City of Orlando, Florida
Municipal Forest Resource Analysis

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Center for Urban Forest Research
USDA Forest Service, Pacific Southwest Research Station

Technical Report to:
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—December 2009—

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Table of Contents

Executive Summary

With nearly 50 million tourists visiting each year, the City of Orlando takes great pride in maintaining its image as "The City Beautiful." Park and street trees are an integral component of that identity, greening and softening downtown business corridors, making streets and residential areas attractive and walkable (Figure 1).

Trees are a critical component of the city in general. Research indicates that healthy trees lessen impacts associated with the built environment by reducing stormwater runoff, energy consumption, and air pollutants. Trees improve urban life, making Orlando a more enjoyable place to live, work, and play, while mitigating the city's environmental impact. Over the past century, Orlando residents and the City have been developing their urban forest on public and private properties. This report evaluates Orlando's public street trees only. The primary question that this study asks is whether the accrued benefits from Orlando's trees 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 city-managed street tree resource:

Figure 1—Trees shade Orlando neighborhoods. Street trees in Orlando provide great benefits, improving air quality, sequestering carbon dioxide, reducing stormwater runoff and beautifying the city. The trees of Orlando return $1.87 in benefits for every $1 spent on tree care.

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

Resource Structure

Orlando's tree inventory includes 68,211 publicly managed trees along streets. These include 202 tree species with live oak (*Quercus virginiana*), crapemyrtle (*Lagerstroemia indica*), and laurel oak (*Quercus laurifolia*) the predominant species. The managers of the city's street trees can be commended for the overall diversity of the tree population in terms of the number of species.

There is approximately one street tree for every three residents for an 80% stocking level with planting space available for about 17,000 additional trees. The existing trees shade approximately 1.5% of the city or 26.7% of the city's streets and sidewalks.

The age structure of Orlando's street tree population appears fairly close to the desired "ideal" distribution initially with small trees (0-6 inch diameter-at-breast height [DBH]) heavily represented by two species – crapemyrtle and holly (*Ilex* sp.)—that total nearly one-quarter of all Orlando street trees. Similarly, the large tree ideal representation is due almost entirely to live and laurel oak. Loss of these large trees before the young tree population matures could represent a sizeable impact on the flow of benefits the city currently receives from street trees. Conversely, if young, large-growing trees survive and grow to full maturity, Orlando can look forward to maintaining benefits in the future, as long as large-tree planting is increased and routine maintenance occurs.

Resource Function and Value

The street trees of Orlando provide great benefits to the citizens. Their ability to intercept rain—thereby reducing stormwater runoff—is substantial, estimated at 283.7 million gallons annually, with an estimated benefit to the city of $539,000. Citywide, the average tree intercepts 4,160 gallons of stormwater each year, valued at $7.90 per tree.

Electricity saved annually in Orlando from both shading and climate effects of the street trees totals 3,369 MWh ($444,000), and annual natural gas saved totals 5,295 therms ($1,400) for a total energy cost savings of $445,400 or $6.53 per tree.

Net annual air pollutants removed, released, and avoided average 0.15 lbs per tree and are valued at $115,000 or $1.69 per tree. Ozone ($O_3$) is the most significant pollutant absorbed by trees, with 25.6 tons per year removed from the air, while nitrogen dioxide (NO_2) is the most important air pollutant whose production is avoided at the power plant due to reduced energy needs (4.9 tons).

Citywide, annual carbon dioxide (CO_2) sequestration and emission reductions due to energy savings by street trees are 11,531 tons and 3,432 tons, respectively. CO_2 released during decomposition and tree-care activities is 1,380 tons. Net annual CO2 reduction is 13,583 tons, valued at $89,600 or $1.31 per tree.

The estimated total annual benefits associated with aesthetics, property value increases, and other less tangible improvements are approximately $2.78 million or $41 per tree on average.

The grand total for all annual benefits – environmental and aesthetic – provided by street trees is nearly $4 million, an average of $58 per street tree. The city's 17,126 live oaks produce the highest total level of benefits at $1.7 million, annually ($99 per tree, 42.5% of total benefits). On a per tree basis, laurel oaks ($117 per tree) also produce significant benefits. Small-stature species, such as crapemyrtle ($10 per tree) provide the lowest benefits. Palms are essentially all "small" trees, based on leaf area (and leaf is what produces many of the benefits). With the exception of queen palm (*Syagrus romanzoffiana*, $12 per tree), Mexican fan palm (*Washingtonia robusta*, $8 per tree) and cabbage palmetto (*Sabal palmetto*, $5 per tree) produced fewer benefits than crapemyrtle.

Orlando spends approximately $2.1 million in a typical year (2007-2008) maintaining its street trees ($31/tree). The highest single cost is infrastructure repair associated with root damage ($547,500), followed by tree removals ($476.000). Laurel oak, due to age and structural problems, accounts for significant proportion of maintenance costs associated with tree removal, storm cleanup, and property and infrastructure damage. It is important to note that the Parks Division forestry budget has been reduced over the past 3 years by 22%, reducing staff from 3 to 2 crews.

Subtracting Orlando's total expenditures on street trees from total services they provide shows that Orlando's municipal street tree population is a valuable asset, providing approximately $1.8 million or $27 per tree ($8 per capita) in net annual benefits to the community. Over the years, the city has invested millions in its urban forest. Citizens are now receiving a return on that investment—**street trees are providing $1.87 in services for every $1 spent on tree care.** Orlando's benefit-cost ratio of 1.87 is greater than that of several cities (e.g. Berkeley, CA $1.80; Charleston, SC, $1.35; Boise, ID,$1.30); it is significantly lower than the majority reported for17 other cities studied to date, including New York City, NY (5.60), Charlotte, NC (3.25), Honolulu, HI (2.98), and Minneapolis, MN (2.73).

A variety of factors can contribute to the benefit-cost ratio being lower than other communities, but on a per tree basis, Orlando spends more on tree removals and infrastructure repair ($7 and $8 per tree, respectively) compared to the other cities that spend an average $4 and $5 per tree, respectively. Average costs for 18 other U.S. cities studied are $25 per tree compared to Orlando's $31 per tree. The benefits for Orlando, while significant, are also lower. The average benefit for 18 U.S. cities is $79 per tree compared to $58 per tree for Orlando. Given that the majority of trees producing this benefit are only in fair condition (61%), it is likely that the city's benefits would increase if there were greater investment in management to improve tree health, reduce mortality, and enhance longevity.

Another way of describing the worth of trees is their replacement value, which assumes that the value of a tree is equal to the cost of replacing it in its current condition. Replacement value is a function of the number, stature, placement and condition of the cities' trees and reflects their value over a lifetime. As a major component of Orlando's green infrastructure, the 68,211 street trees are estimated to have a replacement value of $181 million or $2,660 per tree. Live and laurel oak account for over 86% of the total value.

Resource Management

Orlando's street trees are a dynamic resource. Managers of the urban forest and the community alike can take pride in knowing that these trees greatly improve the quality of life in the city. However, the trees are also a fragile resource needing constant care to maximize and sustain production of benefits into the future while also protecting the public from potential hazard. The challenge as the city continues to grow will be to sustain and expand the existing canopy cover to take advantage of the increased environmental and aesthetic benefits the trees can provide to the community.

Management recommendations focused on sustaining existing benefits and increasing future benefits follow. These will help Orlando meet its goals of creating a greener, more sustainable community through the Green Works Orlando initiative and other programs:

1. Where conditions are suitable, increase stocking level with large-growing shade tree species to maximize benefits.
2. Evaluate non-oak species planted over the past 20 years to determine those that are performing best and increase their numbers to help guard against potential catastrophic losses of laurel and live oak due to storms, pests or disease.
3. Where small, understory trees are needed, broaden the planting palette to reduce the predominance of crapemyrtle.
4. Plan and fund regular inspection and pruning cycles to reduce street tree mortality rates, insure tree survival and public safety. Plans should address:
    - an improved young-tree care program that details inspections and structural pruning at least twice during the initial five years after planting to reduce young-tree mortality and provide a good foundation for the trees.
    - planned inspection and pruning cycles for mature trees (e.g., laurel and live oak) to prolong the functional life spans of these trees and increase current benefits.
    - a tree removal and replacement program designed to gradually and systematically replace dead, declining and hazardous trees. The program should insure that every removal is replaced and that current empty sites are planted with a tree that will grow to a mature size appropriate for the available space.
    - continued removal of Category I and II invasive tree species and replacement with non-invasives.

- coordination with public works department to introduce and employ strategies to reduce conflicts (e.g. sidewalk engineering, structural soils, replacing old sewer systems, re-assessing tree size for planting space when replacing; see Costello and Jones 2003).

5. Continue funding the updating, maintenance, and use of a working inventory of all public trees to properly assess, track, and manage the resource.

6. Use existing outreach and education programs to continue educating the public and civic leaders about the environmental services trees provide, including how those benefits increase for well-maintained trees.

These recommendations build on a history of dedicated management and commitment to natural resource preservation and Orlando now has the opportunity to put itself on a course toward providing citizens with an urban forest resource that is increasingly functional and sustainable.

Figure 2—Stately trees shade a residential street in Orlando.

Chapter One—Introduction

From its origins in 1838 as a small community of cattle and cotton farmers nestled around U.S. Army's Fort Gatlin, the city of Orlando has grown into a large and economically diverse community that hosts nearly 50 million tourists a year. It is home to technology and aerospace industries, citrus growers, military facilities, many colleges and universities, and, of course, theme parks – Disney World, Universal Studios, and Sea World. From its beginnings, trees have held a special place in the hearts of residents—from the Seminole leaders who met beneath the Council Oak during the Seminole Indian War (1835-1842) to the citrus growers who made Florida and oranges synonymous, to the Keep Orlando Beautiful and Green Works programs active today. Over the past century, Orlando residents and the city have continued planting trees on public and private properties. Orlando's Parks Division actively manages more than 88,000 public trees in addition to over 3,300 acres of park property (Aldridge 2009). The city believes the public's investment in stewardship of the urban forest produces benefits that far outweigh the costs to the community and that investing in Orlando's green infrastructure makes sense economically, environmentally, and socially.

Research indicates healthy city trees can mitigate impacts associated with urban environs: polluted stormwater runoff, poor air quality, high requirements for 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, social, and physical 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 municipal forest makes Orlando a more enjoyable place to visit, live, work, and play while mitigating the city's environmental impact (Figure 2).

In an era of decreasing public funds and rising costs, however, there is a need to scrutinize public expenditures that are often viewed as "non-essential," such as planting and maintaining street trees. Some may question the need for the level of service presently provided. Hence, the primary question that this study asks is *whether the accrued benefits from Orlando's street 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 Orlando's urban forest.
- Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.
- Highlight the relevance and relationship of Orlando's street tree resource to local quality of life issues such as environmental health, economic development, and psychological well-being.
- 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 includes six chapters and three appendices:

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

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

Chapter Three—Costs of Managing Orlando's Municipal Trees: Details management expenditures for publicly-managed right-of-way trees.

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

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 tree numbers in the population of street trees.

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

References—Lists publications cited in the study.

***Figure 3*—**Orlando's trees provide citizens with many environmental and aesthetic benefits.

Chapter Two—Orlando's Municipal Tree Resource

Many Orlando citizens are passionate about their trees, believing that they add character, beauty, and serenity to the city (Figure 3). Residents and city government have been planting trees on public and private property since the 1870s. This long-standing emphasis on trees is memorialized in a letter from Mayor James Giles in 1917 in which he recommended asking property owners along streets to pay one dollar for each tree planted in the parkways adjacent to their homes. While that initial program has been changed many times, the commitment was expanded in the 1930s and 50s with extensive street tree plantings, enhanced in the 1980s with the start of Green Up Orlando Program and it continues as part of Mayor Dyer's "Green Works Orlando Initiative."

