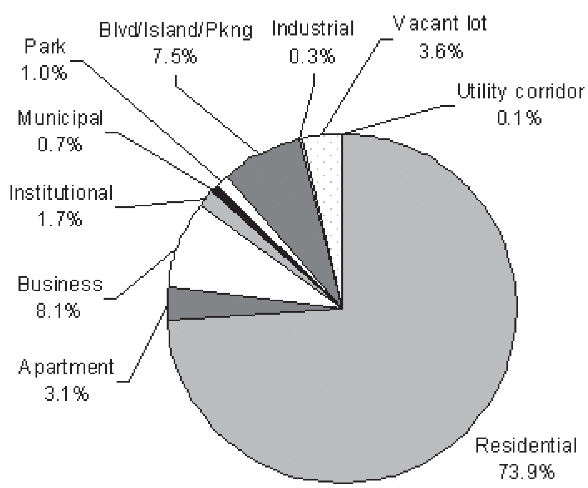

Figure 6—Distribution of street trees by adjacent land use.

Table 5—*Maintenance needs by DBH class.*

Maintenance Type	DBH Class										
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total Population
None	3,507	6,982	10,221	6,358	2,214	1,260	1,038	523	336	32,439	38%
Priority removal	195	350	551	396	182	81	52	31	25	1,863	2%
Priority prune	1	19	228	528	614	701	710	400	317	3,518	4%
Routine prune, large tree	773	1,284	6,351	5,363	2,578	1,469	1,024	532	271	19,645	23%
Routine prune, small tree	5,008	6,441	4,902	1,679	152	15	2	1	-	18,200	21%
Training prune	2,266	3,631	1,403	-	-	-	-	-	-	7,300	9%
Clearance trim	326	522	757	469	69	23	11	2	2	2,181	3%
Citywide total	12,076	19,229	24,413	14,793	5,809	3,549	2,837	1,489	951	85,146	100%

ing trees that were planted recently, or they may contain unmanageable defects and hazards. Trees classified as needing removal and replacement are eyesores at best, and represent the potential for substantial costs or public safety hazards at worst. Data in *Table 5* can be used with tree-care cost estimates to calculate the amount of funding required to address current management needs.

Figure 7—Trees grace a boulevard into a Charlotte neighborhood.

Chapter Three—Costs of Managing Charlotte's Municipal Trees

Costs of Managing Public Trees

The benefits that Charlotte's trees provide come at a cost. This chapter presents a breakdown of annual expenditures for fiscal year 2004. Total annual tree-related expenditures for Charlotte's municipal forestry program are approximately $1.8 million (*Table 6*) (McSween 2005). This amount represents 0.13% of Charlotte's total 2004 operating budget ($1.39 billion) and $3/capita. Based on the 85,146 actively managed street and park trees included in the inventory, the city spends $21 per tree on average during the fiscal year, equal to the 1997 mean value of $19 per tree reported for 256 California cities after adjusting for inflation (Thompson and Ahern 2000). However, non-program expenditures (e.g., sidewalk repair, litter clean-up) were not included in the California survey. Charlotte's annual expenditure is approximately equal to that of Cheyenne, WY ($19), and far less than Fort Collins, CO ($32), and some California communities such as Santa Monica ($53) and Berkeley ($65) (McPherson et al. 2005). Forestry program expenditures fall into three general categories: tree planting and establishment, pruning and general tree care, and administration.

Tree Planting and Establishment

Quality nursery stock, careful planting, and follow-up care are critical to perpetuation of a healthy urban forest. By planting only relatively large new trees with DBH of 2.5–3 inches, the city of Charlotte is giving its urban forest a healthy start. The city plants about 700 trees annually, 30% at new sites and 70% as replacements for removed trees. Tree planting activities, including materials, labor, administration, and equipment costs, account for 9.9% of the program budget or approximately $180,000. Additional trees not included in this budget are planted as a part of Capital Improvement Projects and to meet zoning requirements.

Pruning, Removals, and General Tree Care

Pruning accounts for more than 20% of the annual expenditures at $380,000 ($4.46 per tree). Tree and stump removal accounts for almost a quarter of the tree-related expenses ($420,000). About 350 large (>24 inch DBH) street trees are removed each year by in-house or contracted labor.

All removed wood is salvaged, processed by Mecklenburg County Solid Waste, and sold to the public. Eighty percent is sold as mulch and 20% as compost. After accounting for administrative and processing costs and sales the program breaks even.

Annual costs for pest and disease control total $1,500 ($0.02 per tree; $30/treated tree). Approximately 500 trees are inspected each year and 50 are treated using the pesticide Merit.

Table 6*—Charlotte's annual municipal forestry-related expenditures.*

Expenditures	Total($)	% of program	$/Tree	$/Capita
Contract Pruning	380,000	20.9%	4.46	0.64
Tree & Stump Removal	420,000	23.0%	4.93	0.70
Pest Management	1,500	0.1%	0.02	0.00
Irrigation	8,000	0.45%	0.09	0.01
Purchasing Trees and Planting	180,000	9.9%	2.11	0.30
Administration	117,960	6.5%	1.39	0.20
Litter Clean-up	4,500	0.25%	0.05	0.01
Infrastructure Repairs	637,500	35.0%	7.49	1.07
Liability/Claim	70,000	3.9%	0.82	0.12
Total Expenditures	1,819,460	100%	21.37	3.05

Repairs and maintenance to the street-tree irrigation system cost approximately $8,000 (0.45%). Two hundred street trees and 85 park trees are watered from April through September. The cost of the water is minimal and is not a part of the department's budget. Clean-up costs for litter pickup and pruning after storm damage are approximately $4,500 annually.

Administration

An additional $117,960 is spent on administration expenses including supplies, travel, training, insurance and workers' compensation. Salaries for managers and clerical staff have been included in other cost categories. Also included in the administration expenses are costs involved in enforcing the Public Property part of the city's Tree Ordinance ($39,500 annually) and inspections and monitoring for the city's Capital Improvement Project ($34,000).

External Tree-Related Expenditures

Tree-related expenditures accrue to the city that are not captured in the Engineering Services Division's budget. Annually, about $637,500 is spent by the city on infrastructure repair related to tree roots. Shallow roots that heave sidewalks, crack curbs, and damage driveways are an important aspect of mature tree care. The Division works to find solutions to tree/sidewalk conflicts (*Figure 8*). Once problems occur, the city attempts to remediate the problem without removing the tree. Strategies include ramping the sidewalk over the root, grinding concrete to level surfaces, removing and replacing concrete, and pruning roots only when necessary. Not all curb and sidewalk damage is due to tree roots, especially in areas where infrastructure is old. However, infill and higher density development will increase tree root–hardscape conflicts unless structural soils, careful species selection, and other practices are used.

Annual expenditures for trip-and-fall claims, property-damage payments, and legal staff time required to process tree-related claims can be substantial in cities with large trees and old infrastructure. Annual payments in Charlotte equal approximately $20,000 and legal fees total about $50,000. These costs are partially offset by income from compensation and/or mitigation fees of $10,000.

Figure 8—Testing is being carried out at the Bartlett Tree Experts Laboratory in Charlotte to study different paving materials to reduce conflict between infrastructure and trees.

Chapter Four—Benefits of Charlotte's Municipal Trees

Introduction

City trees work ceaselessly, providing ecosystem services that directly improve human health and quality of life. In this section the benefits of Charlotte's street trees are described. It should be noted that this is not a full accounting because some benefits are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). Also, our limited knowledge about the physical processes at work and their interactions makes these estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable. A true and full accounting of benefits and costs must consider variability among sites throughout the city (e.g., tree species, growing conditions, maintenance practices), as well as variability in tree growth.

Therefore, these estimates provide first-order approximations of tree value. Our approach is a general accounting of the benefits produced by municipal trees in Charlotte—an accounting with an accepted degree of uncertainty that can nonetheless provide a platform from which decisions can be made (Maco and McPherson 2003). Methods used to quantify and price these benefits are described in more detail in Appendix B.

Energy Savings

Trees modify climate and conserve energy in three principal ways (*Figure 9*):

- Shading reduces the amount of radiant energy absorbed and stored by built surfaces.
- Transpiration converts moisture to water vapor and thus cools the air by using solar energy that would otherwise result in heating of the air.
- Wind-speed reduction reduces the movement of outside air into interior spaces and conductive heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees and other vegetation within building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace (Chandler 1965). At the larger scale of city-wide climate (6 miles or 10 km square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992). The relative importance of these effects depends on the size and configuration of trees and other landscape elements (McPherson 1993). Tree spacing, crown spread, and vertical distribution of leaf area influence the transport of warm air and pollutants along streets and out of urban canyons.

Trees reduce air movement into buildings and conductive heat loss from buildings. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed reduces heat transfer through conductive materials as well. Appendix B provides additional informa-

Figure 9—Trees shade a downtown Charlotte neighborhood and reduce energy use for cooling.

Table 7—Net annual energy savings produced by Charlotte street trees.

Species	Electricity (MWh)	Electricity ($)	Natural gas (MBtu)	Natural gas ($)	Total ($)	% of total tree nos.	% of total $	Avg. $/tree
Willow oak	2,952	224,081	10,670	111,610	335,692	16.7	36.7	23.56
Common crapemyrtle	204	15,492	1,255	13,124	28,615	14.1	3.1	2.38
Pear	469	35,580	2,175	22,755	58,335	7.6	6.4	9.07
Red maple	462	35,049	2,110	22,074	57,123	6.7	6.3	9.98
Flowering dogwood	148	11,249	882	9,222	20,472	5.4	2.2	4.49
Sugar maple	291	22,063	1,337	13,984	36,047	3.5	3.9	12.11
Plum	108	8,226	573	5,994	14,220	2.9	1.6	5.75
Eastern red cedar	97	7,357	326	3,411	10,768	2.4	1.2	5.20
Silver maple	318	24,116	1,322	13,825	37,941	2.4	4.2	18.59
Sweetgum	196	14,881	821	8,584	23,466	2.2	2.6	12.73
Shortleaf pine	126	9,541	501	5,237	14,778	1.3	1.6	13.01
Apple	44	3,340	265	2,773	6,113	1.2	0.7	6.00
American holly	17	1,282	89	933	2,215	1.1	0.2	2.28
Unknown tree	81	6,168	369	3,862	10,030	1.1	1.1	10.37
Dogwood	28	2,124	165	1,727	3,851	1.1	0.4	4.04
Privet	13	1,000	75	781	1,781	1.1	0.2	1.92
Loblolly pine	93	7,030	299	3,125	10,155	1.1	1.1	11.05
Callery pear	70	5,294	314	3,280	8,574	1.1	0.9	9.57
Yoshino cherry	60	4,520	308	3,224	7,744	1.1	0.9	8.66
Water oak	162	12,314	592	6,188	18,501	1.0	2.0	20.93
Other street trees	1,719	130,505	7,368	77,074	207,579	24.9	22.7	9.78
Citywide total	7,658	581,212	31,815	332,789	914,000	100.0	100.0	10.73

tion on specific contributions that trees make toward energy savings.

Electricity and Natural Gas Results

Electricity and natural gas saved annually in Charlotte from both shading and climate effects total 7,658 MWh ($581,212) and 31,815 Mbtu ($332,789), respectively, for a total retail savings of $914,000 (*Table 7*) or a citywide average of $10.73 per tree. Willow oak, water oak, and silver maple are the primary contributors to energy savings on a per tree basis.

Among street trees, willow oaks account for 16.7% of total tree numbers, but provide 36.7% of the energy savings, as expected for a tree species with an Importance Value (IV) of 38. Water oaks and silver maples also provide energy savings far greater than their share of the population. In contrast, crapemyrtles make up 14.1% of the population and provide only 3.1% of energy savings, consistent with their IV of 5.8. Deciduous trees provide greater energy saving benefits than conifers and broadleaf evergreen trees (*Table 8*). Energy benefits associated with evergreen trees are less than deciduous tree benefits because of the detrimental effect of their winter shade on heating costs.

Table 8*—Annual energy savings produced by Charlotte public trees by tree type.*

Size	Broadleaf deciduous	Broadleaf evergreen	Conifer
Small	5.03	2.36	4.80
Large	18.23	15.58	11.95

Atmospheric Carbon Dioxide Reductions

Urban forests can reduce atmospheric CO_2 in two ways:

- Trees directly sequester CO_2 as woody and foliar biomass while they grow.

- Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production and consumption of natural gas.

At the same time, however, CO_2 is released by vehicles, chain saws, chippers, and other equipment during the process of planting and maintaining trees. Eventually, all trees die and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere as they decompose unless recycled. These factors must be taken into consideration when calculating the carbon dioxide benefits of trees.

Carbon Dioxide Reductions

Citywide, Charlotte's municipal forest reduced atmospheric CO_2 by 13,237 tons annually. This benefit was valued at $198,500 or $2.33 per tree. CO_2 released through decomposition and tree care activities totaled 859.4 tons, or 6.5% of the net total benefit. Avoided CO_2 emissions from power plants due to cooling energy savings totaled 3,235 tons, while CO_2 sequestered by trees was 10,860 tons. Avoided emissions are important in North Carolina because coal, which has a relatively high CO_2 emissions factor, accounts for 43% of the fuel used in power plants that generate electricity (US EPA 2003). Shading by trees during summer reduces the need for air conditioning, resulting in reduced use of coal for electricity generation.

On an individual tree basis, willow oak, water oak, and silver maple provide the greatest CO_2 benefits (*Table 9*). Because of its great numbers, willow oak also provides the greatest total CO_2 benefits, accounting for 37.4% of citywide CO_2 reduction. Crapemyrtle represents only 1.6% of the benefits, although it makes up 14.1% of the population.

Table 9*—CO_2 reductions, releases, and net benefits produced by street trees.*

Species	Sequestered (lb)	Decomp. release (lb)	Maint. Release (lb)	Avoided (lb)	Net total (lb)	Total ($)	% of trees	% of Total $	Avg. $/tree
Willow oak	8,388,412	-949,102	-39,804	2,495,206	9,894,711	74,210	16.7	37.4	5.21
Ccrapemyrtle	264,267	-7,249	-2,340	172,503	427,180	3,204	14.1	1.6	0.27
Pear	1,320,137	-52,905	-1,254	396,188	1,662,165	12,466	7.6	6.3	1.94
Red maple	1,347,752	-62,067	-7,398	390,276	1,668,563	12,514	6.7	6.3	2.19
Dogwood	438,056	-20,323	-889	125,266	542,109	4,066	5.4	2.1	0.89
Sugar maple	683,485	-30,175	-3,718	245,678	895,270	6,715	3.5	3.4	2.26
Plum	162,799	-4,267	-482	91,603	249,652	1,872	2.9	0.9	0.76
Eastern red cedar	208,850	-10,487	-2,599	81,919	277,682	2,083	2.4	1.1	1.01
Silver maple	980,733	-52,998	-4,105	268,535	1,192,165	8,941	2.4	4.5	4.38
Sweetgum	447,084	-23,243	-3,385	165,706	586,161	4,396	2.2	2.2	2.38
Shortleaf pine	333,052	-15,705	-222	106,240	423,365	3,175	1.3	1.6	2.80
Apple	142,936	-3,877	-199	37,190	176,051	1,320	1.2	0.7	1.30
American holly	38,580	-2,040	-648	14,276	50,169	376	1.1	0.2	0.39
Unknown tree	352,542	-9,937	-189	68,679	411,095	3,083	1.1	1.6	3.19
Dogwood	78,185	-3,840	-186	23,653	97,812	734	1.1	0.4	0.77
Privet	29,728	-1,487	-539	11,140	38,841	291	1.1	0.2	0.31
Loblolly pine	238,730	-11,962	-179	78,276	304,865	2,286	1.1	1.2	2.49
Callery pear	191,052	-8,119	-175	58,949	241,707	1,813	1.1	0.9	2.02
Yoshino cherry	93,961	-2,975	-174	50,337	141,149	1,059	1.1	0.5	1.18
Water oak	512,182	-43,250	-2,140	137,116	603,908	4,529	1.0	2.3	5.12
Other street trees	5,467,574	-310,652	-21,459	1,453,209	6,588,672	49,415	24.9	24.9	2.33
Citywide total	21,720,090	-1,626,660	-92,083	6,471,942	26,473,290	198,550	100.0	100.0	2.33

Air Quality Improvement

Urban trees improve air quality in five main ways (*Figure 10*):

- Absorbing gaseous pollutants (ozone, nitrogen oxides) through leaf surfaces
- Intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke)
- Reducing emissions from power generation by reducing energy consumption
- Releasing oxygen through photosynthesis
- Transpiring water and shading surfaces, resulting in lower local air temperatures, thereby reducing ozone levels

In the absence of the cooling effects of trees, higher temperatures contribute to ozone formation. On the other hand, most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can also contribute to ozone formation. The ozone-forming potential of different tree species varies considerably (Benjamin and Winer 1998). The contribution of BVOC emissions from city trees to ozone formation depends on complex geographic and atmospheric interactions that have not been studied in most cities.

Figure 10—Trees in Charlotte's downtown area improve air quality by absorbing pollutants, sequestering carbon dioxide and reducing energy for cooling.

Deposition and Interception

Reduction of nitrogen dioxide (NO_2), small particulate matter (PM_{10}), ozone (O_3), and sulfur dioxide (SO_2) by trees (pollution deposition and particulate interception) in Charlotte is 14.8 tons, or $136,943 for all trees. Charlotte's trees are most effective at removing O_3 and PM_{10}, with an implied annual value of $101,978. Again, due to its great numbers and large leaf area, willow oak contributes the most to pollutant uptake (*Table 10*). Surprisingly, considering their relatively small size, pear trees intercept the second highest amount of air pollutants.

Avoided Pollutants

Energy savings result in reduced air-pollutant emissions of NO_2, PM_{10}, volatile organic compounds (VOCs), and SO_2 (*Table 10*). Together, 28.1 tons of pollutants are avoided annually with an implied value of $198,413. In terms of mass, avoided emissions of SO_2 are greatest (34,433 lb); in dollar terms, however, the higher cost of NO_2 means that its reduction (15,845 lbs) is the most valuable.

BVOC Emissions

Biogenic volatile organic compound (BVOC) emissions from trees are substantial. At a total of 29.7 tons, these emissions offset air quality improvements and are valued as a cost to the city of $371,626. The majority (two-thirds) of these emissions come from willow oaks, which emit 2.8 lb of BVOCs per year on average. Sweetgum (1.8 lb/year) and loblolly pine (1.9 lb/year) are also high emitters.

Net Air Quality Improvement

Although most tree species in Charlotte provide net air quality benefits, the high BVOC emissions of

Table 10—Pollutant deposition, avoided and BVOC emissions, and net air-quality benefits produced by predominant street tree species.

Species	Deposition (lb)				Avoided (lb)				Emitted BVOCs (lb)	Net Total (lb)	Total ($)	% of trees	Avg. $/tree
	O_3	NO_2	PM_{10}	SO_2	NO_2	PM_{10}	VOC	SO_2					
Willow oak	3,817	1,797	4,389	881	5,977	1,185	1,165	13,242	-39,907	-7,454	-124,900	16.7	-8.77
Crapemyrtle	282	100	262	45	456	85	83	920	0	2,233	8,774	14.1	0.73
Pear	725	305	740	159	989	192	188	2,114	0	5,413	21,202	7.6	3.30
Red maple	589	210	547	94	973	189	185	2,082	-713	4,155	14,417	6.7	2.52
Flowering dogwood	249	81	211	39	328	62	60	667	0	1,698	6,759	5.4	1.48
Sugar maple	293	126	303	60	614	119	116	1,310	-317	2,624	9,259	3.5	3.11
Plum	142	51	132	23	234	45	44	488	-46	1,111	4,225	2.9	1.71
Eastern red cedar	318	108	231	63	192	39	38	436	-104	1,320	5,281	2.4	2.55
Silver maple	417	148	387	66	658	129	126	1,428	-382	2,979	10,643	2.4	5.21
Sweetgum	242	86	225	39	408	80	78	886	-3,465	-1,421	-13,799	2.2	-7.48
Shortleaf pine	394	133	287	78	258	51	50	567	-360	1,458	5,314	1.3	4.68
Apple	59	21	55	9	98	18	18	198	-0	476	1,868	1.2	1.83
American holly	60	20	43	12	36	7	7	76	0	261	1,101	1.1	1.13
Unknown sp.	106	38	99	17	171	33	32	366	-6	855	3,307	1.1	3.42
Dogwood sp.	47	15	39	7	62	12	11	126	0	319	1,271	1.1	1.33
Privet	48	16	35	10	29	5	5	59	0	207	875	1.1	0.94
Loblolly pine	300	102	219	60	183	37	36	417	-1,705	-352	-5,041	1.1	-5.49
Callery pear	107	45	109	23	146	28	28	315	0	801	3,135	1.1	3.50
Yoshino cherry	78	28	73	13	128	24	24	268	-1	634	2,471	1.1	2.76
Water oak	209	98	240	48	329	65	64	728	-2,116	-334	-6,388	1.0	-7.23
Other street trees	2,800	1,113	2,652	572	3,577	699	686	7,741	-10,242	9,597	13,956	24.9	0.66
Citywide total	11,281	4,641	11,279	2,319	15,845	3,103	3,046	34,433	-59,365	26,582	-36,270	100.0	-0.43

willow oaks result in a slightly negative net effect on air quality in Charlotte, valued as a cost to the city of $36,270 ($0.43 per tree). Trees vary dramatically in their ability to produce net air-quality benefits. Trees with positive values for air quality include red maple ($2.52 benefits per year), sugar maple ($3.11) and silver maple ($5.21). Smaller species with good air quality results include pear ($3.30) and flowering cherry ($2.76).

Stormwater Runoff Reductions

According to federal Clean Water Act regulations, municipalities must obtain a permit for managing their stormwater discharges into water bodies. Each city's program must identify the Best Management Practices (BMPs) it will implement to reduce its pollutant discharge. Trees are mini-reservoirs, controlling runoff at the source. Healthy urban trees can reduce the amount of runoff and pollutant loading in receiving waters in three primary ways:

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.
- Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.
- Tree canopies reduce soil erosion and surface transport by diminishing the impact of raindrops on barren surfaces.

Charlotte's municipal trees intercept 28 million cubic ft of stormwater annually, or 2,464 gal per tree on average. The total value of this benefit to the city is $2,077,393, or $24.40 per tree.