Today thousands of trees grace Orlando, earning the city recognition as a National Arbor Day Foundation "Tree City USA" for 32 years. The only city to receive the award longer than Orlando is Nebraska City, the first Tree City USA in the country. Additionally, Orlando has received the Foundation's Growth Award for 18 years and recognition from the Florida Urban Forestry Council for its municipal program and public awareness projects. The Parks Division is responsible for the preservation, protection and management of more than 88,000 publicly-owned street and park trees in the City of Orlando and over 3,300 acres of Orlando parks property. The division sponsors tree-planting events, workshops and seminars for the tree professional, the public, neighborhood groups, and staff.

The Green Up Orlando Program was started in 1985 to increase the City's tree canopy and to improve the appearance of the community. The program encourages individual citizens and groups to plant trees and shrubs, beautify their neighborhoods, raise public awareness and pride in Orlando and promote the benefits of volunteer efforts in partnership with the City. Increasing the amount of trees and greenspace was one of Mayor Buddy Dyer's 6 key components of the Green Works Orlando initiative, a program designed to achieve the goal of transforming Orlando into one of the most environmentally-conscious cities in America. Through programs like these, citizens and the city are striving to monitor and improve all aspects of their urban forest, continuing to make Orlando an enjoyable and healthy place to live and visit.

Tree Numbers

The City of Orlando maintains an inventory of 88,363 street and park trees with a new inventory conducted in 2007. At the time of this study 68,211 street trees were tallied that were distributed through the 5 Orlando areas as shown in Figure 4. In addition, the inventory listed a total of 16,882 available planting spaces, including 249 spaces that will require stump removals prior to planting.

Deciduous trees predominate in the Orlando street tree population (51.3% of the total) with broadleaf evergreens second at 36.2%. Palms account for 9.3% while conifers represent only 3.2% of the street tree population. Deciduous trees provide protection against the harsh summer sun, while still allowing some of the sun's warming rays to reach buildings and streets during cooler winter days.

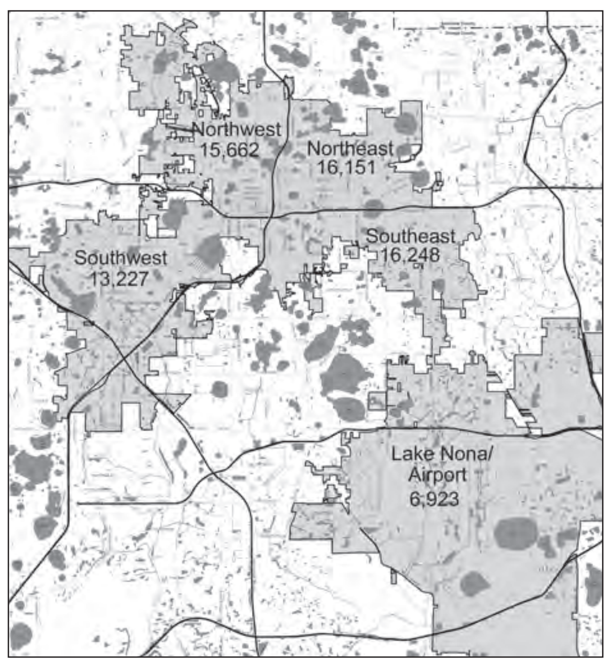

Figure 4—Urban forest management areas in Orlando described in this report with number of trees in each.

Table 1—*Planted and unplanted sites as listed in 2007 inventory.*

Zone	Unplanted Sites	Planted Sites	Total No. of Tree Sites	Stocking (%)	Total No. of Unplanted Sites			
					Small	Medium	Large	Undefined
Northeast	2,628	16,151	8,779	86	1,402	476	698	52
Northwest	4,204	15,662	19,866	79	2,029	795	1,322	58
Southeast	5,050	16,248	21,298	76	2,526	304	2,166	54
Southwest	3,771	13,227	16,998	78	2,035	522	1,135	79
Lake Nona/Airport	1,229	6,923	8,152	85	529	439	255	6
Citywide total	16,882	68,211	85,093	80	8,521	2,536	5,576	249

Street Tree Stocking Level

During the 2007 tree inventory, available planting spaces were also inventoried using parameters defined by the Parks Division to determine space availability for small, medium, and large-growing trees. Spaces requiring stump removal prior to planting replacement trees were also inventoried. Table 1 shows an 80% stocking level citywide, with space available for an additional 16,882 new trees. Stocking varies by zone from 24% available for planting in the Southeast to only 14% in the Northeast.

Street Trees Per Capita

Calculations of street trees per capita are one indication of how well-forested a city is. Assuming a human population of 230,519 (US Census Bureau 2008) and a street tree population of 68,211, Orlando's number of street trees per capita is 0.30 – approximately one tree for every three people – somewhat below the mean ratio of 0.37 reported for 22 U.S. cities (McPherson and Rowntree 1989). More recent research shows that Orlando's ratio equals or exceeds that of 12 of 16 iTree Streets reference cities nationwide, exceeded only by Minneapolis, MN (0 .52), Modesto and Claremont, CA (0.41 and 0.67, respectively) (McPherson et al. 2000, 2001, 2005b).

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 Orlando—likely represent less than 20% of the entire urban forest (Moll and Kollin 1993). The tree canopy in Orlando represented by street trees in the inventory is estimated at 1,084 acres and shades approximately 26.7% of public street and sidewalk surfaces.

Species Richness, Composition and Diversity

The street tree population in Orlando includes a mix of 202 different species and cultivars—nearly 4 times more than 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 predominant municipal street tree species are live oak (*Quercus virginiana*, 25.1%), crapemyrtle (*Lagerstroemia indica*, 22.0%), and laurel oak (*Quercus laurifolia*, 15.6%) (Table 2; see also Appendix A). Taken together these three species compose over 62% of the street tree population, nearly 43,000 of the city's 68, 211 trees. Each exceeds the general rule that no single species should represent more than 10% of the population. The oak, as a genus, constitute 43% of the street tree population. Dominance of this kind is of concern because of the impact that drought, disease, pests, or other stressors can have on an urban forest.

At the management zone level, the problem of overly dominant species is reflected in all five zones (Table 3). It is exacerbated in the Lake Nona/Airport area where almost 58% of the trees are live

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

	DBH Class (in)										
Species	**0-3**	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**	**% of Total**
Broadleaf Deciduous Large (BDL)											
Laurel oak	86	476	1,270	1,676	2,173	2,142	1,449	767	581	10,620	15.6
Shumard oak	75	676	534	106	10	3	-	-	-	1,404	2.1
BDL OTHER	178	350	616	399	259	128	55	18	15	2,018	3.0
Total	339	1,502	2,420	2,181	2,442	2,273	1,504	785	596	14,042	20.6
Broadleaf Deciduous Medium (BDM)											
Chinese elm	123	1,076	1,266	132	7	3	1	1	-	2,609	3.8
Red maple	54	182	708	567	220	61	18	3	1	1,814	2.7
BDM OTHER	89	167	419	244	105	25	2	1	1	1,053	1.5
Total	266	1,425	2,393	943	332	89	21	5	2	5,476	8.0
Broadleaf Deciduous Small (BDS)											
Common crape-myrtle	5,546	8,129	1,248	50	12	2	1	-	-	14,988	22.0
BDS OTHER	107	193	115	46	23	1	2	1	-	488	0.7
Total	5,653	8,322	1,363	96	35	3	3	1	-	15,476	22.7
Broadleaf Evergreen Large (BEL)											
Live oak	680	4,367	4,463	2,608	1,996	1,205	683	470	654	17,126	25.1
Southern magnolia	662	730	382	131	28	10	6	3	-	1,952	2.9
BEL OTHER	143	203	112	42	30	24	7	6	4	571	0.8
Total	1,485	5,300	4,957	2,781	2,054	1,239	696	479	658	19,649	28.8
Broadleaf Evergreen Medium (BEM)											
Camphor tree	38	105	241	177	111	79	57	27	44	879	1.3
BEM OTHER	98	180	139	32	7	2	1	-	-	459	0.7
Total	136	285	380	209	118	81	58	27	44	1,338	2.0
Broadleaf Evergreen Small (BES)											
Holly	133	927	605	26	2	-	-	-	-	1,693	2.5
BES OTHER	384	934	599	96	10	3	1	-	1	2,028	3.0
Total	517	1,861	1,204	122	12	3	1	-	1	3,721	5.5
Conifer Evergreen Large (CEL)											
Slash pine	81	131	348	317	64	4	-	-	-	945	1.4
CEL OTHER	68	110	119	74	67	15	2	-	-	455	0.7
Total	149	241	467	391	131	19	2	-	-	1,400	2.1
Conifer Evergreen Medium (CEM)											
CEM OTHER	47	70	79	49	27	13	6	2	-	293	0.4
Total	47	70	79	49	27	13	6	2	-	293	0.4
Conifer Evergreen Small (CES)											
CES OTHER	60	239	133	31	7	-	-	-	-	470	0.7
Total	60	239	133	31	7	-	-	-	-	470	0.7
Palm Evergreen Large (PEL)											
Queen palm	26	164	540	87	-	-	-	-	-	817	1.2
PEL OTHER	3	15	44	22	46	32	6	2	-	170	0.2
Total	29	179	584	109	46	32	6	2	-	987	1.4

__Table 2 (Cont.)__—Most abundant street tree species in order of predominance by DBH class and tree type.

	DBH Class (in)										
Species	**0-3**	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**	**% of Total**
Palm Evergreen Medium (PEM)											
Cabbage palmetto	5	33	904	1,624	269	20	-	-	-	2,855	4.2
PEM OTHER	14	30	77	123	212	18	1	1	-	476	0.7
Total	19	63	981	1,747	481	38	1	1	-	3,331	4.9
Palm Evergreen Small (PES)											
Mexican fan palm	5	6	247	777	339	9	1	-	-	1,384	2.0
PES OTHER	28	232	87	165	96	32	3	1	-	644	0.9
Total	33	238	334	942	435	41	4	1	-	2,028	3.0
Citywide Total	87,33	19,725	15,295	9,601	6,120	3,831	2,302	1,303	1,301	68,211	100.0

oak. Citywide, the decline in benefits would be huge were the oaks decimated by disease or pests, but that is particularly true in the Lake Nona/Airport zone.

Invasive non-native species

More than 1,300 species of plants have been introduced to Florida over the past 100 years. These now constitute nearly 30 percent of the plant species growing on their own without cultivation in natural areas. Although few become serious pests, those that do are a grave threat to Florida's fragile ecosystems. Invasive species can destroy native ecosystems, displace native plants, disturb habitats for native fauna, and increase fire risk.

Not all nonnative plant species are dangerous; many have great economic or aesthetic value and pose little risk to local ecosystems. Invasive exotic plants in Florida are termed Category I invasives when they are altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives. This definition does not rely on the economic severity or geographic range of the problem, but on the documented ecological damage caused. Category II invasive exotics have increased in abundance or frequency but have not yet altered Florida plant communities to the extent shown by Category I species. These species may become Category I if ecological damage is demonstrated (FLEPCC 2009).