Certain species are much better at reducing stormwater runoff than others (*Table 11*). Leaf type and area, branching pattern and bark, as well as tree size and shape all affect the amount of precipita-

***Table 11**—Annual stormwater reduction benefits of Charlotte's public trees by species.*

Species	Rainfall interception (CCF)	Total ($)	% of trees	% of total $	Avg. $/tree
Willow oak	142,568	1,055,817	16.7	50.8	74.10
Crapemyrtle	3,270	24,219	14.1	1.2	2.02
Pear	10,003	74,080	7.6	3.6	11.52
Red maple	14,805	109,638	6.7	5.3	19.16
Flowering dogwood	2,601	19,263	5.4	0.9	4.23
Sugar maple	7,284	53,940	3.5	2.6	18.12
Plum	2,023	14,985	2.9	0.7	6.06
Eastern red cedar	2,237	16,566	2.4	0.8	8.01
Silver maple	9,253	68,525	2.4	3.3	33.57
Sweetgum	7,122	52,743	2.2	2.5	28.60
Shortleaf pine	3,700	27,400	1.3	1.3	24.12
Apple	603	4,465	1.2	0.2	4.39
American holly	305	2,262	1.1	0.1	2.32
Unknown tree	2,159	15,986	1.1	0.8	16.53
Dogwood	483	3,576	1.1	0.2	3.76
Privet	232	1,719	1.1	0.1	1.85
Loblolly pine	3,355	24,849	1.1	1.2	27.04
Callery pear	1,498	11,092	1.1	0.5	12.38
Yoshino cherry	1,135	8,408	1.1	0.4	9.41
Water oak	7,119	52,721	1.0	2.5	59.64
Other street trees	58,757	435,139	24.9	21.0	20.51
Citywide total	280,512	2,077,393	100.0	100.0	24.40

Table 12*—Total annual increases in property value produced by street trees.*

Species	Total ($)	% of Total Tree Numbers	% of Total $	Avg. $/tree
Willow oak	1,036,267	16.7	37.6	72.73
Common crapemyrtle	39,252	14.1	1.4	3.27
Pear	128,841	7.6	4.7	20.03
Red maple	254,855	6.7	9.2	44.55
Flowering dogwood	27,058	5.4	1.0	5.94
Sugar maple	118,376	3.5	4.3	39.78
Plum	31,819	2.9	1.2	12.86
Eastern red cedar	13,022	2.4	0.5	6.29
Silver maple	106,010	2.4	3.8	51.94
Sweetgum	100,120	2.2	3.6	54.29
Shortleaf pine	31,401	1.3	1.1	27.64
Apple	5,886	1.2	0.2	5.78
American holly	1,760	1.1	0.1	1.81
Dogwood	5,134	1.1	0.2	5.39
Privet	1,420	1.1	0.1	1.53
Loblolly pine	33,165	1.1	1.2	36.09
Callery pear	18,271	1.1	0.7	20.39
Yoshino flowering cherry	14,032	1.1	0.5	15.70
Water oak	63,650	1.0	2.3	72.00
Other street trees	726,879	26.0	26.3	32.79
Citywide total	2,757,217	100.0	100.0	32.38

tion trees can intercept and hold to reduce runoff. Trees that perform well include willow oak ($74 per tree), water oak ($60 per tree), and silver maple ($34 per tree). Interception by willow oak alone accounts for 51% of the total dollar benefit for street trees. Poor performers are species with relatively little leaf and stem surface areas, such as privet and crapemyrtle.

Property Values and Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place, and well-being are products that are difficult to price (*Figure 11*). However, the value of some of these benefits may be captured in the property values of the land on which trees stand. To estimate the value of these "other" intangible benefits, research that compares differences in sales prices of houses was used to estimate the contribution associated with trees. The difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with trees. This approach has the virtue of capturing what buyers perceive as both the benefits and costs of trees in the sales price. One limitation of using this approach is the difficulty associated with extrapolating results from front-yard trees on residential properties to street trees in various locations (e.g., commercial vs. residential) (see Appendix B for more details).

The estimated total annual benefit associated with property value increases and other less tangible benefits is approximately $2.76 million, or $32 per tree on average (*Table 12*). Tree species that produce the highest average annual benefits include willow oak ($73 per tree), water oak ($72 per tree), and silver maple ($52), while small trees such as privet ($2 per tree) and American holly ($2 per tree) are examples of trees that produce the least

Figure 11—Trees add value to residential property.

benefits. Some species rank high due to their size and growth rates, but may not be desirable to plant for other reasons. For example, the city no longer plants silver maple due to its brittle wood and aggressive roots.

Total Annual Net Benefits and Benefit–Cost Ratio (BCR)

Total annual benefits produced by Charlotte's street trees are estimated at $5.9 million ($69 per tree, $10 per capita) (*Table 13*). Over the same period, tree-related expenditures are estimated to be $1.8 million ($21 per tree, $3 per capita). Net annual benefits (benefits minus costs) are $4.1 million, or $48 per tree and $7/capita. The Charlotte municipal forest currently returns $3.25 to the community for every $1 spent on management. Charlotte's benefit-cost ratio of 3.25 exceeds those reported for Glendale, AZ (2.41), Fort Collins, CO (2.18), Cheyenne, WY (2.09), Minneapolis, MN (1.57) and Berkeley, CA (1.37) (McPherson et al. 2005).

Charlotte's municipal trees have beneficial effects on the environment. More than half (53%) of the annual benefits provided to residents of the city are environmental services. Stormwater runoff reduction represents 65% of environmental benefits, with energy savings accounting for another 29%. Carbon dioxide reduction (6%) provides the remaining environmental benefits. The negative

Table 13—*Benefit–cost summary for all public trees.*

Benefits	Total ($)	$/tree	$/capita
Energy	914,000	10.73	1.53
CO_2	198,550	2.33	0.33
Air Quality	-36,270	-0.43	-0.06
Stormwater	2,077,393	24.40	3.48
Aesthetic/Other	2,757,216	32.38	4.62
Total Benefits	5,910,889	69.42	9.90
Costs			
Contract Pruning	380,000	4.46	0.64
Tree & Stump Removal	420,000	4.93	0.70
Pest Management	1,500	0.02	0.00
Irrigation	8,000	0.09	0.01
Purchasing Trees and Planting	180,000	2.11	0.30
Administration	117,960	1.39	0.20
Litter Clean-up	4,500	0.05	0.01
Infrastructure Repairs	637,500	7.49	1.07
Liability/Claim	70,000	0.82	0.12
Total Expenditures	1,819,460	21.37	3.05
Net Benefits	4,091,429	48.05	6.85
Benefit-cost ratio		3.25	

Table 14—Average annual benefits ($ per tree) of street trees by species.

Species	Energy	CO_2	Air quality	Stormwater	Aesthetic/other	Total $/tree	% of total $
Willow oak	23.56	5.21	-8.77	74.10	72.73	166.82	40.22
Crapemyrtle	2.38	0.27	0.73	2.02	3.27	8.67	1.76
Pear	9.07	1.94	3.30	11.52	20.03	45.85	4.99
Red maple	9.98	2.19	2.52	19.16	44.55	78.40	7.59
Dogwood	4.49	0.89	1.48	4.23	5.94	17.03	1.31
Sugar maple	12.11	2.26	3.11	18.13	39.78	75.38	3.80
Plum	5.75	0.76	1.71	6.06	12.86	27.13	1.14
Eastern red cedar	5.20	1.01	2.55	8.01	6.29	23.06	0.81
Silver maple	18.59	4.38	5.21	33.57	51.94	113.70	3.93
Sweetgum	12.73	2.38	-7.48	28.60	54.29	90.52	2.82
Shortleaf pine	13.01	2.80	4.68	24.12	27.64	72.24	1.39
Apple	6.00	1.30	1.83	4.39	5.78	19.31	0.33
American holly	2.28	0.39	1.13	2.32	1.81	7.93	0.13
Dogwood	4.05	0.77	1.33	3.76	5.39	15.30	0.25
Privet	1.92	0.31	0.94	1.85	1.53	6.56	0.10
Loblolly pine	11.05	2.49	-5.49	27.04	36.09	71.18	1.11
Callery pear	9.57	2.02	3.50	12.38	20.39	47.86	0.73
Yoshino cherry	8.66	1.18	2.76	9.41	15.70	37.71	0.57
Water oak	20.93	5.12	-7.23	59.64	72.00	150.47	2.25
Other street trees	9.78	2.33	0.66	20.51	32.79	66.08	23.72

effects of emitted BVOCs reduce overall environmental benefits by a mere 2%. Annual increases in property value are a substantial benefit, accounting for 47% of total annual benefits in Charlotte.

Table 14 shows the distribution of total annual benefits in dollars for the predominant street tree species in Charlotte. Willow oaks produce the greatest benefits among street trees ($167 per tree, 40% of total benefits). On a per tree basis, water oak ($150 per tree) and silver maple ($114 per tree) also produced significant benefits. Due to their large numbers, red maple ($79 per tree) provided 8% of the total benefits.

As trees grow larger their ability to provide environmental services and benefits increases dramatically. *Figure 12* shows the average annual benefits per tree for the different size classes. The ability of trees to capture and retain stormwater as their leaf area increases with tree size is particularly significant in Charlotte, as is the aesthetic benefit. Planning that provides adequate space for large species early in the development process is critical to making these potential benefits a reality.

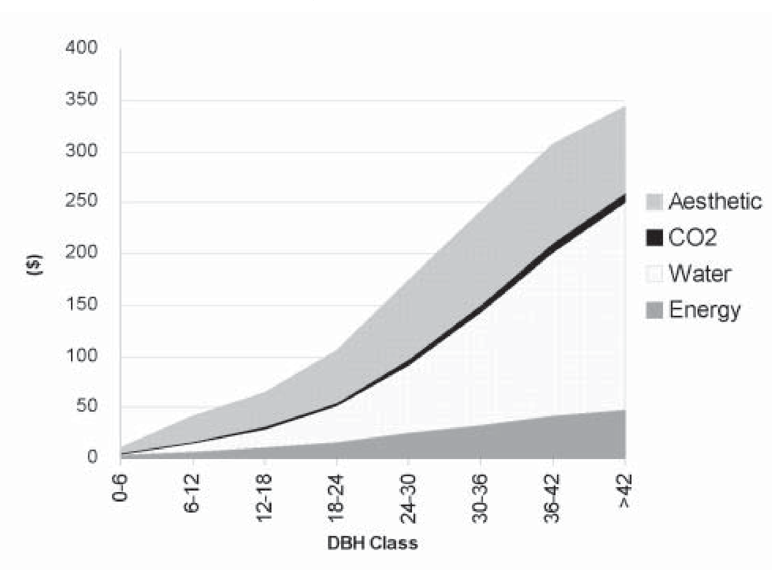

Figure 12—Average annual benefits by size class provided by street trees in Charlotte. Impacts on air quality (a slightly negative value) are not shown.

Chapter Five—Management Implications

Charlotte's urban forest reflects the values, lifestyles, preferences, and aspirations of current and past residents. It is a dynamic legacy whose character will change greatly over the next decades. Although this study provides a "snapshot" in time of the resource, it also serves as an opportunity to speculate about the future. Given the status of Charlotte's street tree population, what future trends are likely and what management challenges will need to be met to sustain this high level of benefits?

Focusing on three components—resource complexity, resource extent, and maintenance—will help refine broader municipal tree management goals. Achieving resource sustainability will produce long-term net benefits to the community while reducing the associated costs incurred in managing the resource.

Resource Complexity

Although Charlotte has a very rich mix of species with 215 species of street trees, willow oak is clearly the dominant species. It has an importance value of 38 and accounts for 40% of all benefits ($160 per tree). However, a disease or pest infestation that targeted this species could result in a severe loss to the city. For this reason, a more diverse mix of species should be planted: some proven performers, some species that are more narrowly adapted, and a small percentage of new introductions for evaluation. Proven performers include trees like the sugar maple (*Acer saccharum*) and loblolly pine (*Pinus taeda*). Species that merit planting and evaluation include hornbeam (*Carpinus* spp.), hickory (*Carya* spp.), Freeman maple (*Acer* x *freemanii*), Japanese zelkova (*Zelkova serrata*), and dawn redwood (*Metasequoia glyptostroboides*). Species that have performed relatively poorly include the flowering cherry (*Prunus yedoensis*) and apple (*Malus* spp.).

Figure 13 displays trees in the smallest DBH size classes, indicating trends in new and replacement trees. Crapemyrtle and dogwood are most common. The vastly disproportionate number of crapemyrtle trees in the smallest size classes is a cause for concern. These trees, because of their small size at maturity provide very little in the way of benefits to the city—only $8 per tree. Although they represent 14% of the population, they provide less than 2% of the total dollar value of benefits. At the time of the inventory, it appears that primarily three larger tree species were being planted and the percentage of these was very small. New plantings of red maple and willow oak (0–6 inch DBH class) represent less than 2% each of the total population; young sugar maples represent only 1.2% of all trees.