Invasive exotics constitute about 7% of Orlando's

__Table 3__—Most abundant street tree species listed by zone with percentage of totals in parenthesis.

Zone	**1st (%)**	**2nd (%)**	**3rd (%)**	**4th (%)**	**5th (%)**	**# of Trees**
Northeast	Live oak (25.7)	Common crape-myrtle (20.9)	Laurel oak (17.4)	Chinese elm (4.5)	Shumard oak (4.2)	16,151
Northwest	Live oak (21.5)	Common crape-myrtle (20.8)	Laurel oak (17)	Cabbage palmetto (5.7)	Chinese elm (4.8)	15,662
Southeast	Common crapemyrtle (23.6)	Laurel oak (20.2)	Live oak (19)	Cabbage palmetto (4.1)	Chinese elm (3.4)	16,248
Southwest	Common crapemyrtle (26.5)	Live oak (18.9)	Laurel oak (13.4)	Cabbage palmetto (5)	Red maple (4.9)	13,227
Lake Nona/ Airport	Live oak (57.9)	Common crape-myrtle (14.8)	Southern magnolia (5.4)	Mexican fan palm (4.1)	Japanese privet (2.6)	6,923
Citywide	Live oak (25.1)	Common crape-myrtle (22)	Laurel oak (15.6)	Cabbage palmetto (4.2)	Chinese elm (3.8)	68,211

street trees. There are 13 Category I invasives (2.4% of the street tree population), with camphor (*Cinnamomum camphora*), Chinese tallow (*Triadica sebifera*), and mountain ebony (*Bauhinia variegata*) accounting for majority of these (2%). None are currently being planted by the city.

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 tree numbers, but canopy cover and leaf area, providing a useful comparison with the total population distribution.

Importance value, 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. Urban 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 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 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 trees can result in short rotations and increased long-term management costs.

Table 4 shows that 3 species – live oak, crapemyrtle, and laurel oak – constitute 63% of Orlando's street tree population, 83% of the total leaf area, and 81% of total canopy cover, for an IV of 76. Orlando is relying most on the functional capacity of these three species. Live oak accounts for over 25% of all public street trees at this point in time, 42% of the total leaf area, and 40% of the total canopy area for an importance value of 36. This makes oak over four times as important as crapemyrtle, the next most populous species. Its importance will increase since 56% of the live oaks are young trees (<12 inches DBH), whereas the crapemyrtle will always remain relatively small. Nearly 15,000 crapemyrtle represent 22% of the total tree population, but these small-stature trees contribute only 1% to the leaf area and 2% to overall canopy cover.

Together, laurel and live oak account for over 67% of the overall importance value. Other medium- and large-growing species in the table have relatively low importance compared to these oaks. They are fewer in number, but their importance will still increase over time because currently the majority are still young trees. For example, over 90% of the Chinese elms (*Ulmus parvifolia*), Shumard oaks (*Quercus shumardii*), and Southern magnolias (*Magnolia grandiflora*) are under 12-in DBH. Over 50% of the red maples (*Acer rubrum*) are younger and 43% of the camphor. Each of these species will increase in importance as they grow, putting on more leaf area and canopy.

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. A desirable dis-

Table 4—*Importance values (IV) indicate which species dominate the street tree population due to their numbers and size.*

Species	Number of Trees	% of Total Trees	Leaf Area (ft2)	% of Total Leaf Area	Canopy Cover (ft2)	% of Total Canopy Cover	Importance Value
Live oak	17,126	25.1	63,984,283	41.9	18,948,548	40.1	35.7
Common crapemyrtle	14,988	22.0	1,584,874	1.0	945,141	2.0	8.3
Laurel oak	10,620	15.6	61,526,822	40.3	18,209,280	38.6	31.5
Other trees	25,477	37.4	25,480,495	16.7	9,121,838	19.3	24.5
Total	68,211	100.0	152,576,474	100.0	47,224,806	100.0	100.0

tribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

At first glance, the overall age structure of Orlando street trees citywide (represented here in terms of DBH) appears nearly ideal (Figure 5). However, in this case, the ideal structure in the lower size classes reflects high, small-stature (at maturity) species representation rather than the desired number of young trees. For example, crapemyrtle and holly (*Ilex* species) rarely grow larger than 12 inches DBH at maturity so, not surprisingly, 99.6% and 98.3%, respectively, are in the smallest size classes. Small trees constitute about one-third of all street trees in the city (31.8%). If small-stature trees are not considered, only about 25% of Orlando's trees are in the 0-6-in age class compared to the desired proportion of 40%.

Ideal age structure in the upper DBH classes is due almost entirely to the live and laurel oaks, large trees that were heavily planted in the past. These two oaks constitute 94% of all trees in the 30-in and greater DBH classes. Without these species the age structure for trees in Orlando would predominantly consist of small and young trees.

Examining the relative age distribution by zone shows a fairly even distribution of young or small trees with the exception of the Lake Nona/Airport area, which is a comparatively newer annexation to the city (Figure 6). As the area is developed, a greater number of trees are being planted. It also explains the lower number of mature, old trees compared to the other four regions.

Palms are excluded from the age structure review because DBH is not indicative of their relative ages.

Tree Condition

Tree condition indicates both how well trees are managed and how well they perform given site-specific conditions. Condition was rated for all street trees during the 2007 survey and is updated whenever trees are visited by forestry staff. Slightly over 1% are dead or dying, with another 7% in poor condition (Figure 7). These values are nearly identical to median values for 19 cities studied to date. However, only 31% are in good or better condition, significantly lower than the median value of 61% for the other cities. Most trees are in fair condition (61%). Condition also varies greatly from species to species. Generally, the palms are in the best health, with all predominant palm species having more than 53% in good or very good condition.

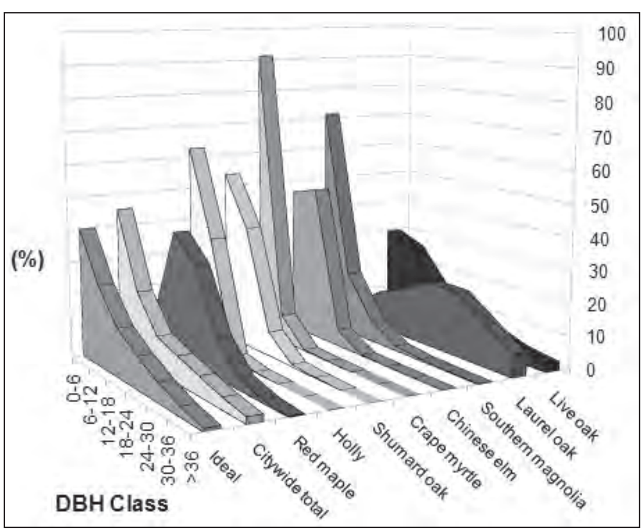

Figure 5—Relative age distribution for Orlando's 8 most abundant street tree species citywide shown with an ideal distribution.

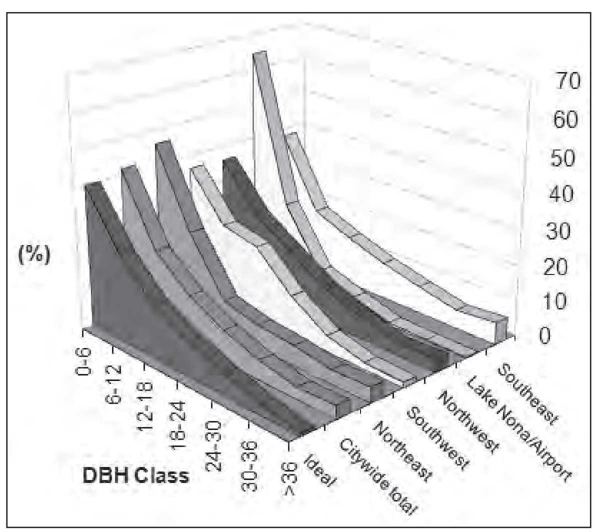

Figure 6—Relative age distribution of all street trees by zone.

Care should be taken when analyzing tree condition to ensure that relevant factors such as age are taken into consideration. For instance, the Shumard oak appears to be doing quite well. By comparing Figure 7 with Figure 5, it is clear that most of these oaks are relatively young (over 90% less than 12 in DBH) and therefore have not yet stood the test of time. Conclusions about their suitability to the region should be postponed until the trees have matured. Nevertheless, a look at the condition of the live oak, with only 4% in poor or worse condition, suggests that even very old, large trees in Orlando can do quite well.

Holly, red maple, laurel oak, and camphor have the highest percentage of trees in poor or worse condition. Sphaeropsis gall has caused the removal of hundreds of hollies in the past year. Red maple, normally relatively short-lived, is suffering from Innotus heart rot (*Innotus rickii*) and many trees planted for fewer than 20 years are facing removal. Laurel oak also has more than 15% in poor or worse condition, but there are also more of these in larger size classes than there are for any other street tree species. During the 2004 hurricanes, laurel oak took a battering, not withstanding the conditions nearly as well as live oak.

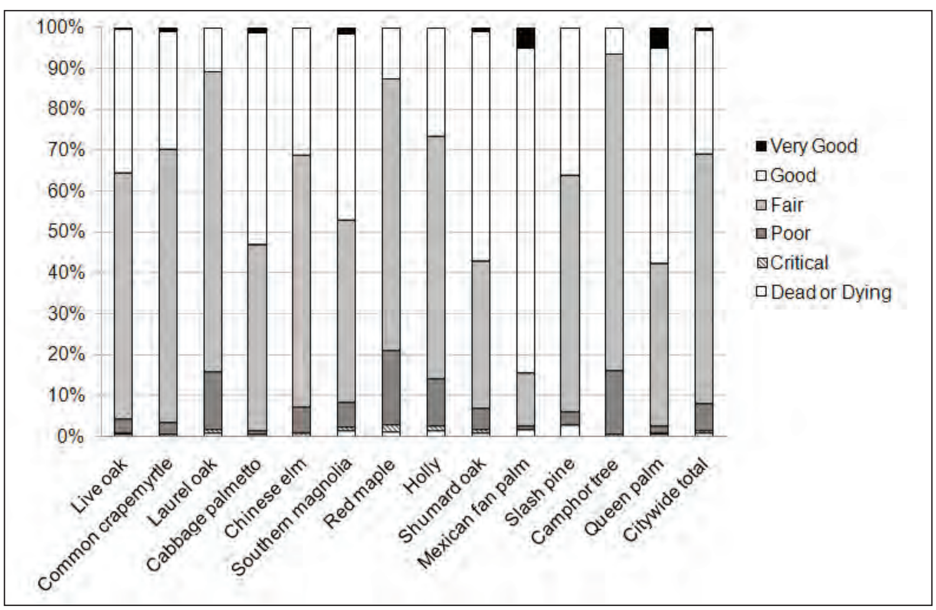

Figure 7—Condition for Orlando's predominant 13 tree species. Citywide, 31% are in good or better condition.

Replacement Value

Replacement value is a way of describing the value of trees at a given time, reflecting their current number, stature, placement, and condition. There are several methods that arborists employ to develop a fair and reasonable perception of a tree's value (CTLA 1992, Watson 2002). The cost approach is widely used today and assumes that value equals the cost of production, or in other words, the cost of replacing a tree in its current state (Cullen 2002).

Replacing the 68,211 municipal street trees in the inventory with trees of similar size, species, and condition if, for example, all were destroyed by a catastrophic storm, would cost approximately $181 million Considered this way, we can see that Orlando's street trees are a valuable legacy and a central component of the city's green infrastructure. The average replacement value per tree is $2,660. Live oak (45.0%) and laurel oak (41.4%) account for over 86% of the total.

Replacement value should be distinguished from the value of annual benefits produced by the street trees. The latter will be described in Chapter 4 as a "snapshot" of benefits during one year, while the former accounts for the historical investment in trees over their lifetimes. Hence, the replacement value of Orlando's street tree population is many times greater than the value of annual benefits it produces.

Chapter Three—Costs of Managing Orlando's Street Trees

The benefits Orlando street trees provide come, of course, at a cost. This chapter presents a breakdown of annual expenditures for fiscal year 2007/2008 which was considered a typical year. However, it is important to note that the Parks Division budget has undergone a 22% reduction over the past 3 years, including a 12% reduction this year alone. This resulted in the loss of a full forestry crew (3 positions).