In recent years, the Landscape Management Division has increased the diversity of its large tree plantings with a number of oak species, including Shumard (*Quercus shumardii*), Nuttall (*Q. texana*) and overcup (*Q. lyrata*); baldcypress (*Taxodium distichum*; the 'Allee' elm cultivar (*Ulmus parvifolia* 'Allee'); and a fruitless cultivar of sweetgum (*Liquidambar styraciflua* 'Rotundifolia'). Several medium-stature maple cultivars, the 'Athena' elm (*Ulmus parvifolia* 'Athena'), 'Dura heat' river

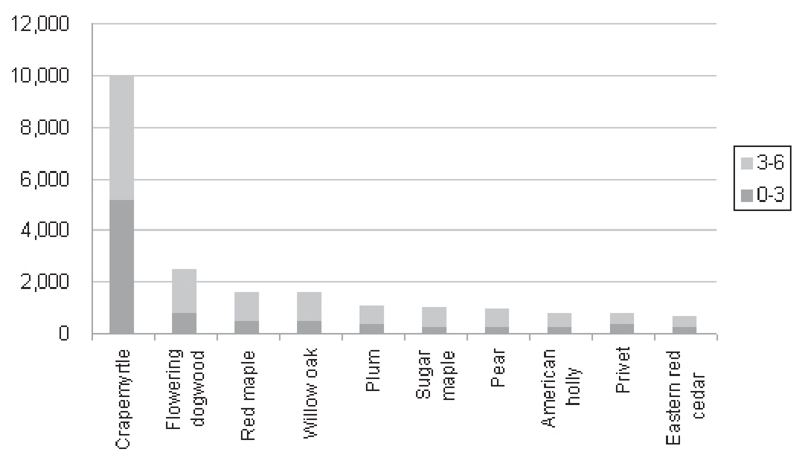

Figure 13—Municipal trees being planted in the highest numbers.

birch (*Betula nigra* ‘Dura heat’), and the Chinese pistache (*Pistacia chinensis*) also add diversity and stability to the urban forest.

Resource Extent

Canopy cover, or more precisely the amount and distribution of leaf surface area, is the driving force behind the urban forest’s ability to produce benefits for the community. As canopy cover increases, so do the benefits afforded by leaf area. Maximizing the return on this investment is contingent upon maximizing and maintaining the quality and extent of Charlotte’s canopy cover.

Increasing street tree canopy cover should be a goal for the city of Charlotte. Currently the stocking rate for street trees is only 23% and their canopy covers less than 1% of the city. These numbers are likely to decrease in the future as the large trees die. Theoretically, there is room along Charlotte’s streets for as many as 400,000 more trees, though restricted space, conflicts with other uses, and the presence of privately owned trees will reduce that number. To provide the greatest level of benefits in the future, sites for large trees should be planted first wherever possible, followed by those for medium and then small trees.

Increased tree planting in parking lots to provide shade and improve air quality is another strategy to increase tree canopy cover that could be applied to new and existing development. Similarly, Charlotte should review the adequacy of current ordinances to preserve and protect large trees from development impacts, and strengthen the ordinances as needed to retain benefits that these heritage trees can produce.

Maintenance

Charlotte’s maintenance challenge in the coming years will be to properly care for large trees as they age. Willow oak, sweetgum, and silver maple have a sizable proportion of their populations in the larger size classes. These mature trees are responsible for a relatively large proportion of current benefits. Therefore, regular inspection and pruning of these trees is essential to sustaining the current high level of benefits in the short term.

If Charlotte aggressively plants trees to increase stocking it will need to develop a strong young-tree-care program. Implementing a strong young-tree-care program is imperative to insure that the trees transition into well-structured, healthy mature trees requiring minimal pruning. Investing in the young-tree-care program will reduce costs for routine care as they mature. Also, well-trained trees are less likely to be damaged during storms than trees that have not developed a strong structure. Young trees should be pruned for structure and form every other year for the first six years after planting.

Reducing sidewalk and sewer line repair expenditures is a cost-savings strategy for Charlotte, which spends about $640,000 ($7.49 per tree) annually on infrastructure repairs. Most conflicts between tree roots and sidewalks occur where trees are located in cutouts and narrow planting strips less than 4-ft wide. Expanding cutouts, meandering sidewalks around trees, and not planting shallow-rooting species are strategies that may be cost-effective when functional benefits associated with increased longevity are considered (Costello and Jones 2003). Using structural soils under paving in commercial areas and parking lots encourages roots to grow down and away from the hardscape. Also, tree species with aggressive, fibrous roots should be avoided near sewer lines (e.g., silver maple, sweetgum, poplar, green ash).

Figure 14—Vegetation softens the stark edges of the Charlotte skyline.

Chapter Six—Conclusion

This analysis describes structural characteristics of the street tree population and uses tree growth and geographic data for Charlotte to model the ecosystem services trees provide the city and its residents. In addition, the benefit–cost ratio has been calculated and management needs are identified. The approach is based on established tree-sampling, numerical-modeling, and statistical methods and provides a general accounting of the benefits produced by street trees in Charlotte that can be used to make informed decisions.

Charlotte's 85,000 street trees are a valuable asset, providing approximately $5.6 million ($66 per tree) in annual gross benefits. Benefits to the community are most pronounced for stormwater reduction and aesthetic benefits. Thus, street trees play a particularly important role in maintaining the environmental and aesthetic qualities of the city (*Figure 14*).

Charlotte spends approximately $1.8 million maintaining its trees or $21 per tree. Expenditures for infrastructure repair account for about one-third of total costs.

After costs are taken into account, Charlotte's municipal tree resource provides approximately $3.8 million, or $45 per tree ($6/capita) in net annual benefits to the community. Over the years, Charlotte has invested millions of dollars in its municipal forest. **Citizens are seeing a return on that investment—receiving $3.25 in benefits for every $1 spent on tree care**. The fact that Charlotte's benefit-cost ratio of 3.25 exceeds ratios reported for other cities (2.41 in Glendale to 1.37 in Berkeley) indicates that the program is not only operationally efficient, but is capitalizing on the functional services its trees can produce. As the resource matures, continued investment in management is critical to insuring that residents will receive this level of return on investment in the future.

Charlotte's municipal trees are a dynamic resource. Managers of this resource and the community alike can take pride in knowing that street trees do improve the quality of life in the city. However, the city's trees are also a fragile resource that needs constant care to maximize and sustain production of benefits into the future. The challenge will be to sustain the city's canopy cover as the population structure changes and the city continues to grow, putting demand for land at a premium.

Management recommendations derived from this analysis are sevenfold:

1) Increase stocking by planting large species where space permits to maximize environmental and other benefits.

2) Continue to plant a broad mix of species to guard against catastrophic losses due to pests, disease, and storm events.

3) Sustain benefits by investing in intensive maintenance of mature trees (e.g., willow oak, sweetgum, silver maple) to prolong their functional lifespans.

4) Develop a strong young-tree care program that includes regular watering, staking adjustment, and inspection and pruning on at least a four-year cycle.

5) Evaluate and test strategies to prevent and mitigate infrastructure repair costs associated with tree root damage.

6) Insure adequate space for trees in new developments. Encourage the use of structural soils when appropriate.

7) Review and revise parking lot shade guidelines and the adequacy of current ordinances to preserve and protect large trees from development impacts to promote tree canopy cover and associated benefits.

These recommendations build on a history of dedicated management that has put Charlotte on course to provide an urban forest resource that is both functional and sustainable.

Appendix A—Tree Distribution

Table A1—*Tree numbers by size class (DBH in inches) for all street and park trees.*

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Broadleaf deciduous large (BDL)										
Quercus phellos	458	1,127	2,514	2,397	1,656	1,902	2,124	1,262	809	14,249
Acer x freemanii	4	118	103	6	3	-	-	-	-	234
Acer macrophyllum	-	-	1	1	-	-	-	-	-	2
Acer nigrum	-	-	1	-	-	-	-	-	-	1
Acer platanoides	7	24	35	6	2	1	-	-	-	75
Acer saccharinum	54	128	549	634	406	189	59	16	6	2,041
Acer saccharum	243	768	1,134	569	190	58	11	-	3	2,976
Aesculus octandra	1	1	-	-	-	-	-	-	-	2
Aesculus glabra	-	-	-	1	-	-	-	-	-	1
Aesculus hippocastanum	-	-	-	-	-	-	1	-	-	1
Ailanthus altissima	8	12	15	7	2	1	-	-	-	45
Carya spp	14	19	48	47	13	10	3	1	-	155
Carya cordiformis	-	1	1	-	-	-	-	-	-	2
Castanea dentata	-	1	2	1	1	-	-	-	-	5
Carya glabra	-	5	10	23	5	1	-	-	-	44
Carya illinoiensis	35	58	144	138	69	16	3	-	-	463
Carya ovata	-	1	9	15	1	-	-	-	-	26
Carya tomentosa	3	1	4	3	2	3	-	-	-	16
Celtis occidentalis	33	56	87	92	30	6	2	-	1	307
Fagus grandifolia	8	18	18	5	13	3	-	3	1	69
Fraxinus americana	11	72	56	35	11	7	3	3	-	198
Fraxinus pennsylvanica	42	149	235	130	74	36	18	11	1	696
Fraxinus quadrangulata	-	-	1	-	-	-	-	-	-	1
Gleditsia triacanthos	1	5	14	4	1	-	-	-	-	25
Gymnocladus dioicus	-	-	3	1	-	-	-	-	-	4
Juglans nigra	19	21	72	44	16	6	2	-	-	180
Larix decidua	2	-	-	1	-	-	-	-	-	3
Liquidambar styraciflua	165	175	454	495	334	155	51	11	4	1,844
Liriodendron tulipifera	19	25	89	193	150	84	83	32	36	711
Magnolia acuminata	-	-	2	-	-	-	-	-	-	2
Metasequoia glyptostroboides	-	-	7	8	5	-	-	-	-	20
Platanus acerifolia	5	46	442	60	22	17	4	2	-	598
Platanus occidentalis	-	11	34	63	35	17	9	2	1	172
Populus alba	-	2	7	10	4	7	5	3	2	40
Populus balsamifera	-	4	20	2	-	1	-	-	-	27
Populus deltoides	-	3	11	27	17	6	3	1	1	69
Prunus serotina	41	150	300	124	43	3	1	-	-	662
Quercus alba	40	61	96	157	165	141	74	24	16	774
Quercus bicolor	-	1	3	1	2	-	-	1	-	8
Quercus coccinea	2	6	23	49	25	14	7	2	2	130
Quercus ellipsoidalis	1	-	-	10	13	5	-	-	-	29
Quercus falcata	13	17	59	87	96	74	59	21	18	444

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Quercus imbricaria	-	3	8	1	4	1	6	-	2	25
Quercus macrocarpa	1	8	6	11	3	8	3	1	1	42
Quercus michauxii	1	-	-	-	1	-	-	-	-	2
Quercus nigra	30	83	180	201	121	105	88	49	27	884
Quercus palustris	28	70	40	58	17	12	2	-	-	227
Quercus rubra	40	82	260	227	55	37	30	14	5	750
Quercus shumardii	8	75	112	60	20	4	3	-	-	282
Quercus stellata	2	7	13	32	16	9	5	-	-	84
Quercus velutina	-	3	7	15	10	8	3	1	1	48
Taxodium distichum	4	28	64	20	3	1	1	-	-	121
Tilia americana	-	-	2	4	-	-	-	-	-	6
Ulmus alata	43	77	127	34	9	3	1	-	-	294
Ulmus americana	35	34	100	170	107	33	18	3	2	502
Ulmus pumila	13	39	127	94	38	15	5	-	-	331
Ulmus spp	28	22	58	28	13	9	1	-	1	160
Zelkova serrata	69	237	295	60	5	1	-	-	-	667
Total	1,531	3,854	8,002	6,461	3,828	3,009	2,688	1,463	940	31,776
Broadleaf deciduous medium (BDM)										
Acer rubrum	483	1,140	2,512	1,057	330	161	32	2	4	5,721
Unknown	113	301	267	192	52	31	10	1	-	967
Betula nigra	33	181	372	102	26	12	3	2	-	731
Ulmus parvifolia	67	205	155	34	19	-	3	-	-	483
Quercus acutissima	2	38	94	154	65	12	-	-	-	365
Carpinus caroliniana	64	130	104	9	1	-	-	-	-	308
Magnolia spp	106	85	26	8	3	-	-	1	-	229
Ginkgo biloba	50	60	50	15	2	2	1	-	-	180
Morus spp	39	44	38	20	5	1	-	-	-	147
Acer campestre	14	69	61	1	-	-	-	-	-	145
Diospyros virginiana	9	28	53	26	10	1	1	-	-	128
Ostrya virginiana	37	66	19	-	-	-	-	-	-	122
Acer negundo	15	11	32	38	12	5	4	-	-	117
Carpinus betulus	10	42	17	-	-	-	-	-	-	69
Nyssa sylvatica	10	14	20	13	6	2	-	-	-	65
Robinia pseudoacacia	8	15	28	7	-	-	-	-	-	58
Sassafras albidum	13	11	17	3	1	1	-	1	-	47
Populus nigra	1	3	16	14	5	1	2	1	-	43
Salix spp	11	13	15	1	2	-	-	-	-	42
Catalpa speciosa	3	13	17	5	-	1	1	-	-	40
Melia azedarach	1	8	12	6	4	2	-	-	-	33
Paulownia tomentosa	2	9	3	4	3	2	-	-	-	23
Betula papyrifera	4	9	6	-	-	-	-	-	-	19
Betula platyphylla	10	5	1	1	-	-	-	-	-	17
Betula utilis	13	1	2	-	-	-	-	-	-	16
Firmiana platanifolia	2	6	4	-	-	-	-	-	-	12
Quercus marilandica	2	2	-	2	3	2	1	-	-	12
Ulmus rubra	-	-	3	2	-	5	2	-	-	12

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Broussonetia papyrifera	1	1	3	2	-	-	-	-	-	7
Quercus lyrata	4	-	-	2	-	-	1	-	-	7
Fraxinus nigra	1	1	3	-	1	-	-	-	-	6
Sophora japonica	-	2	1	2	1	-	-	-	-	6
Cladrastis kentukea	-	-	2	3	-	-	-	-	-	5
Salix nigra	-	4	-	-	1	-	-	-	-	5
Castanea mollissima	-	-	1	3	-	-	-	-	-	4
Tilia cordata	-	1	2	1	-	-	-	-	-	4
Halesia carolina	1	2	-	-	-	-	-	-	-	3
Maclura pomifera	-	-	1	2	-	-	-	-	-	3
Prunus padus	-	1	1	1	-	-	-	-	-	3
Betula lenta	-	-	-	1	1	-	-	-	-	2
Betula pendula	1	-	1	-	-	-	-	-	-	2
Juglans regia	-	-	-	2	-	-	-	-	-	2
Phellodendron amurense	-	-	-	1	-	-	-	-	-	1
Pistacia chinensis	-	-	1	-	-	-	-	-	-	1
Quercus muehlenbergii	1	-	-	-	-	-	-	-	-	1
Salix matsudana	1	-	-	-	-	-	-	-	-	1
Total	1,132	2,521	3,960	1,734	553	241	61	8	4	10,214
Broadleaf deciduous small (BDS)										
Lagerstroemia spp	5,154	4,813	1,569	326	104	26	5	1	2	12,000
Pyrus spp	251	695	3,044	2,251	172	17	2	1	-	6,433
Cornus florida	784	1,702	1,830	213	21	1	1	3	2	4,557
Prunus spp	381	689	952	363	78	10	1	-	-	2,474
Malus spp	109	378	433	85	10	2	-	-	1	1,018
Cornus species	289	346	247	65	5	-	-	-	-	952
Pyrus calleryana	27	196	250	384	39	-	-	-	-	896
Prunus yedoensis	38	148	375	247	60	18	7	1	-	894
Cercis canadensis	131	189	266	62	9	3	2	-	-	662
Prunus serrulata	10	58	153	79	11	-	2	-	-	313
Acer palmatum	151	93	55	6	-	-	-	-	-	305
Albizia julibrissin	73	56	53	18	4	1	1	-	-	206
Hibiscus syriacus	86	40	12	3	-	-	-	-	-	141
Amelanchier spp	31	70	6	-	-	-	-	-	-	107
Acer buergeranum	9	66	13	3	1	-	1	-	-	93
Magnolia x soulangiana	14	36	13	8	-	1	-	-	-	72
Cornus kousa	20	30	4	-	-	-	-	-	-	54
Crataegus spp	6	8	19	6	-	-	-	-	-	39
Prunus campanulata	-	39	-	-	-	-	-	-	-	39
Prunus subhirtella	11	14	8	3	1	-	-	-	-	37
Acer ginnala	8	6	11	1	-	-	-	-	-	26
Koelreuteria paniculata	4	2	5	4	2	-	-	-	-	17
Prunus persica	5	7	3	-	-	-	-	-	-	15
Aesculus pavia	2	-	6	5	1	-	-	-	-	14
Prunus cerasifera	4	4	4	1	1	-	-	-	-	14
Acer truncatum	-	10	3	-	-	-	-	-	-	13

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Malus sylvestris	1	5	6	1	-	-	-	-	-	13
Crataegus phaenopyrum	1	11	-	-	-	-	-	-	-	12
Viburnum spp	6	2	1	2	-	-	-	-	-	11
Amelanchier arborea	6	4	-	-	-	-	-	-	-	10
Prunus tomentosa	1	4	2	-	-	-	-	-	-	7
Chionanthus retusus	-	3	3	-	-	-	-	-	-	6
Cornus alternifolia	5	1	-	-	-	-	-	-	-	6
Cotinus coggygria	1	1	3	-	-	-	-	-	-	5
Syringa spp	2	1	1	-	-	-	-	-	-	4
Buddleja davidii	2	1	-	-	-	-	-	-	-	3
Crataegus viridis	-	1	-	1	1	-	-	-	-	3
Salix gracilistyla	2	1	-	-	-	-	-	-	-	3
Vitex agnus-castus	1	2	-	-	-	-	-	-	-	3
Clerodendrun trichotomum	-	2	-	-	-	-	-	-	-	2
Ficus carica	-	2	-	-	-	-	-	-	-	2
Forsythia species	2	-	-	-	-	-	-	-	-	2
Hamamelis virginiana	2	-	-	-	-	-	-	-	-	2
Rhus spp	1	1	-	-	-	-	-	-	-	2
Sorbus aucuparia	1	-	-	-	1	-	-	-	-	2
Sapium sebiferum	-	-	1	1	-	-	-	-	-	2
Asimina triloba	-	1	-	-	-	-	-	-	-	1
Chionanthus virginicus	-	1	-	-	-	-	-	-	-	1
Cornus mas	-	-	-	1	-	-	-	-	-	1
Malus tschonoskii	-	-	-	1	-	-	-	-	-	1
Rhamnus spp	-	-	1	-	-	-	-	-	-	1
Rosa banksiae	1	-	-	-	-	-	-	-	-	1
Viburnum prunifolium	-	1	-	-	-	-	-	-	-	1
Total	7,633	9,740	9,352	4,140	521	79	22	6	5	31,498
Broadleaf evergreen large (BEL)										
Quercus virginiana	1	7	13	22	15	5	6	1	1	71
Eucalyptus spp	11	3	1	-	-	-	-	-	-	15
Total	12	10	14	22	15	5	6	1	1	86
Broadleaf evergreen medium (BEM)										
Magnolia grandiflora	62	137	304	181	45	12	9	4	-	754
Quercus hemisphaerica	-	-	-	1	-	-	-	-	-	1
Total	62	137	304	182	45	12	9	4	-	755
Broadleaf evergreen small (BES)										
Ilex opaca	229	531	165	40	7	1	-	-	-	973
Ligustrum spp	327	425	155	15	4	1	1	-	-	928
Photinia spp	173	359	108	4	1	1	-	-	-	646
Ilex spp	154	318	135	16	2	-	-	1	-	626
Ilex cornuta	1	14	54	65	-	1	1	-	-	136
Photinia x fraseri	1	32	36	12	2	1	-	-	-	84
Prunus caroliniana	7	19	25	8	3	-	1	-	-	63
Myrica cerifera	6	9	14	7	-	-	-	-	-	36

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Pyracantha spp	18	6	-	-	-	-	-	-	-	24
Ilex cassine	-	16	3	-	-	-	-	-	-	19
Camellia japonica	5	1	1	-	-	-	-	-	-	7
Ilex aquifolium	-	2	2	-	-	-	-	-	-	4
Pyracantha koidzumii	2	-	-	-	-	-	-	-	-	2
Acacia baileyana	1	-	-	-	-	-	-	-	-	1
Aucuba spp	1	-	-	-	-	-	-	-	-	1
Buxus spp	1	-	-	-	-	-	-	-	-	1
Elaeagnus umbellata	-	1	-	-	-	-	-	-	-	1
Mahonia bealei	1	-	-	-	-	-	-	-	-	1
Total	927	1,733	698	167	19	5	3	1	-	3,553
Conifer evergreen large (CEL)										
Pinus echinata	14	41	263	583	206	26	3	-	-	1,136
Pinus taeda	54	86	196	342	180	51	10	-	-	919
Pinus strobus	9	36	229	266	127	40	7	1	-	715
Pinus spp	19	34	127	227	95	26	4	-	-	532
x Cupressocyparis leylandii	37	124	47	6	2	-	-	1	-	217
Pinus palustris	5	4	14	52	47	12	5	-	-	139
Cedrus deodara	5	6	3	15	14	9	10	3	1	66
Picea abies	7	17	20	12	3	1	-	-	-	60
Cryptomeria japonica	38	7	11	1	-	-	-	-	-	57
Celtis laevigata	-	3	17	24	5	-	3	-	-	52
Abies spp	2	2	2	-	-	-	-	-	-	6
Pinus resinosa	-	2	-	1	1	-	-	-	-	4
Araucaria araucana	-	-	-	3	-	-	-	-	-	3
Cunninghamia lanceolata	1	-	1	1	-	-	-	-	-	3
Total	191	362	930	1,533	680	165	42	5	1	3,909
Conifer evergreen medium (CEM)										
Juniperus virginiana	221	442	774	467	131	29	5	-	-	2,069
Thuja occidentalis	266	293	163	19	-	-	-	-	-	741
Chamaecyparis thyoides	29	48	64	9	3	-	-	-	-	153
Juniperus spp	20	38	37	11	-	-	-	-	-	106
Tsuga canadensis	19	23	38	9	4	1	-	-	-	94
Pinus sylvestris	5	5	18	18	2	-	-	-	-	48
Pinus nigra	1	3	18	12	-	-	-	-	-	34
Pinus virginiana	3	2	14	6	2	-	-	-	-	27
Picea pungens	12	7	2	1	-	-	-	-	-	22
Cedrus atlantica	6	1	6	1	4	1	1	-	-	20
Picea spp	2	3	2	-	-	-	-	-	-	7
Picea glauca	3	1	2	-	-	-	-	-	-	6
Total	587	866	1,138	553	146	31	6	-	-	3,327

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Conifer evergreen small (CES)										
Pinus mugo	1	1	3	-	-	-	-	-	-	5
Torreya taxifolia	-	1	1	1	1	1	-	-	-	5
Chamaecyparis pisifera	-	-	-	-	1	1	-	1	-	3
Pinus contorta var. *bolanderi*	-	1	1	-	-	-	-	-	-	2
Total	1	3	5	1	2	2	-	1	-	15
Palm evergreen medium (PEM)										
Sabal palmetto	-	-	1	-	-	-	-	-	-	1
Total	-	-	1	-	-	-	-	-	-	1
Palm evergreen small (PES)										
Serenoa repens	-	3	7	-	-	-	-	-	-	10
Washingtonia filifera	-	-	1	-	-	-	-	-	-	1
Yucca spp	-	-	1	-	-	-	-	-	-	1
Total	-	3	9	-	-	-	-	-	-	12
Citywide Total	12,076	19,229	24,413	14,793	5,809	3,549	2,837	1,489	951	85,146

Appendix B—Methodology and Procedures

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information:

1. Resource structure (species composition, diversity, age distribution, condition, etc.)
2. Resource function (magnitude of environmental and aesthetic benefits)
3. Resource value (dollar value of benefits realized)
4. Resource management needs (sustainability, pruning, planting, and conflict mitigation)

This Appendix describes street tree sampling, tree growth modeling, and the model inputs and calculations used to derive the aforementioned outputs.