Table 5 shows that total annual tree-related expenditures for Orlando's street trees are approximately $2,128,025 (Aldridge 2009). This represents about one quarter of 1% of the City of Orlando's total operating budget ($820 million) or $9 per person. Actual forestry program expenditures account for $1,442,928 of the total city expenditures on street trees, with the remaining $685,097 paid by other divisions within the city.

***Table 5**—Orlando's annual municipal forestry-related expenditures for street trees.*

Expenditures	Total ($)	$ /Tree	$ /Capita	% of total
Purchasing Trees and Planting	237,588	3.48	1.03	11.2
Pruning	308,121	4.52	1.34	14.5
Irrigation	25,956	0.38	0.11	1.2
Removal	475,666	6.97	2.06	22.4
Administration	143,442	2.10	0.62	6.7
Inspection/Service	154,100	2.26	0.67	7.2
Infrastructure Repairs	547,500	8.03	2.38	25.7
Litter Clean-up	190,210	2.79	0.83	8.9
Liability/Claim	14,709	0.22	0.06	0.7
Other Cost	30,733	0.45	0.13	1.4
Total Expenditures	2,128,025	31.20	9.23	100.0

The city spends about $31 per street tree on average during the year, over one and a half times greater than the mean value of $19 per tree reported for 256 California cities after adjusting for inflation (Thompson and Ahern 2000) and higher than the $25 per tree average for the 18 U.S. cities we have studied to date. The Orlando figure includes significant non-program expenditures (e.g., sidewalk, curb, gutter, and sewer repair, litter clean-up) that were not included in the California survey. Orlando's annual expenditure is similar to that of Charleston, SC ($35 per tree) and New York City ($37 per tree) and less than Minneapolis, MN ($46), Santa Monica ($53) and Berkeley, CA ($65) (McPherson et al. 2005a, b, 2006, Peper et al. 2007).

Forestry program expenditures fall into three general categories: tree planting and establishment, pruning removals, and general tree care, and administration.

Tree Planting and Establishment

Quality nursery stock, proper planting, and follow-up care are critical to perpetuation of a healthy urban forest. The Parks Division purchases Florida #1 or better trees that are, on average, 2 inches DBH. In a typical year, about 1,263 street trees are planted (Figure 8) or nearly 2,500 total municipal trees (streets, parks, and other city property). The city is in the 5th year of a 10,000-tree planting campaign initiated in 2005 to help replace the tree canopy lost to the 2004 hurricanes. Planting activities including materials, labor, administration, and equipment costs, currently account for 9% of the program budget or approximately $238,000.

Pruning, Removals, and General Tree Care

Internal crew pruning activities account for about 14% of the annual expenditures at $308,100 ($4.52 per tree). There is no young tree pruning program, nor does Orlando have a planned cyclical pruning program. All pruning is reactive to customer service and inspection requests, on an as needed basis, or as storm damage occurs and only over streets and sidewalks as required by city code. As previously mentioned, the city pruning program has been reduced by one full crew over the past two years.

Tree and stump removal account for about 22% of tree-related expenses ($475,700 or $7 per tree). About 336 street trees are removed each year. Inspecting trees for damage and disease costs

$154,000 annually with no expenditures on pest control. Storm and debris cleanup for street trees costs the Parks Division approximately $145,210 annually and other city departments about $45,000 for a total $3 per tree, making this the highest cost line item in the budget. Cleanup costs by other departments are estimated at 10 percent of their total cleanup costs, based on data collected in other reference cities showing that street trees compose less than 10 percent of total tree populations. Other cities studied average $1 per tree for litter cleanup; however, Charleston, South Carolina, also subject to significant hurricane and storm damage, also spends about $3 per tree on cleanup. There is some question as to whether all external infrastructure repair costs for Orlando are attributable to street trees only, but the public works department has no method for identifying the percentage of costs attributable only to street trees rather than street, front yard and other residential neighborhood trees.

Irrigation costs for newly planted trees totaled $26,000 or about 1% of the budget.

Infrastructure Repair and Liability

The highest expense associated with street trees is $547,500 spent on infrastructure repair – including sewer, curb, gutter and sidewalks. This amounts to 26% of the overall budget or $8 per tree.

Liability costs, including legal costs for limb or tree failures or trip and fall accidents are limited to $15,000 annually, less than 1% of the budget.

Administration

About $143,400 (7%) is spent on administrative expenses including taking calls, training classes on chainsaws and related equipment, code enforcement, attending meetings (e.g., plans review, issuing permits, city council workshops, creating work orders, upgrading software, running reports, payroll, paying invoices, revenue collection, and implementation of tree management plan).

Other Tree-Related Expenditures

The Parks Division spends about $31,000 on the Green Up Orlando program, dedicated to increasing Orlando's tree canopy and further beautifying the city through community tree planting opportunities, education, and outreach.

Figure 8—Young trees thriving in downtown Orlando.

Chapter Four—Benefits of Orlando's Municipal Trees

City trees work ceaselessly, providing ecosystem services that directly improve human health and quality of life. In this section, the benefits of Orlando's municipal 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 and physical 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.

For these reasons, the estimates given here provide first-order approximations of tree value. Our approach is a general accounting of the benefits produced by municipal street trees in Orlando—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 information on specific contributions that trees make toward energy savings.

Figure 9—Trees in Orlando neighborhoods reduce energy use for cooling and cleaning the air.

Table 6—*Net annual energy savings produced by Orlando street trees.*

Species	Total Electricity (MWh)	Electricity ($)	Total Natural Gas (Therms)	Natural Gas ($)	Total ($)	% of Total Tree Numbers	Avg. $/tree
Live oak	1,396	184,005	1,564	419	184,424	25.1	10.77
Common crapemyrtle	56	7,333	191	51	7,384	22.0	0.49
Laurel oak	1,252	165,041	2,386	639	165,680	15.6	15.6
Cabbage palmetto	41	5,412	84	22	5,435	4.2	1.9
Chinese elm	97	12,819	192	51	12,871	3.8	4.93
Southern magnolia	22	2,941	34	9	2,950	2.9	1.51
Red maple	76	10,073	80	22	10,094	2.7	5.56
Holly	21	2,825	57	15	2,840	2.5	1.68
Shumard oak	35	4,594	73	20	4,614	2.1	3.29
Mexican fan palm	17	2,287	45	12	2,299	2.0	1.66
Slash pine	30	3,981	33	9	3,990	1.4	4.22
Camphor tree	58	7,632	73	19	7,651	1.3	8.7
Queen palm	6	754	11	3	757	1.2	0.93
Other street trees	261	34,337	472	126	34,463	13.4	3.78
Citywide total	3,369	444,034	5,295	1,418	445,451	100.0	6.53

Electricity and Natural Gas Results

Electricity and natural gas saved annually in Orlando from both shading and climate effects equal 3,369 MWh ($444,034) and 5,295 therms ($1,418), respectively, for a total retail savings of $445,451 or a citywide average of $6.53 per tree (Table 6). Live oak provides 41.4% of the energy savings as expected for a tree species with such a high Importance Value (IV). Laurel oak (37.2%) makes the next greatest contributions to overall energy savings. On a per tree basis, these two species are the greatest contributors, reducing energy needs by approximately $10.57 and $15.77, respectively, per tree annually. Camphor and red maple provide the next greatest savings on a per tree basis ($8.70 and $5.56).

It should be noted again that this analysis describes benefits from the street tree population as it existed at the time of the inventory. This explains why, on a per tree basis, the benefits for other large-growing trees are small compared to the live and laurel oak. Southern magnolia, Chinese elm, red maple, and Shumard oak energy benefits will increase as their crowns mature. However, it is unlikely that the palms, holly or crapemyrtle will provide significantly more shade benefits due to small mature size. Although some of the palms grow quite tall, energy benefits are closely associated with the amount of shade a tree casts, and most palm crowns remain relatively small over the course of their lives in comparison with shade trees like laurel and live oak, maple, Southern magnolia, and elm.

Atmospheric Carbon Dioxide Reduction

Urban forests can reduce atmospheric carbon dioxide in two ways:

- Trees directly sequester CO_2 as root, woody and foliar biomass as 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, CO2 is released by vehicles, chainsaws, chippers, and other equipment during the process of planting and maintaining trees. Also, eventually all trees die and most of the CO2 that has accumulated in their woody biomass is released into the atmosphere as they decompose unless it is recycled. These factors must be taken into consideration when calculating the carbon dioxide benefits of trees.

Avoided and Sequestered Carbon Dioxide

Citywide, Orlando's street trees reduce atmospheric CO2 by a net of 13,583 tons annually (Table 7). This benefit was valued at $89,645 or $1.31 per tree and is equivalent to storing enough CO2 in 2007 (year of inventory) to offset CO2 production for 2,173 vehicles each year (using EPA assumption that the average vehicle produces 12,500 lbs of CO2 per year; U.S.EPA 2009a). Carbon dioxide released through decomposition and tree care activities totaled 1,380 tons, or 9.2% of the net total benefit. Reduced CO2 emissions from power plants due to cooling energy savings totaled 3,432 tons, while CO2 sequestered by trees was 11,531tons. Reduced CO2 emissions are important in Orlando because coal, which has a relatively high CO2 emissions factor, accounts for 98% of the fuel used in power plants that generate electricity (US EPA 2009b).

On a per tree basis, laurel oak ($3.49), live oak ($2.18) and camphor ($1.52) provide the greatest CO2 benefits (Table 7). Although crapemyrtle accounts for 22% of the tree population, its contribution is only 1.6% of the total carbon benefit due to its small stature.

Air Quality Improvement

Urban trees improve air quality in five main ways:

- 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.

Table 7*—CO2 reductions, releases, and net benefits produced by street trees.*

Species	Sequestered (lb)	Decomposition Release (lb)	Maintenance Release (lb)	Avoided (lb)	Net Total (lb)	Total ($)	% of Total Trees	% of Total $	Avg. $ /tree
Live oak	9,620,234	-1,083,716	-83,382	2,843,867	11,297,004	37,280	25.1	41.6	2.18
Common crapemyrtle	345,862	-8,732	-7,720	113,335	442,745	1,461	22.0	1.6	0.1
Laurel oak	9,958,794	-1,200,296	-83,961	2,550,773	11,225,311	37,044	15.6	41.3	3.49
Cabbage palmetto	6,458	-2,367	-1,471	83,647	86,267	285	4.2	0.3	0.1
Chinese elm	235,336	-14,953	-6,420	198,126	412,089	1,360	3.8	1.5	0.52
Southern magnolia	87,441	-5,472	-3,727	45,459	123,702	408	2.9	0.5	0.21
Red maple	403,011	-31,843	-7,829	155,677	519,016	1,713	2.7	1.9	0.94
Holly	187,827	-7,326	-872	43,658	223,287	737	2.5	0.8	0.44
Shumard oak	229,308	-9,913	-3,380	71,004	287,020	947	2.1	1.1	0.67
Mexican fan palm	4,416	-1,323	-4,255	35,350	34,188	113	2.0	0.1	0.08
Slash pine	127,877	-8,529	-3,451	61,531	177,428	586	1.4	0.7	0.62
Camphor tree	326,580	-35,393	-5,015	117,955	404,128	1,334	1.3	1.5	1.52
Queen palm	4,525	-533	-421	11,653	15,224	50	1.2	0.1	0.06
Other street trees	1,524,961	-117,859	-19,958	530,687	1,917,831	6,329	13.4	7.1	0.69
Citywide total	23,062,630	-2,528,254	-231,860	6,862,723	27,165,238	89,645	100.0	100.0	1.31

Table 8—*Pollutant deposition, avoided and BVOC emissions, and net air-quality benefits produced by predominant street tree species.*