Growth Modeling

A stratified random sample of street trees, drawn from Charlotte's municipal tree database, was inventoried to establish relations between tree age, size, leaf area and biomass; subsequently, estimates for determining the magnitude of annual benefits in relation to predicted tree size were derived. The sample was composed of the 21 most abundant species; from these data, growth of all street trees was inferred.

To obtain information spanning the life cycle of predominant tree species, the inventory was stratified into nine DBH classes:

- 0–3 in (0–7.62 cm)
- 3–6 in (7.62–15.24 cm)
- 6–12 in (15.24–30.48 cm
- 12–18 in (30.48–45.72 cm)
- 18–24 in (45.72–60.96 cm)
- 24–30 in (60.96–76.2 cm)
- 30–36 in (76.2–91.44)
- 36–42 in (91.44–106.68 cm)
- >42 in (>106.68 cm)

Thirty to 50 randomly selected trees of each species were selected to survey, along with an equal number of alternative trees. Tree measurements included DBH (to nearest 0.1 cm by sonar measuring device), tree crown and crown base (to nearest 0.5 m by altimeter), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5 m by sonar measuring device), tree condition and location. Replacement trees were sampled when trees from the original sample population could not be located. Tree age was determined by street tree managers. Fieldwork was conducted in August 2004.

Crown volume and leaf area were estimated from computer processing of tree crown images obtained using a digital camera. The method has shown greater accuracy than other techniques (±25% of actual leaf area) in estimating crown volume and leaf area of open-grown trees (Peper and McPherson 2003).

Linear regression was used to fit predictive models—with DBH as a function of age—for each of the 21 sampled species. Predictions of leaf surface area (LSA), crown diameter, and height metrics were modeled as a function of DBH using best-fit models (Peper et al. 2001).

Identifying and Calculating Benefits

Annual benefits for Charlotte's municipal trees were estimated for the fiscal year 2004. Growth rate modeling information was used to perform computer-simulated growth of the existing tree population for one year and account for the associated annual benefits. This "snapshot" analysis assumed that no trees were added to, or removed from, the existing population during the year. (Calculations of CO_2 released due to decomposition of wood from removed trees did consider average annual mortality.) This approach directly connects benefits with tree-size variables such as DBH and LSA. Many functional benefits of trees are related to processes that involve interactions between leaves and the atmosphere (e.g., interception, transpiration, photosynthesis); therefore, benefits increase as tree canopy cover and leaf surface area increase.

For each of the modeled benefits, an annual resource unit was determined on a per-tree basis. Resource units are measured as MWh of electricity saved per tree; MBtu of natural gas conserved per tree; lbs of atmospheric CO_2 reduced per tree; lbs of NO_2, PM_{10}, and VOCs reduced per tree; cubic feet of stormwater runoff reduced per tree; and square feet of leaf area added per tree to increase property values.

Prices were assigned to each resource unit (e.g., heating/cooling energy savings, air-pollution absorption, stormwater-runoff reduction) using economic indicators of society's willingness to pay for the environmental benefits trees provide. Estimates of benefits are initial approximations as some benefits are difficult to quantify (e.g., impacts on psychological health, crime, and violence). In addition, limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Therefore, this method of quantification provides first-order approximations. It is meant to be a general accounting of the benefits produced by urban trees—an accounting with an accepted degree of uncertainty that can, nonetheless, provide a science-based platform for decision-making.

Energy Savings

Buildings and paving, along with little tree canopy cover and soil cover, increase the ambient temperatures within a city. Research shows that even in temperate climate zones temperatures in urban centers are steadily increasing by approximately 0.5°F per decade. Winter benefits of this warming do not compensate for the detrimental effects of increased summertime temperatures. Because the electricity demand of cities increases about 1–2% per 1°F increase in temperature, approximately 3–8% of the current electric demand for cooling is used to compensate for this urban heat island effect (Akbari et al. 1992).

Warmer temperatures in cities have other implications. Increases in CO_2 emissions from fossil-fuel power plants, increased municipal water demand, unhealthy ozone levels, and human discomfort and disease are all symptoms associated with urban heat islands. In Charlotte, there are opportunities to ameliorate the problems associated with hardscape through strategic tree planting and stewardship of existing trees thereby creating street and park landscapes that reduce stormwater runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits.

For individual buildings, street trees can increase energy efficiency in summer and increase or decrease energy efficiency in winter, depending on their location. During the summer, the sun is low in the eastern and western sky for several hours each day. Tree shade to protect east—and especially west—walls helps keep buildings cool. In the winter, allowing the sun to strike the southern side of buildings can warm interior spaces.

Trees reduce air movement into buildings and conductive heat loss from buildings. The rates at which outside air moves into a building can increase substantially with wind speed. In cold, windy weather, the entire volume of air, even in newer or tightly sealed homes, may change every two to three hours. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed reduces heat transfer through conductive materials as well. Cool winter winds, blowing against single-pane windows, can contribute significantly to the heating load of homes and buildings

Calculating Electricity and Natural Gas Benefits

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate, and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per-tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950-1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same floor area, and other construction characteristics. Shading effects for each of the 21 tree species were simulated at three tree-to-building distances, for eight orientations and for nine tree sizes.

The shading coefficients of the trees in leaf (gaps in the crown as a percentage of total crown silhouette) were estimated using a photographic method that has been shown to produce good estimates (Wilkinson 1991). Crown areas were obtained using the method of Peper and McPherson (2003) from digital photographs of trees from which background features were digitally removed. Values for tree species that were not sampled, and leaf-off values for use in calculating winter shade, were based on published values where available (McPherson 1984; Hammond et al. 1980). Where published values were not available, visual densities were assigned based on taxonomic considerations (trees of the same genus were assigned the same value) or observed similarity to known species. Foliation periods for deciduous trees were obtained from the literature (McPherson 1984; Hammond et al.1980) and adjusted for Charlotte's climate based on consultation with forestry supervisors (Hartel 2005).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to Charlotte (i.e., frequency of trees located at different distances from buildings [setbacks] and tree orientation with respect to buildings). Setbacks were assigned to four distance classes: 0–20 ft, 20–40 ft, 40–60 ft and >60 ft. It was assumed that street trees within 60 ft of buildings provided direct shade on walls and windows. Savings per tree at each location were multiplied by tree distribution to determine location-weighted savings per tree for each species and DBH class, independent of location. Location-weighted savings per tree were multiplied by the number of trees of each species and DBH class and then summed to find total savings for the city. Tree locations were based on the stratified random sample conducted in summer 2004.

Land use (single-family residential, multifamily residential, commercial/industrial, other) for right-of-way trees was based on the same tree sample. Park trees were distributed according to the predominant land use surrounding each park. A constant tree distribution was used for all land uses.

Three prototype buildings were used in the simulations to represent pre-1950, 1950–1980, and post-1980 construction practices (Ritschard et al. 1992). Building footprints were modeled as square, which was found to be reflective of average impacts for a large number of buildings (Simpson 2002). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37%, and were assumed to be closed when the air conditioner was operating. Thermostat settings were 78°F for cooling and 68°F for heating, with a 60°F night setback in winter. Unit energy consumptions were adjusted to account for equipment saturations (percentage of structures with different types of heating and cooling equipment such as central air conditioners, room air conditioners, and evaporative coolers) (*Table B1*).

Weather data for a typical meteorological year (TMY2) from Charlotte were used (Renewable Resource Data Center 2005). Dollar values for energy savings were based on electricity and natural gas prices of $0.0759/kWh and $1.046/therm, respectively (Duke Power Company 2005 and Piedmont Natural Gas 2004).

Table B1—Saturation adjustments for cooling (%).

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Instit./ Trans-porta-tion
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
								Cooling equipment factors										
Central air/ heat pump	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Evaporative cooler	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Wall/window unit	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
								Cooling saturations										
Central air/ heat pump	15	40	76	15	40	76	15	40	76	15	40	76	15	40	76	86	86	86
Evaporative cooler	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wall/window unit	36	23	14	36	23	14	36	23	14	36	23	14	36	23	14	9	9	9
None	48	37	10	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
Adjusted cooling saturation	24	46	80	24	46	80	24	46	80	24	46	80	24	46	80	88	88	88

Single-Family Residence Adjustments

Unit energy consumptions for simulated single-family residences were adjusted for type and saturation of heating and cooling equipment, and for various factors (F) that modified the effects of shade and climate on heating and cooling loads:

$$\Delta UEC_x = \Delta UEC^{sh}_{SFD} \times F^{sh} + \Delta UEC^{cl}_{SFD} \times F^{cl}$$ *Equation 1*

where

$F^{sh} = F_{equipment} \times APSF \times F_{adjacent\ shade} \times F_{multiple\ tree}$

$F^{cl} = F_{equipment} \times PCF$

$F_{equipment} = Sat_{CAC} + Sat_{window} \times 0.25 + Sat_{evap} \times$ (0.33 for cooling and 1.0 for heating).

Changes in energy use for higher density residential and commercial structures were calculated from single-family residential results adjusted by average potential shade factors (APSF) and potential climate factors (PCF); values were set to 1.0 for single family residential buildings.

Total change in energy use for a particular land use was found by multiplying the change in UEC per tree by the number of trees (*N*):

$$\text{Total change} = N \times \Delta UEC_x$$ *Equation 2*

Subscript *x* refers to residential structures with 1, 2–4 or ≥5 units, SFD to simulated single-family detached structures, sh to shade, and cl to climate effects.

Estimated shade savings for all residential structures were adjusted to account for shading of neighboring buildings and for overlapping shade from trees adjacent to one another. Homes adjacent to those with shade trees may benefit from the trees on the neighboring properties. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an additional estimated energy savings equal to 15% of that found for program participants; this value was used here ($F_{adjacent\ shade}$ = 1.15). In addition, shade from multiple trees may overlap, resulting in less building shade from an added tree than would result if there were no existing trees. Simpson (2002) estimated that the fractional reductions in average cooling and heating energy use were approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5–3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% was used here, equivalent to approximately three existing trees per residence.

In addition to localized shade effects, which were assumed to accrue only to street trees within 18–60 ft of buildings, lowered air temperatures and wind speeds due to neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for summer cooling and winter heating. Reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances. To estimate climate effects on energy use, air-temperature and wind-speed reductions as a function of neighborhood canopy cover were estimated from published values following McPherson and Simpson (1999), then used as input for the building-energy-use simulations described earlier. Peak summer air temperatures were assumed to be reduced by 0.2°F for each percentage increase in canopy cover. Wind speed reductions were based on the change in total tree plus building canopy cover resulting from the addition of the particular tree being simulated (Heisler 1990). A lot size of 10,000 ft^2 was assumed.

Cooling and heating effects were reduced based on the type and saturation of air conditioning (*Table B1*) or heating (*Table B2*) equipment by vintage. Equipment factors of 33 and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (*Table B3*). Heating loads were converted to

Table B2*—Saturation adjustments for heating (%, except AFUE [fraction] and HSPF [kBtu/kWh).*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**Small**	**Large**	
Equipment efficiencies																		
AFUE	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.78	0.78	0.78
HSPF	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	8	8	8
HSPF	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412
Electric heat saturations																		
Electric resistance	2.8	6.0	8.9	2.8	6.0	8.9	2.8	6.0	8.9	2.8	6.0	8.9	2.8	6.0	8.9	4.9	4.9	4.9
Heat pump	6.3	13.3	19.7	6.3	13.3	19.7	6.3	13.3	19.7	6.3	13.3	19.7	6.3	13.3	19.7	5.4	5.4	5.4
Adjusted electric heat saturations	1.7	3.7	5.4	1.7	3.7	5.4	1.7	3.7	5.4	1.7	3.7	5.4	1.7	3.7	5.4	1.7	1.7	1.7
Natural gas and other heating saturations																		
Natural gas	69.7	61.3	52.4	69.7	61.3	52.4	69.7	61.3	52.4	69.7	61.3	52.4	69.7	61.3	52.4	89.7	89.7	89.7
Oil	7.6	1.6	2.4	7.6	1.6	2.4	7.6	1.6	2.4	7.6	1.6	2.4	7.6	1.6	2.4	0	0	0
Other	13.6	17.7	16.7	13.6	17.7	16.7	13.6	17.7	16.7	13.6	17.7	16.7	13.6	17.7	16.7	0	0	0
NG heat saturations	91	81	71	91	81	71	91	81	71	91	81	71	91	81	71	90	90	90

Table B3—Building vintage distribution and combined vintage/saturation factors for heating and air conditioning.

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Vintage distribution by building type	13	36	50	13	36	50	13	36	50	13	36	50	13	36	50	100	100	100
Tree distribution by vintage and building type	8.89	24.05	33.35	1.15	3.12	4.32	1.28	3.47	4.82	0.11	0.30	0.41	0.35	0.96	1.33	3.9	2.3	3.7
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	2.11	10.81	26.00	0.27	1.40	3.37	0.27	1.37	3.30	0.02	0.10	0.24	0.03	0.18	0.42	1.2	0.4	0.0
Cooling factor: climate	2.16	11.06	26.60	0.24	1.25	3.00	0.20	1.03	2.49	0.02	0.08	0.19	0.04	0.21	0.50	2.4	4.7	0.0
Combined vintage, equipment saturation for heating																		
Heating factor, natural gas: shade	7.90	18.96	23.29	1.02	2.46	3.02	1.00	2.41	2.96	0.07	0.17	0.21	0.13	0.31	0.38	1.2	0.4	0.0
Heating factor, electric: shade	0.15	0.88	1.75	0.02	0.11	0.23	0.02	0.11	0.22	0.00	0.01	0.02	0.00	0.01	0.03	0.02	0.01	0.00
Heating factor, natural gas: climate	8.08	19.40	23.82	0.58	1.40	1.72	0.83	2.00	2.46	0.06	0.13	0.16	0.12	0.28	0.34	4.0	7.8	0.0
Heating factor, electric: climate	0.15	0.90	1.79	0.01	0.06	0.13	0.02	0.09	0.18	0.00	0.01	0.01	0.00	0.01	0.03	0.08	0.15	0.0

fuel use based on efficiencies in *Table B2*. The "other" and "fuel oil" heating equipment types were assumed to be natural gas for the purpose of this analysis. Building vintage distributions were combined with adjusted saturations to compute combined vintage/saturation factors for natural gas and electric heating (*Table B3*).

Multi-Family Residence Analysis

Unit energy consumptions (UECs) from single-family residential UECs were adjusted for multi-family residences (MFRs) to account for reduced shade resulting from common walls and multi-story construction. To do this, potential shade factors (PSFs) were calculated as ratios of exposed wall or roof (ceiling) surface area to total surface area, where total surface area includes common walls and ceilings between attached units in addition to exposed surfaces (Simpson 1998). A PSF of 1 indicates that all exterior walls and roof are exposed and could be shaded by a tree, while a PSF of 0 indicates that no shading is possible (i.e., the common wall between duplex units). Potential shade factors were estimated separately for walls and roofs for both single- and multi-story structures. Average potential shade factors were 0.74 for multi-family residences of 2–4 units and 0.41 for ≥5 units.

Unit energy consumptions were also adjusted to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes. Since estimates for these PCFs were unavailable for multi-family structures, a multi-family PCF value of 0.80 was selected (less than single-family detached PCF of 1.0 and greater than small commercial PCF of 0.40; see next section).

Commercial and Other Buildings

Reductions in unit energy consumptions for commercial/industrial (C/I) and industrial/transportation (I/T) land uses due to presence of trees were determined in a manner similar to that used for multi-family land uses. Potential shade factors of 0.40 were assumed for small C/I, and 0.0 for large C/I. No energy impacts were ascribed to large C/I structures since they are expected to have surface-to-volume ratios an order of magnitude larger than smaller buildings and less extensive window area. Average potential shade factors for I/T structures were estimated to lie between these extremes; a value of 0.15 was used here. However, data relating I/T land use to building-space conditioning were not readily available, so no energy impacts were ascribed to I/T structures. A multiple tree reduction factor of 0.85 was used, and no benefit was assigned for shading of buildings on adjacent lots.

Potential climate-effect factors of 0.40, 0.25 and 0.20 were used for small C/I, large C/I, and I/T, respectively. These values are based on estimates by Akbari (1992) and others who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

The beneficial effects of shade on UECs tend to increase with conditioned floor area (CFA) for typical residential structures. As building surface area increases so does the area shaded. This occurs up to a certain point because the projected crown area of a mature tree (approximately 700–3,500 ft^2) is often larger than the building surface areas being shaded. A point is reached, however, at which no additional area is shaded as surface area increases. At this point, ΔUECs will tend to level off as CFA increases. Since information on the precise relationships between change in UEC, CFA, and tree size is not available, it was conservatively assumed that ΔUECs in Equation 1 did not change for C/I and I/T land uses.

Atmospheric Carbon Dioxide Reduction

Sequestration (the net rate of CO_2 storage in above- and below-ground biomass over the course of one growing season) is calculated for each species using the tree-growth equations for DBH and height, described above, to calculate either tree volume or biomass. Equations from Pillsbury et al. (1998) are used when calculating volume. Fresh weight (kg/m^3) and specific gravity ratios from Alden (1995, 1997) are then applied to convert volume to biomass. When volumetric equations for urban trees are unavailable, biomass equations derived from data collected in rural forests are applied (Tritton and Hornbeck 1982; Ter-Mikaelian and Korzukhin 1997).

Carbon dioxide released through decomposition of dead woody biomass varies with characteristics of the wood itself, the fate of the wood (e.g., amount left standing, chipped, or burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. Calculations were conservative because they assumed that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year. Total annual decomposition is based on the number of trees in each species and age class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. Tree mortality for Charlotte was 2.0% per year for the first five years after planting for street trees and 0.65% every year thereafter (McSween 2005). Finally, CO_2 released during tree maintenance was estimated to be 0.08 lb CO_2 per inch DBH based on annual fuel consumption of gasoline (775 gal) and diesel fuel (2,750 gal) (McSween 2005).

Calculating Avoided CO_2 Emissions

Reducing building energy use reduces emissions of CO_2. Emissions were calculated as the product of energy use and CO_2 emission factors for electricity and heating. Heating fuel is largely natural gas and electricity in Charlotte. The fuel mix for electrical generation included mainly coal (43%) and nuclear (56%) (U.S. EPA 2003).

Emissions factors for electricity (lb/MWh) and natural gas (lb/MBtu) fuel mixes are given in *Table B4*. The monetary value of avoided CO_2 was \$0.0075/lb based on average high and low estimates for emerging carbon trading markets (CO2e.com 2005) (*Table B4*).

Improving Air Quality

Calculating Other Avoided Emissions

Reductions in building energy use also result in reduced emissions of criteria air pollutants (those for which a national standard has been set by the EPA) from power plants and space-heating equipment. This analysis considered volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)—both precursors of ozone (O_3) formation—as well as sulfur dioxide (SO_2) and particulate matter of <10 micron diameter (PM_{10}). Changes in average annual emissions and their monetary values were calculated in the same way as for CO_2, again using utility specific emission factors for electricity and heating fuels (U.S. Environmental Protection Agency 2002). The price of emissions savings were derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from U.S. EPA (2005, *Table B4*), and population estimates from the US Census Bureau (2003) (*Table B4*).

***Table B4**—Emissions factors and monetary implied values for CO_2 and criteria air pollutants.*

	Emission factor		Implied
	Electricity (lb/MWh)[a]	Natural gas (lb/MBtu)[b]	value[c] ($/lb)
CO_2	845	118.0	0.0075
NO_2	1.981	0.1020	6.55
SO_2	5.113	0.0006	1.91
PM_{10}	0.434	0.0075	2.31
VOCs	0.433	0.0054	6.23

[a] USEPA 1998, eGRID 2002, except Ottinger et al. 1990 for VOCs
[b] USEPA 1998
[c] CO_2 from CO2e.com (2005), values for all other pollutants are based on methods of Wang and Santini (1995) using emissions concentrations from U.S. EPA (2005) and population estimates from the U.S. Census Bureau (2003).

Calculating Deposition and Interception

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of the deposition velocity $Vd = 1/(Ra+Rb+Rc)$, pollutant concentration (C), canopy projection (CP) area, and time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances Ra, Rb, and Rc estimated for each hour over a year using formulations described by Scott et al. (1998). Hourly concentrations for NO_2, SO_2, O_3 and PM_{10}

and hourly meteorological data (i.e., air temperature, wind speed, solar radiation) for Charlotte were obtained from the North Carolina Department of Environment and Natural Resources. The year 2003 was chosen because data were available and it closely approximated long-term, regional climate records.

Deposition was determined for deciduous species only when trees were in-leaf. A 50% re-suspension rate was applied to PM_{10} deposition. Methods described in the section "Calculating Avoided Emissions" were used to value emissions reductions; NO_2 prices were used for ozone since ozone control measures typically aim at reducing NO_2.

Calculating BVOC Emissions

Emissions of biogenic volatile organic carbon (sometimes called biogenic hydrocarbons or BVOCs) associated with increased ozone formation were estimated for the tree canopy using methods described by McPherson et al. (1998). In this approach, the hourly emissions of carbon in the form of isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or simply temperature (monoterpene). Annual dry foliar biomass was derived from field data collected in Charlotte, NC during summer 2004. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data for 2003 described in the pollutant uptake section were used as model inputs.

Hourly emissions were summed to get annual totals. The cost of these emissions is based on control cost estimates and was valued at $6.23/lb for Charlotte (*Table B4*).

The ozone-reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from biogenic sources, was estimated as a function of canopy cover following McPherson and Simpson (1999). Peak summer air temperatures were reduced by 0.2°F for each percentage increase in canopy cover. Hourly changes in air temperature were calculated by reducing this peak air temperature at every hour based on the hourly maximum and minimum temperature for that day, the maximum and minimum values of total global solar radiation for the year. Simulation results from Los Angeles indicate that ozone reduction benefits of tree planting with "low-emitting" species exceeded costs associated with their BVOC emissions (Taha 1996). This is a conservative approach, since the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from anthropogenic sources were not accounted for.

Reducing Stormwater Runoff

The social benefits that result from reduced peak runoff include reduced property damage from flooding and reduced loss of soil and habitat due to erosion and sediment flow. Reduced runoff also results in improved water quality in streams, lakes, and rivers. This can translate into improved aquatic habitats, less human disease and illness due to contact with contaminated water and reduced stormwater treatment costs.

Calculating Stormwater Runoff Reductions

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 1998). The interception model accounts for rainwater intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored on canopy leaf and bark surfaces. Once the storage capacity of the tree canopy is exceeded, rainwater temporarily stored on the tree surface will drip from the leaf surface and flow down the stem surface to the ground. Some of the stored water will evaporate. Tree canopy parameters related to stormwater-runoff reductions include species, leaf and stem surface area, shade coefficient (visual density of the crown), tree height, crown diameter, and foliation period. Wind speeds were estimated for different heights above the ground; from this, rates of evaporation were estimated.

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and the depth of water captured by the canopy surface. Tree surface saturation was 0.04 in. Species-specific shading coefficient, foliation period, and tree surface saturation storage capacity influence the amount of projected throughfall.

Hourly meteorological and rainfall data for 2004 from the Douglas International Airport, NC (KCLT) (Station: KCLT – Douglas International Airport, Charlotte, NC; latitude 35.21° N, longitude −80.94° W) were used for this simulation. Annual precipitation during 2004 was 56.2 in (1,426.8 mm). Storm events less than 0.2 in (5.1 mm) were assumed not to produce runoff and were dropped from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998, 2000).