	Deposition (lb)					Avoided (lb)					BVOC emissions		Net total		% of trees	Avg. $/tree
Species	O3 (lb)	NO2 (lb)	PM10 (lb)	SO2 (lb)	Total $	NO2 (lb)	PM10 (lb)	VOC (lb)	SO2(lb)	Total $	(lb)	($)	(lb)	($)		
Live oak	21,850	1,739	7,160	256	67,446	3,936	1,376	1,375	3,151	19,298	-54,620	-56,259	-13,777	30,486	25.1	1.78
Common crape-myrtle	840	63	276	7	2,581	158	55	55	126	772	0	0	1,580	3,353	22.0	0.22
Laurel oak	18,640	1,361	5,965	172	56,876	3,540	1,235	1,234	2,826	17,334	-22,315	-22,984	12,659	51,225	15.6	4.82
Cabbage pal-metto	657	52	215	8	2,028	116	40	40	93	569	-1,464	-1,507	-242	1,089	4.2	0.38
Chinese elm	1,257	91	405	11	3,839	275	96	96	220	1,347	0	0	2,451	5,185	3.8	1.99
Southern mag-nolia	339	27	111	4	1,046	63	22	22	50	309	-714	-735	-75	620	2.9	0.32
Red maple	1,022	78	329	12	3,134	215	75	75	172	1,056	-591	-608	1,388	3,582	2.7	1.97
Holly	383	30	125	4	1,182	61	21	21	48	297	-7	-7	688	1,472	2.5	0.87
Shumard oak	504	37	161	5	1,537	99	34	34	79	483	-957	-986	-4	1,034	2.1	0.74
Mexican fan palm	277	22	91	3	855	49	17	17	39	241	-232	-239	283	856	2.0	0.62
Slash pine	400	32	131	5	1,235	85	30	30	68	418	-17	-17	764	1,636	1.4	1.73
Camphor tree	892	71	292	10	2,753	163	57	57	131	801	0	0	1,673	3,553	1.3	4.04
Queen palm	265	21	87	3	818	16	6	6	13	79	-122	-126	295	772	1.2	0.95
Other street trees	3,817	289	1,236	39	11,707	736	257	257	588	3,606	-4,795	-4,939	2,424	10,374	13.4	1.14
Citywide total	51,143	3,914	16,585	539	157,037	9,513	3,321	3,319	7,604	46,608	-85,832	-88,407	10,107	115,237	100.0	1.69

Deposition and Interception

Each year 36.1 tons ($157,037) of nitrogen dioxide (NO_2), small particulate matter (PM_{10}), ozone (O_3), and sulfur dioxide (SO_2) are intercepted or absorbed by street trees in Orlando (Table 8). Trees are most effective at removing O_3 and PM_{10}, with an implied annual value of $112,514. Due to its substantial leaf area and predominance, live oak contributes the most to pollutant uptake, removing 15.5 tons each year. Laurel oak removes an additional 13.1 tons, annually.

Avoided Pollutants

Energy savings result in reduced air pollutant emissions of NO_2, PM_{10}, volatile organic compounds (VOCs), and SO_2 (Table 8). Together, 11.9 tons of pollutant emissions are avoided annually with an implied value of $46,608. In terms of amount and dollar, avoided emissions of NO_2 are greatest (4.8 tons, $20,929). Live oak has the greatest impact on reducing energy needs; by moderating the climate they account for 4.9 tons of pollutants whose production is avoided in power plants each year. Laurel oak comes in at a close second, reducing 4.4 tons of pollutants annually.

BVOC Emissions

Biogenic volatile organic compound (BVOC) emissions from trees must be considered. At a total of 42.9 tons, these emissions offset about 89% of air quality improvements and are calculated as a cost to the city of $88,407. Live and laurel oak are the highest emitters of BVOCs among Orlando's predominant tree species, accounting for 64% and 26% of the urban forest's total annual emissions, respectively.

Net Air Quality Improvement

Net air pollutants removed, released, and avoided are valued at $115,237 annually. The average benefit per street tree is $1.69 (0.15 lb). Trees vary dramatically in their ability to produce net air-quality benefits. Large-canopied trees with large leaf surface areas that are not high emitters produce the greatest benefits. Although live and laurel oak are classified as high BVOC emitters, the large amount of leaf area associated with these populations result in substantial net air quality benefits ($81,711 total; $1.78 and $4.82 per tree, respectively).

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.

Orlando's street trees intercept 283.7 million gallons of stormwater annually, or 4,160 gal per tree on average (Table 9). The total value of this benefit to the city is $539,151 or $7.90 per tree.

Certain species are much better at reducing stormwater runoff than others. Leaf type and area, branching pattern and bark, as well as tree size and shape all affect the amount of precipitation trees can intercept and hold to reduce runoff. Trees that perform well include laurel oak ($18.78 per tree), live oak ($14.50 per tree), and camphor ($10.31). Interception by live oak alone accounts for 43% of the total dollar benefit from street trees. When combined with laurel oak, these two species account for 74% of the total interception benefit. Comparatively poor performers are species with relatively small leaf and stem surface areas, such as crapemyrtle, holly, and queen palm (*Syagrus romanzoffiana*). Smaller stature species like these simply do not intercept as much due to less leaf and bark surface area. Although large-growing, the Chinese elm, Shumard oak, and Southern magnolia are currently young and small. Their stormwater benefit value will increase as they mature.

Aesthetic, Property Value, Social, Economic and Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Wildlife habitat, beautification, privacy, and shade that increases human comfort, a sense of place, and well-being are difficult to price. However, the value of some of these benefits may be captured in the property values of the land on which trees stand (Figure 10). To estimate the value of these "other" intangible benefits, research comparing 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

Table 9—*Annual stormwater reduction benefits of Orlando's street trees by species*

Species	Total Rainfall Interception (Gal)	Total ($)	% of Trees	% of $	Avg. $ /tree
Common crapemyrtle	2,174,008	4,131	22.0	0.8	0.28
Laurel oak	104,982,283	199,480	15.6	37.0	18.78
Cabbage palmetto	2,613,200	4,965	4.2	0.9	1.74
Chinese elm	4,365,593	8,295	3.8	1.5	3.18
Southern magnolia	2,719,584	5,168	2.9	1.0	2.65
Red maple	6,107,844	11,606	2.7	2.2	6.40
Holly	1,038,186	1,973	2.5	0.4	1.17
Shumard oak	3,376,805	6,416	2.1	1.2	4.57
Mexican fan palm	889,382	1,690	2.0	0.3	1.22
Slash pine	1,385,745	2,633	1.4	0.5	2.79
Camphor tree	4,771,383	9,066	1.3	1.7	10.31
Queen palm	431,852	821	1.2	0.2	1.00
Other trees	18,241,933	34,662	13.4	6.4	3.80
Citywide total	283,744,020	539,151	100.0	100.0	7.90

Figure 10—Trees add beauty and value to residential property.

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 trees in other 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 attributable to Orlando street trees is $2,782,003 or $40.79 per tree on average (Table 10). Generally, the larger the tree, the more benefits provided. Therefore, the Orlando street tree species that produce the highest average annual benefits are among the largest trees currently in the population. These include laurel oak ($73.97 per tree) and live oak ($69.44 per tree).

Table 10—*Total annual increases in property value produced by street trees.*

Species	Total ($)	% of Tree Numbers	% of Total $	Avg. $/tree
Live oak	1,189,226	25.1	42.8	69.44
Common crape-myrtle	128,468	22.0	4.6	8.57
Laurel oak	785,566	15.6	28.2	73.97
Cabbage palmetto	3,162	4.2	0.1	1.11
Chinese elm	104,849	3.8	3.8	40.19
Southern magnolia	50,478	2.9	1.8	25.86
Red maple	75,934	2.7	2.7	41.86
Holly	30,395	2.5	1.1	17.95
Shumard oak	82,792	2.1	3.0	58.97
Mexican fan palm	5,679	2.0	0.2	4.10
Slash pine	21,118	1.4	0.8	22.35
Camphor tree	38,807	1.3	1.4	44.15
Queen palm	7,780	1.2	0.3	9.52
Other street trees	257,749	13.4	9.3	28.25
Citywide total	2,782,003	100.0	100.0	40.79

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

Total annual benefits produced by Orlando's municipal street trees are estimated at $3,971,487 ($58.22 per tree, $17.23 per capita) (Table 11). Over the same period, tree-related expenditures are estimated to be $2,128,025 ($31.20 per tree,

Table 11—*Benefit–cost summary for all street trees.*

Benefits	Total ($)	$/tree	$/capita
Energy	445,451	6.53	1.93
CO2	89,645	1.31	0.39
Air Quality	115,237	1.69	0.50
Stormwater	539,151	7.90	2.34
Aesthetic/Other	2,782,003	40.79	12.07
Total Benefits	3,971,487	58.22	17.23
Costs			
Planting	237,588	3.48	1.03
Pruning	308,121	4.52	1.34
Irrigation	25,956	0.38	0.11
Removal	475,666	6.97	2.06
Administration	143,442	2.10	0.62
Inspection/Service	154,100	2.26	0.67
Infrastructure Repairs	547,500	8.03	2.38
Litter Clean-up	190,210	2.79	0.83
Liability/Claims	14,709	0.22	0.06
Other Costs	30,733	0.45	0.13
Total Costs	2,128,025	31.20	9.23
Net Benefits	1,843,462	27.03	8.00
Benefit-cost ratio		1.87	

$9.23 per capita). Net annual benefits (benefits minus costs) are $1,843,462 or $27.03 per tree and $8 per capita. Orlando's street trees currently return $1.87 to the community for every $1 spent on their management. Orlando's benefit-cost ratio of 1.87 is greater than that of several cities (e.g. Berkeley, CA $1.80; Charleston, SC, $1.35; Boise, ID,$1.30) it is significantly lower than the majority reported for 17 other cities studied to date, including New York City, NY (5.60), Charlotte, NC (3.25), Honolulu, HI (2.98), and Minneapolis, MN (2.73) (Peper et al. 2007; McPherson et al. 2005c; Vargas et al. 2007; McPherson et al. 2005b). Also, the $58 per tree benefits Orlando receives is over one-quarter less than the $79 per tree average across 18 U.S. cities studied thus far.

Orlando's street trees have beneficial effects on the environment. Nearly one-third (30%) of the annual benefits provided to residents of the city are environmental services. Stormwater runoff reduction represents 45% of environmental benefits, with energy savings accounting for another 37%. Air quality improvement (10%) and carbon dioxide re-

Table 12—*Average annual benefits ($ per tree) of street trees by species.*

Species	Energy	CO2	Air Quality	Storm-water	Aesthetic/ Other	Total ($)	% of Total $	$/tree
Live oak	10.77	2.18	1.78	14.50	69.44	1,689,660	42.5	98.66
Laurel oak	15.60	3.49	4.82	18.78	73.97	1,238,995	31.2	116.67
Common crapemyrtle	0.49	0.10	0.22	0.28	8.57	144,797	3.6	9.66
Chinese elm	4.93	0.52	1.99	3.18	40.19	132,560	3.3	50.81
Red maple	5.56	0.94	1.97	6.40	41.86	102,929	2.6	56.74
Shumard oak	3.29	0.67	0.74	4.57	58.97	95,804	2.4	68.24
Camphor tree	8.70	1.52	4.04	10.31	44.15	60,412	1.5	68.73
Southern magnolia	1.51	0.21	0.32	2.65	25.86	59,624	1.5	30.55
Holly	1.68	0.44	0.87	1.17	17.95	37,416	0.9	22.10
Slash pine	4.22	0.62	1.73	2.79	22.35	29,962	0.8	31.71
Cabbage palmetto	1.90	0.10	0.38	1.74	1.11	14,935	0.4	5.23
Mexican fan palm	1.66	0.08	0.62	1.22	4.10	10,638	0.3	7.69
Queen palm	0.93	0.06	0.95	1.00	9.52	10,180	0.3	12.46
Other street trees	3.78	0.69	1.14	3.80	28.25	343,576	8.7	37.65

duction (8%) provide the remaining environmental benefits. Non-environmental benefits associated with annual increases in property value by street trees provide the remaining 70% of total annual benefits.