The social benefits that result from reduced peak runoff include reduced property damage from flooding and reduced loss of soil and habitat due to erosion and sediment flow. Reduced runoff also results in improved water quality in streams, lakes, and rivers. This can translate into improved aquatic habitats, less human disease and illness due to contact with contaminated water and reduced stormwater treatment costs.

Charlotte, NC assesses monthly stormwater fees to cover the costs of its stormwater management program. These fees are used as a proxy for the public's willingness to pay for stormwater management. Residential and commercial customers are charged the same amount, $93 per month per acre of impervious surface (Glotfelty 2005). The cost of controlling runoff from a 10-year storm is used as the basis for valuing rainfall interception by trees in Charlotte. This event is selected because most Best Managment Practices (BMPs), such as retention-detention basins, are designed to operate effectively for storm events up to this size. Runoff from larger events are assumed to bypass BMPs, directly entering the system without pretreatment. Also, tree crown interception does not increase after crowns are saturated, which usually occurs before storm events reach this magnitude. Runoff from 1 acre of impervious surface for a 10-year, 24-hour storm event (4.9 in) is 113,114 gals, assuming an average runoff coefficient of 0.85. Assuming an annual stormwater management fee of $1,116 per acre of impervious surface, the resulting control cost is $0.0099 per gal.

Property Value and Other Benefits

Trees provide a host of aesthetic, social, economic, and health benefits that should be included in any benefit–cost analysis. One of the most frequently cited reasons for planting trees is beautification. Trees add color, texture, line, and form to the landscape softening the hard geometry that dominates built environments. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality (Schroeder and Cannon 1983). Consumer surveys have shown that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers indicated that they shopped more often and longer in well-landscaped business districts, and were willing to pay more for goods and services (Wolf 1999). Research in public-housing complexes found that outdoor spaces with trees were used significantly more often than spaces without trees. By facilitating interactions among residents, trees can contribute to reduced levels of violence, as well as foster safer and more sociable neighborhood environments (Sullivan and Kuo 1996).

Well-maintained trees increase the "curb appeal" of properties. Research comparing sales prices of residential properties with different numbers and sizes of trees suggests that people are willing to pay 3–7% more for properties with ample trees versus few or no trees. One of the most comprehensive studies on the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1% increase in sales price (Anderson and Cordell 1988). Depending on average home sale prices, the value of this benefit can contribute significantly to property tax revenues.

Scientific studies confirm our intuition that trees in cities provide social and psychological benefits. Humans derive substantial pleasure from trees, whether it is inspiration from their beauty, a spiritual connection, or a sense of meaning (Dwyer et al. 1992; Lewis 1996). Following natural disasters, people often report a sense of loss if the urban forest in their community has been damaged (Hull 1992). Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan and Kaplan 1989). Desk-workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared to those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation and relaxation in and near cities. The act of planting trees can have social value, for community bonds between people and local groups often result.

The presence of trees in cities provides public health benefits and improves the well being of those who live, work and play in cities. Physical and emotional stress has both short-term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving showed that views of nature reduce the stress response of both body and mind (Parsons et al. 1998). City nature also appears to have an "immunization effect," in that people show less stress response if they have had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, have a better outlook, and recover quicker than patients without connections to nature (Ulrich 1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

Certain environmental benefits from trees are more difficult to quantify than those previously described, but can be just as important. Noise can reach unhealthy levels in cities. Trucks, trains, and planes can produce noise that exceeds 100 decibels, twice the level at which noise becomes a health risk. Thick strips of vegetation in conjunction with landforms or solid barriers can reduce highway noise by 6–15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Miller 1997).

Urban forests can be oases, sometimes containing more vegetative diversity than surrounding rural areas. Numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Street-tree corridors can connect a city to surrounding wetlands, parks, and other greenspace resources that provide habitats that conserve biodiversity (Platt et al.1994).

Urban and community forestry can provide jobs for both skilled and unskilled labor. Public service programs and grassroots-led urban and community forestry programs provide horticultural training to volunteers across the United States. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience (McPherson and Mathis 1999). Local nonprofit tree groups, along with municipal volunteer programs, often provide educational materials, work with area schools, and offer hands-on training in the care of trees.

Calculating Changes in Property Values and Other Benefits

In an Athens, GA, study (Anderson and Cordell 1988), a large front-yard tree was found to be associated with a 0.88% increase in average home resale values. In our study, the annual increase in leaf surface area of a typical mature large tree (30-year-old willow oak, average leaf surface area 7,374 ft^2) was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the city of Charlotte, each large tree would be worth $1,422 based on the 2004 average single-family-home resale price in Charlotte

($161,600) (Bankrate.com 2004). However, not all trees are as effective as front-yard trees in increasing property values. For example, trees adjacent to multifamily housing units will not increase the property value at the same rate as trees in front of single-family homes. Therefore, a citywide street tree reduction factor (0.923) was applied to prorate trees' value based on the assumption that trees adjacent to different land-uses make different contributions to property sales prices. For this analysis, the street reduction factor reflects the distribution of street trees in Charlotte by land-use. Reductions factors were single-home residential (100%), multi-home residential (70%), small commercial (66%), industrial/institititional/large commercial (40%), park/vacant/other (40%) (Gonzales 2004, McPherson et al. 2001).

Given these assumptions, a typical large street tree was estimated to increase property values by $0.19/ft^2 of LSA. For example, it was estimated that a single, street-side willow oak added about 3,163 ft^2 of LSA per year when growing in the DBH range of 12–18 in. Therefore, during this period of growth, willow oak trees effectively added $600.97, annually, to the value of an adjacent home, condominium, or business property (3,163 ft^{2}x $0.19/ft^2 = $600.97).

Estimating Magnitude of Benefits

Resource units describe the absolute value of the benefits of Charlotte's street trees on a per-tree basis. They include kWh of electricity saved per tree, kBtu of natural gas conserved per tree, lbs of atmospheric CO_2 reduced per tree, lbs of NO_2, PM_{10}, and VOCs reduced per tree, cubic feet of stormwater runoff reduced per tree, and square feet of leaf area added per tree to increase property values. A dollar value was assigned to each resource unit based on local costs.

Estimating the magnitude of the resource units produced by all street and park trees in Charlotte required four steps: (1) categorizing street trees by species and DBH based on the city's street-tree inventory, (2) matching other significant species with those that were modeled, (3) grouping remaining "other" trees by type, and (4) applying resource units to each tree.

Categorizing Trees by DBH Class

The first step in accomplishing this task involved categorizing the total number of street trees by relative age (as a function of DBH class). The inventory was used to group trees into the following classes:

- 0–3 in
- 3–6 in
- 6–12 in
- 12–18 in
- 18–24 in
- 24–30 in
- 30–36 in
- 36–42 in
- >42 in

Next, the median value for each DBH class was determined and subsequently used as a single value to represent all trees in each class. For each DBH value and species, resource units were estimated using linear interpolation.

Applying Resource Units to Each Tree

The interpolated resource-unit values were used to calculate the total magnitude of benefits for each DBH class and species. For example, assume that there are 300 silver maples citywide in the 30–36 in DBH class. The interpolated electricity and natural gas resource unit values for the class midpoint (33 in) were 319 kWh and 1,147 kBtu per tree, respectively. Therefore, multiplying the resource units for the class by 300 trees equals the magnitude of annual heating and cooling benefits produced by this segment of the population: 95,700 kWh of electricity saved and 344,100 kBtu of natural gas saved.

Matching Significant Species with Modeled Species

To extrapolate from the 21 municipal species modeled for growth to the entire inventoried tree population, each species representing over 1% of the population was matched with the modeled species that it most closely resembled. Less abundant species that were not matched were then grouped into the "Other" categories described below.

Grouping Remaining "Other" Trees by Type

The species that were less than 1% of the population were labeled "other" and were categorized according into classes based on tree type (one of four life forms and three mature sizes):

- Broadleaf deciduous: large (BDL), medium (BDM), and small (BDS).
- Broadleaf evergreen: large (BEL), medium (BEM), and small (BES).
- Coniferous evergreen: large (CEL), medium (CEM), and small (CES).
- Palm: large (PEL), medium (PEM), and small (PES).

Large, medium, and small trees were >40 ft, 25–40 ft, and <25 ft in mature height, respectively. A typical tree was chosen to represent each of the above 15 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = Willow oak (*Quercus phellos*)
BDM Other = River birch (*Betula nigra*)
BDS Other = Flowering dogwood (*Cornus florida*)
BEL Other = Water oak (*Quercus nigra*)
BEM Other = Southern magnolia (*Magnolia grandiflora*)
BES Other = American holly (*Ilex opaca*)
CEL Other = Shortleaf pine (*Pinus echinata*)
CEM Other = Eastern red cedar (*Juniperus virginiana*)
CES Other = Bolleana shore pine (*Pinus contorta*)

When local data did not exist for specific categories (CES), growth data from similar-sized species in a different region were used.

Calculating Net Benefits And Benefit–Cost Ratio

It is impossible to quantify all the benefits and costs produced by trees. For example, owners of property with large street trees can receive benefits from increased property values, but they may also benefit directly from improved health (e.g., reduced exposure to cancer-causing UV radiation) and greater psychological well-being through visual and direct contact with trees. On the cost side, increased health-care costs may be incurred because of nearby trees, due to allergies and respiratory ailments related to pollen. The values of many of these benefits and costs are difficult to determine. We assume that some of these intangible benefits and costs are reflected in what we term "property value and other benefits." Other types of benefits we can only describe, such as the social, educational, and employment/training benefits associated with the city's street tree resource. To some extent connecting people with their city trees reduces costs for health care, welfare, crime prevention, and other social service programs.

Charlotte residents can obtain additional economic benefits from street trees depending on tree location and condition. For example, street trees can provide energy savings by lowering wind velocities and subsequent building infiltration, thereby reducing heating costs. This benefit can extend to the neighborhood, as the aggregate effect of many street trees reduces wind speed and reduces citywide winter energy use. Neighborhood property values can be influenced by the extent of tree canopy cover on streets. The community benefits from cleaner air and water. Reductions in atmospheric CO_2 concentrations due to trees can have global benefits.

Net Benefits and Costs Methodology

To assess the total value of annual benefits (*B*) for each park and street tree (*i*) in each management area (*j*) benefits were summed:

$$B = \sum_{1}^{n} j \left(\sum_{1}^{n} i \left(e_{ij} + a_{ij} + c_{ij} + h_{ij} + p_{ij} \right) \right)$$

Equation 3

where

e = price of net annual energy savings = annual natural gas savings + annual electricity savings

a = price of annual net air quality improvement = PM_{10} interception + NO_2 and O_3 absorption + avoided power plant emissions – BVOC emissions

c = price of annual carbon dioxide reductions = CO_2 sequestered – releases + CO_2 avoided from reduced energy use

h = price of annual stormwater runoff reductions = effective rainfall interception

p = price of aesthetics = annual increase in property value

Total net expenditures were calculated based on all identifiable internal and external costs associated with the annual management of municipal trees citywide (Koch 2004). Annual costs for the municipality (*C*) were summed:

$$C = p + t + r + d + e + s + c + l + a + q$$

p = annual planting expenditure
t = annual pruning expenditure
r = annual tree and stump removal and disposal expenditure
d = annual pest and disease control expenditure
e = annual establishment/irrigation expenditure
s = annual price of repair/mitigation of infrastructure damage
c = annual price of litter/storm clean-up
l = average annual litigation and settlements expenditures due to tree-related claims
a = annual expenditure for program administration
q = annual expenditures for inspection/answer service requests

Total citywide annual net benefits as well as the benefit–cost ratio (BCR) were calculated using the sums of benefits and costs:

$$\text{Citywide Net Benefits} = B - C \qquad \text{Equation 4}$$

$$\text{BCR} = B - C \qquad \text{Equation 5}$$

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