Table 12 shows the distribution of total annual benefits in dollars for the predominant municipal street tree species in Orlando. On a per tree basis, laurel oak ($117 per tree) and live oak ($99 per tree) produced the largest benefit, followed by camphor ($69). At the species level, laurel and live oak account for over 74% of all benefits. It should be noted once again that this analysis provides benefits for a snapshot in time. It should be noted that because the remaining large-stature species are significantly fewer in number and relatively young (hence, smaller in size and leaf area), it is likely that live and laurel oak will remain the city's most

beneficial species in the near future. However, benefit production should increase each year for these other large-growing species. Note that smaller-stature species, such as crapemyrtle ($10 per tree), cabbage palmetto ($5 per tree), Mexican fan ($8 per tree) and queen palms ($12 per tree) will provide lower benefits despite increased new plantings. Crapemyrtle is the second most predominant tree, yet laurel oak with over 4,000 fewer trees produces over 9 times the dollar value in benefits produced, and live oak produces over 12 times the value.

Figure 11 illustrates the average annual benefits per tree by zone and reflects differences in tree types and ages. Trees in the Southeast produce the greatest benefits (about $1.1 million annually or $62 per tree), followed by the Northwest ($1.1 million annually or $67 per tree) and the Northwest ($974,000 annually or $62 per tree). For Orlando, there is a direct relationship between the number of large trees (> 18-in DBH) present in each zone and total benefits. The Lake Nona/Airport region, producing the fewest benefits has the fewest trees (6,923) and only 355 of these are larger than 18 inches DBH. By comparison, the Southeast region of the city has 16,248 trees with 30 percent greater than 18 inches. Although the Northwest zone has 490 fewer trees overall than the Northeast, it has a greater number of large trees. Large trees produce larger benefits for a community.

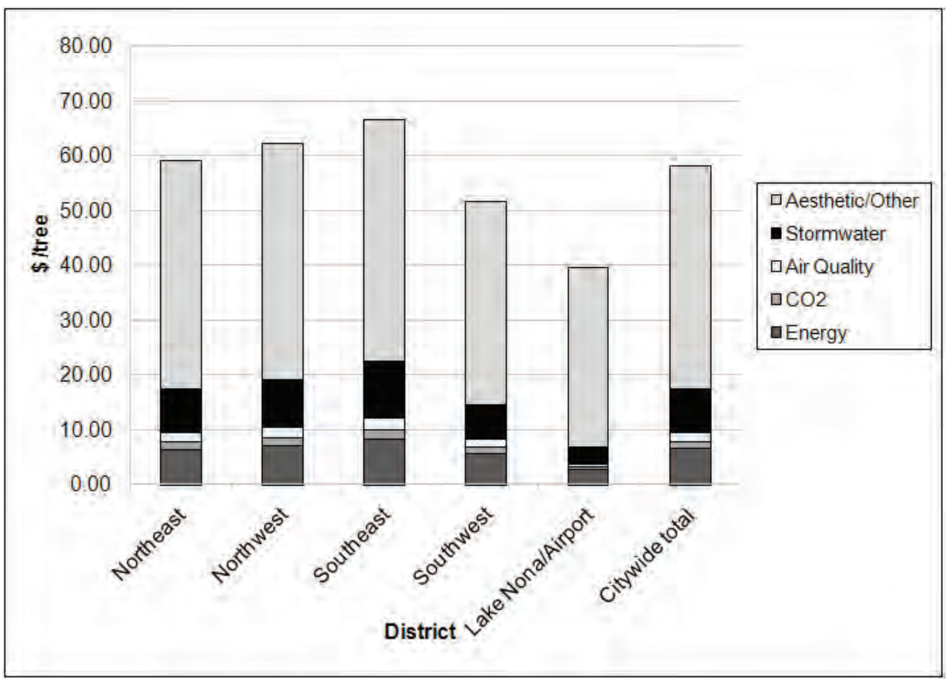

Figure 11—Average annual street tree benefits per tree by zone.

Chapter Five—Management Implications

Orlando'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 municipal street tree resource, it also serves as an opportunity to speculate about the future. Given the status of Orlando's street tree population, what future trends are likely and what management challenges will need to be met to sustain or increase this 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

The Orlando Parks Division is to be commended for its current commitment to increasing the diversity of the urban forest. Although the number of street tree species (202) is excellent, it is evident from the age distribution that efforts to diversify are fairly recent. Beyond live and laurel oak, maple and camphor, the majority of larger growing species are few in number, still young and, therefore, smaller in stature. Continued diversification is vital given that 3 species –crapemyrtle, live and laurel oak—account for 68% of the population. By themselves, laurel and live oak account for over 40% of the population and produce 74% of all benefits. Such dependence increase the possibility of catastrophic losses in the flow of urban forest benefits should disaster, disease, or pests strike. And disasters do strike; in 2004 the region was pummeled by Hurricanes Charley, Frances, and Jeanne. Over 20,000 public and private trees were downed by winds, torrential rains, and flooding in the city.

Live oak and the second most common tree—crapemyrtle—fared well during hurricanes while laurel oak did not (Crawford 2005). Live oak is a native species and a stalwart feature of Central Florida communities. Crapemyrtle serves as a colorful understory tree, but laurel oak—another native—was among the most common trees sustaining damage from the hurricanes. In its native habitat, it is a "forest" tree with a weak-wooded structure better-suited for more protected, forested environs than open sites along urban streets. In contrast, live oak typically grows in open environments, without crowding, and is well-suited as a street tree, with strong branches creating a broad canopy.

Because oaks produce the majority of environmental and aesthetic benefits in Orlando, they should be monitored and maintained to continue the flow of benefits they produce while additional large-stature species are planted to increase diversity wherever space comes available. Ninety-two percent of all trees in the largest size classes (>30 in DBH) are live and laurel oak, and very few species of similar stature are being planted to replace them as they age and are removed.

Figure 12 displays trees in the smallest DBH size classes, indicating trends in new and replacement

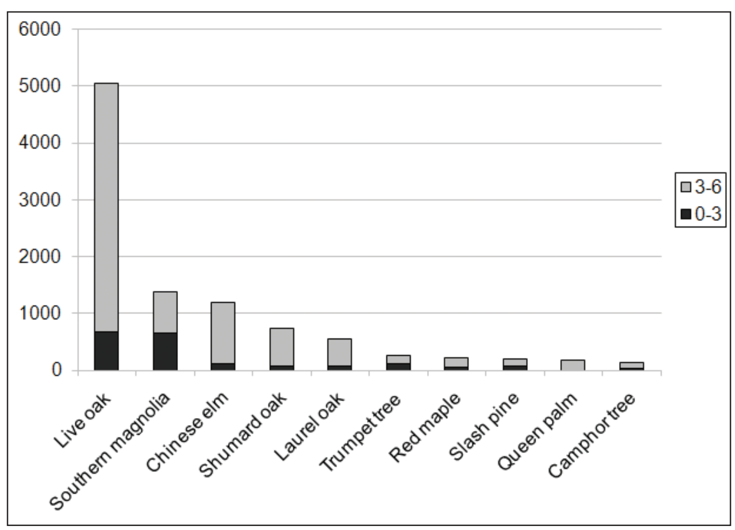

Figure 12—Predominant species in the smallest diameter classes (0-6" DBH) indicating relatively recent tree planting and survival trend.

trees. These are the 10 predominant species based on 0-6 inch size classes. Together they represent 87% of all trees in the 0-6 inch size classes. Crapemyrtle alone accounts for over 48% of the trees in the 0-6 in class and 22% of all trees in all size classes. Sixty percent of all trees in the 0-6 inch range are small-growing, 8% are medium, and 32% are large. This suggests that the street tree population is being downsized given that overall inventory representation for small, medium, and large-growing trees is 31.8, 15.3, and 52.9%, respectively.

Looking at only the large- and medium-growing trees being planted in the greatest numbers, live oak still dominates, oak as a genus remains the most common large tree, while few of the others will ever have the stature and grandeur of the oaks (Figure 13). Red maple suffers from disease currently and most are being removed before age 20. Queen palm is classified as a "large" tree based on crown size relative to other palms, but all palms produce benefits similar to or less than small, broadleaf trees. The city should focus on planting more non-oak, broadleaf, large-growing species to improve diversification and maintain the flow of benefits generated predominantly by live and laurel oak now.

As previously mentioned, invasive exotics constitute about 7% of Orlando's street trees. There are 13 Category I invasive trees in the inventory including camphor, Chinese tallow, and mountain ebony. In addition, Queen palm is classified by Florida as a Category II invasive. The inventory includes 9 Category II invasives, the bulk of which are palms (79%), particularly queen and Washington fan palm. None of the invasive species are being planted by the Parks Division currently. Owners of private property (residential and commercial) are required to obtain permits from the city for tree removal on their property. If inspectors find one of the listed Category I invasives on the property, they also stipulate its removal as part of the requirement for receiving the permit. If the invasive is on the city right-of-way, the tree is removed, using the request for a removal permit and the requisite inspection as a catalyst. Category I invasives should continue to be removed and replaced by non-invasive, large-growing trees when space allows.

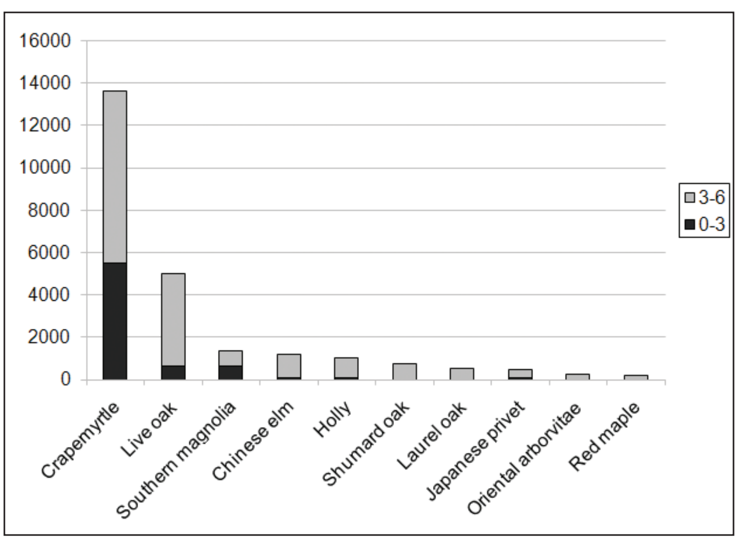

Figure 13—Medium- and large-growing trees in the smallest diameter classes planted in the greatest number.

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 the number of trees, and therefore canopy cover increases, so do the benefits afforded by leaf area. Maximizing the return on investment is contingent upon maximizing and maintaining the quality and extent of Orlando's canopy cover.

Orlando's estimated street tree stocking level is 80%, with available space inventoried for an additional 16,882 trees. Of these, 50.5% are suitable for small trees, 15% for medium trees, and 33% for large trees. An additional 1.5% had stumps needing removal prior to planting. Suitable tree size for those spaces was not recorded. Overall, this translates into only about 5,600 sites for large trees. Davey Resource Group conducted the site inventory and based tree size on planting space availability (e.g., a large tree requires a 10-ft minimum planting space width, shortest dimension). There is the potential for additional planting space in areas where the city right-of-way does not include any plantable portion of residential front yards. The Parks Division recently began a private street tree program offering homeowners in these areas a free tree where front yard space is available with the thought that these trees will grow to shade municipal sidewalks and roadways. This is an innovative program focused on increasing the available planting space for large trees. It provides residents the opportunity to plant trees and receive benefits in the form of increased property value and environmental services while also benefitting their neighborhood and community at large.

As additional land within the city limits is developed, providing adequate planting space for large trees should be considered as a component of infrastructure design. By working together with city planners and officials as well as the public, sufficient space can be allotted in new developments to allow trees room to grow. Parking lots offer another opportunity for expanding the urban forest. Trees can create a continuous canopy for maximum rainfall interception, even in commercial areas. Installing swales in parking lot islands and perimeters can filter runoff and provide ample space for large trees (Figure 14). Parking-space-sized planters contain the soil volume required to grow healthy, large trees (Xiao and McPherson 2009). Many cities, including Orlando, have adopted shade ordinances requiring a certain percentage of parking lots surfaces to be shaded (McPherson 2004). In parking lots or areas with on-street parking, trees can have an additional benefit of reducing pollutant emissions from parked cars by lowering local air temperature (Scott et al. 1999). Evaporative emissions from non-operating vehicles account for 16% of total vehicular emissions; lowering the air temperature by increasing shade cover in Sacramento parking lots to 50% from 8% was estimated to reduce overall emissions by 2% (0.85 tons per day). Although seemingly modest, many existing programs to improve air quality have similar goals.

When working to increase the extent of the urban forest, ways to maximize benefits should be kept in mind. Any tree added to a city adds benefits in terms of air quality improvement, climate moderation, reductions in energy use, stormwater management, and aesthetic improvement—benefits that have been described in detail above. Planting trees along streets and in parking lots, however, offers additional benefits beyond those that come from planting trees in parks. Most importantly, trees located along streets and in parking lots are more

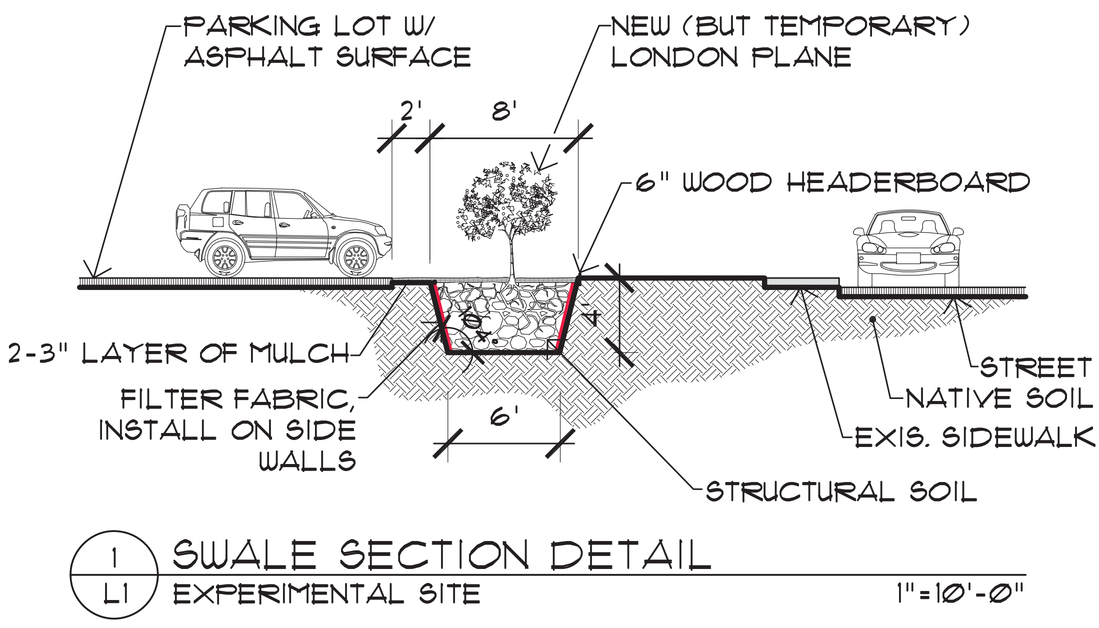

Figure 14—Trees can create a continuous canopy for maximum rainfall interception, even in commercial areas. In this example, a swale in the median filters runoff and provides ample space for large trees.

likely to shade structures. By moderating the immediate climate around a building, energy use is reduced, lowering costs for building owners and simultaneously reducing air pollutants and CO_2.

By shading the gray infrastructure, canopy cover over streets and sidewalks contributes directly to reducing urban heat island effects, reducing energy consumption, ground level ozone, and the formation of greenhouse gases. As cities grow, carbon emissions, and air and water pollution typically increase. However, the value of the benefits that trees provide typically also increases.

Trees along streets have also been shown to reduce the wear on asphalt by lowering surface temperatures and thereby reducing maintenance costs (McPherson and Muchnick 2005). A study comparing several blocks in Modesto, CA, demonstrated that streets shaded by large trees required fewer than half the number of slurry seals (2.5 vs. 6 on an unshaded street) over a 30-year period, with associated savings of $0.66/ft2.

The importance of size in achieving high levels of benefits should not be forgotten. Large species should be planted wherever possible.

Maintenance

In 2007, all of Orlando's street trees were independently assessed for maintenance needs during the tree inventory. Nearly 90% were in need of routine pruning, including training pruning for over 12,000 young trees and routine pruning for over 21,000 small trees and 28,000 large trees. Over 10% of the population requires either removal or priority pruning to reduce the risk of injury to citizens or damage to property. Additionally, the majority of the street tree population (61%) is only in fair condition. These statistics point to the need for the city to establish a routine maintenance program with planned pruning cycles.

Live and laurel oak produce the bulk of the environmental and aesthetic benefits, but nearly 65% and 89% of them, respectively, are in fair or worse condition. The future of these species should be considered with special care. For these reasons, a careful plan should be developed to begin planting similarly beneficial and beautiful trees *before* the older trees decline completely and require removal. Planned replacement involves assessing the tree population, particularly in those neighborhoods dominated by even-aged trees of the same species, and establishing a program of systematic removal and replacement so that the neighborhood will not suffer suddenly from a complete die-off or removal of hazardous trees. This program should also address the removal of Category I and II invasive tree species, as addressed previously.

Orlando faces a new maintenance challenge as well. A few years ago, Mayor Buddy Dyer, initiated the Green Works Orlando program, the city's plan to encourage environmentally-friendly life styles and "going green". Part of this program is the planting of 10,000 new trees over 5 years, a reasonable goal that is well on its way to being met. But regular maintenance is required for new trees—staking, pruning, eventual removal of stakes and hardware—if long-term sustainability and high benefit returns are to be achieved. With at least 2,000 new trees planted each year for 5 years, a strong young-tree care program is imperative to insure, first, that the trees survive, and second, they transition into well-structured, healthy mature trees.

Investing in the young-tree care program will reduce costs for routine maintenance as trees mature and reduce removal and replacement costs for dead trees. Although tree planting has been funded in Orlando, the budget for maintenance has been reduced by 22%. An independent analysis by Davey Resource Group developing a tree inventory management plan recommended that 4 crews are necessary to establish a routine maintenance program with a 7-year pruning cycle (2007). However, with budget cutbacks, the city is now down to 2 tree maintenance crews.

A six-week long, routine pruning program conducted in the Southern Oaks neighborhood of Orlando 15 years ago provides a local example of the potential effectiveness a routine pruning program would have. Over 500 street trees are in Southern Oaks. All were inspected and pruned as needed. Fifteen months passed before the Parks Division received a call from a resident requesting inspection of a street tree. Generally, it is more cost-effective to inspect and prune by neighborhoods than it is to move staff and equipment city-wide in response to citizen calls.

Other Management Implications

The street tree population in Orlando is at a critical juncture. The city, along with partners and the community, is doing an admirable job of finding new ways to get more trees planted, but the fact remains young trees are not receiving enough care during the first five years of establishment. Mature trees provide many of the benefits currently enjoyed by the community, but neither young nor maturing trees are receiving the care necessary to support them into maturity, insuring that citizens reap a higher level of benefits over a longer period. The budget for providing these trees with minimal care has eroded in the past few years. The Green Works Orlando program speaks to tree planting, but the act of planting trees is not enough to insure an increase in canopy and benefits. Orlando needs to establish stable funding for a long-range planting and care program providing adequate care and maintenance to reduce high street tree mortality, insure survival of new plantings, and improve the health of established plantings.

New and recent plantings should be closely monitored to evaluate species success. Only about 60% of trees planted appear to reach their full mature stature, and the reason for this remains unclear. Pest issues, poor species selection, lack of irrigation compounded by drought, or insufficient soil quality or volume to allow for full growth are a few possible explanations. Funding to allow for a suitable monitoring program will help the Parks Division determine what changes need to be made to ensure trees grow to their full size and provide maximum benefits. Through monitoring trees that do best can be selected for planting in greater numbers to increase diversity.

Chapter Six—Conclusion

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

The 68,211 street trees in the City of Orlando are a valuable asset, providing nearly $4 million ($58 per tree) in annual benefits. Benefits to the community are most pronounced for stormwater runoff reductions, energy savings, and aesthetic and other benefits. Thus, municipal street trees play a particularly important role in maintaining the environmental and aesthetic qualities of the city (Figure 15). Orlando spends approximately $2.1 million maintaining these trees or $31 per tree.

After expenditures are taken into account, Orlando's street tree resource currently provides approximately $1.8 million or $27 per tree ($8 per capita) in net annual benefits to the community. Over the years, Orlando has invested millions of dollars in these trees. **Citizens are seeing a return on that investment—receiving $1.87 in benefits for every $1 spent on tree care**.

The street trees of Orlando are a dynamic resource. Managers of the urban forest and the community alike can take pride in knowing that these trees greatly improve the quality of life in the city. However, the trees are also a fragile resource needing constant care to maximize and sustain production of benefits into the future while also protecting the public from potential hazard. It is remarkable that the Parks Division has been able to sustain the street tree population this effectively, given fiscal reduc-

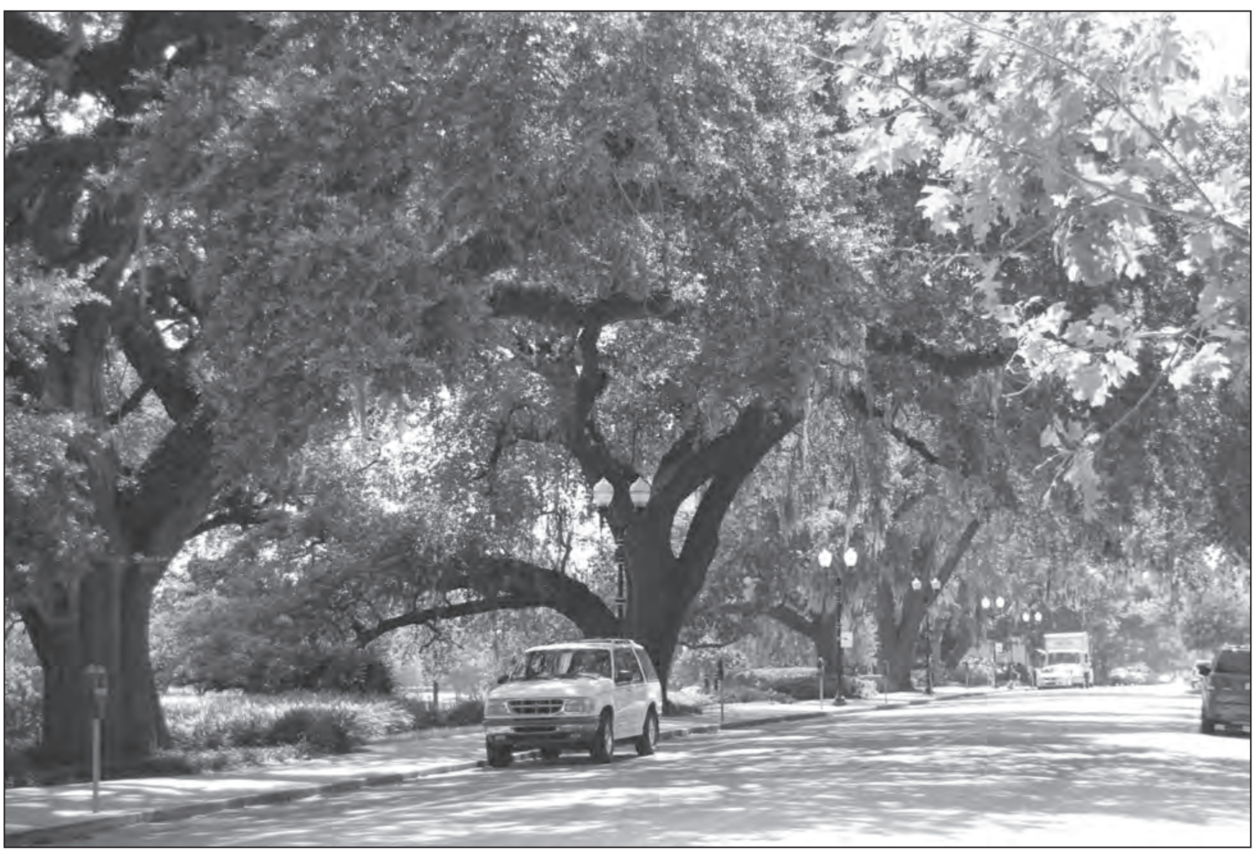

Figure 15—Old trees grace city streets.

tions which include loss of personnel and funding for tree care. The challenge as the city continues to grow is to sustain and expand the existing canopy cover to take advantage of the increased environmental and aesthetic benefits the trees can provide to the community.

Management recommendations focused on sustaining existing benefits and increasing future benefits follow. These will also help Orlando meet its goals of creating a greener, more sustainable community through the Green Works Orlando initiative and other programs:

1. Where conditions are suitable, increase stocking level with large-growing shade tree species to maximize benefits.
2. Evaluate non-oak species planted over the past 20 years to determine those that are performing best and increase their numbers to help guard against potential catastrophic losses of laurel and live oak due to storms, pests or disease.
3. Where small, understory trees are needed, broaden the planting palette to reduce the predominance of crapemyrtle.
4. Plan and fund regular inspection and pruning cycles to reduce street tree mortality rates, insure tree survival and public safety. Plans should address:
    - an improved young-tree care program that details inspections and structural pruning at least twice during the initial five years after planting to reduce young-tree mortality and provide a good foundation for the trees.
    - planned inspection and pruning cycles for mature trees (e.g., laurel and live oak) to prolong the functional life spans of these trees and increase current benefits.
    - a tree removal and replacement program designed to gradually and systematically replace dead, declining and hazardous trees with those that will grow to a similar stature. The program should insure that every removal is replaced and that current empty sites are planted.
    - continued removal of Category I and II invasive tree species and replacement with non-invasives.
    - coordination with public works department to introduce and employ strategies to reduce conflicts (e.g. sidewalk engineering, structural soils, replacing old sewer systems, re-assessing tree size for planting space when replacing; see Costello and Jones 2003).
5. Continue funding the updating, maintenance, and use of a working inventory of all public trees to properly assess, track, and manage the resource.
6. Use existing outreach and education programs to continue educating the public and civic leaders about the environmental services trees provide, including how those benefits increase for well-maintained trees.

These recommendations build on a history of dedicated management and commitment to natural resource preservation and Orlando now has the opportunity to put itself on a course toward providing citizens with an urban forest resource that is increasingly functional and sustainable.

Appendix A—Tree Distribution

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

	DBH class (in)									
Species	**0-3**	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**
Broadleaf Deciduous Large (BDL)										
Laurel oak	86	476	1,270	1,676	2,173	2,142	1,449	767	581	10,620
Shumard oak	75	676	534	106	10	3	-	-	-	1,404
Trumpet-tree	117	154	97	9	2	1	-	-	-	380
Sweetgum	5	22	72	88	63	26	8	-	-	284
American sycamore	1	25	75	118	52	11	2	-	-	284
Baldcypress	3	61	158	39	5	4	-	-	-	270
Water oak	1	4	29	35	48	25	18	5	3	168
Willow oak	-	3	12	21	33	39	19	12	6	145
Black cherry	16	24	58	25	8	3	1	-	-	135
Oriental sweetgum	1	8	34	16	26	4	1	-	-	90
Pecan	4	1	18	16	8	6	4	1	2	60
Ear pod tree	-	10	6	8	5	3	2	-	3	37
Winged elm	10	7	15	1	-	-	-	-	-	33
Oak	1	12	1	1	-	-	-	-	-	15
Green ash	1	-	4	4	1	1	-	-	-	11
Silk floss tree	2	3	5	-	-	-	-	-	-	10
Elm	2	-	4	2	-	2	-	-	-	10
Tulip tree	2	1	4	1	1	-	-	-	-	9
Tipu tree	-	1	4	1	1	1	-	-	-	8
Hickory	4	3	-	-	-	-	-	-	-	7
Swamp chestnut oak	-	-	5	1	1	-	-	-	-	7
Acacia amarilla	-	2	3	-	1	-	-	-	-	6
Southern red oak	1	2	1	2	-	-	-	-	-	6
Pignut hickory	-	1	1	1	2	-	-	-	-	5
Frangipani	4	1	-	-	-	-	-	-	-	5
American elm	-	1	1	1	1	1	-	-	-	5
Pond cypress	-	-	-	3	1	-	-	-	-	4
Red hickory	-	-	-	3	-	-	-	-	-	3
Mockernut hickory	-	-	1	1	-	1	-	-	-	3
Mahogany	1	1	-	1	-	-	-	-	-	3
Siberian elm	-	-	3	-	-	-	-	-	-	3
Hybrid elm	2	-	1	-	-	-	-	-	-	3
India rosewood	-	-	1	1	-	-	-	-	-	2
White oak	-	1	1	-	-	-	-	-	-	2
Texas red oak	-	1	1	-	-	-	-	-	-	2
Shagbark hickory	-	-	-	-	-	-	-	-	1	1
Thornless honeylocust	-	1	-	-	-	-	-	-	-	1
Eastern cottonwood	-	-	1	-	-	-	-	-	-	1
Total	339	1,502	2,420	2,181	2,442	2,273	1,504	785	596	14,042
Broadleaf Deciduous Medium (BDM)										
Chinese elm	123	1,076	1,266	132	7	3	1	1	-	2,609

Species	DBH class (in) 0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Red maple	54	182	708	567	220	61	18	3	1	1,814
Tallowtree	14	54	185	114	32	5	2	-	-	406
Chineseraintree	31	40	138	82	54	11	-	-	1	357
Chinaberry	9	18	26	29	14	6	-	1	-	103
Unknown tree	11	10	14	6	-	1	-	-	-	42
White mulberry	9	7	9	1	1	-	-	-	-	27
Paper mulberry	-	7	14	3	2	-	-	-	-	26
Jacaranda	2	11	10	1	-	-	-	-	-	24
Common persimmon	-	7	2	1	-	1	-	-	-	11
Slippery elm	-	1	7	2	1	-	-	-	-	11
River birch	-	2	4	1	-	-	-	-	-	7
Boxelder	-	1	3	2	-	-	-	-	-	6
Black tupelo	1	-	3	-	1	-	-	-	-	5
Weeping willow	4	-	-	1	-	-	-	-	-	5
Canafistula	2	1	1	-	-	-	-	-	-	4
Carolina ash	-	2	1	-	-	1	-	-	-	4
Sea hibiscus	1	2	-	-	-	-	-	-	-	3
Paradise apple	1	1	-	-	-	-	-	-	-	2
Rough-shell macadamia	1	-	1	-	-	-	-	-	-	2
Royal paulownia	1	1	-	-	-	-	-	-	-	2
Common pear	-	2	-	-	-	-	-	-	-	2
Birch	-	-	1	-	-	-	-	-	-	1
American hornbeam	-	-	-	1	-	-	-	-	-	1
Ginkgo	1	-	-	-	-	-	-	-	-	1
Sawtooth oak	1	-	-	-	-	-	-	-	-	1
Total	266	1,425	2,393	943	332	89	21	5	2	5,476
Broadleaf Deciduous Small (BDS)										
Common crapemyrtle	5,546	8,129	1,248	50	12	2	1	-	-	14,988
Callery pear	8	19	35	32	19	-	-	-	-	113
Flowering dogwood	15	47	21	1	-	-	-	-	-	84
Brazilian pepper	14	37	14	-	-	-	1	-	-	66
Mimosa	7	17	21	8	2	-	1	1	-	57
Eastern redbud	13	19	5	1	-	-	-	-	-	38
Plum	18	10	3	1	-	-	-	-	-	32
Cassia	10	8	-	-	-	-	-	-	-	18
Peach	4	10	3	-	-	-	-	-	-	17
Jerusalem thorn	3	7	2	-	-	-	-	-	-	12
European black elderberry	-	5	3	-	-	-	-	-	-	8
Royal poinciana	-	1	6	-	-	-	-	-	-	7
Indiantree spurge	1	4	-	-	-	-	-	-	-	5
Chickasaw plum	1	2	1	1	-	-	-	-	-	5
Winter cassia	2	2	-	-	-	-	-	-	-	4
Chinese magnolia; Saucer magnolia	3	1	-	-	-	-	-	-	-	4
Turkey oak	-	-	-	1	2	1	-	-	-	4
Common fig	3	-	-	-	-	-	-	-	-	3

	DBH class (in)									
Species	**0-3**	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**
Rose mallow hibiscus	1	2	-	-	-	-	-	-	-	3
Rattlebox	3	-	-	-	-	-	-	-	-	3
Star magnolia	-	2	-	-	-	-	-	-	-	2
Unknown shrub	-	-	1	1	-	-	-	-	-	2
Japanese maple	1	-	-	-	-	-	-	-	-	1
Total	5,653	8,322	1,363	96	35	3	3	1	-	15,476
Broadleaf Evergreen Large (BEL)										
Live oak	680	4,367	4,463	2,608	1,996	1,205	683	470	654	17,126
Southern magnolia	662	730	382	131	28	10	6	3	-	1,952
Golden tabebuia	47	58	17	1	-	-	-	-	-	123
Japanese blueberry tree	33	37	23	-	1	-	-	-	-	94
Sand live oak	-	-	9	15	20	18	7	5	3	77
Indian banyan	20	40	3	1	-	-	-	-	-	64
Punktree	-	4	30	6	4	4	-	-	1	49
Avocado	6	18	9	3	1	-	-	-	-	37
Rubber plant	17	10	1	-	-	-	-	-	-	28
Schefflera	8	14	-	-	-	-	-	-	-	22
Broad leaf podocarpus	-	4	3	4	1	1	-	1	-	14
Australian pine	-	-	5	5	1	1	-	-	-	12
Gum	1	2	3	4	1	-	-	-	-	11
White cedar	4	4	3	-	-	-	-	-	-	11
Canada yew	2	7	-	-	-	-	-	-	-	9
Redbay	-	-	3	2	-	-	-	-	-	5
Fiddle leaf fig	2	1	1	-	-	-	-	-	-	4
Silk oak	-	-	2	-	1	-	-	-	-	3
India tamarind	2	-	-	1	-	-	-	-	-	3
Loblolly bay	-	2	-	-	-	-	-	-	-	2
Paradise tree	-	2	-	-	-	-	-	-	-	2
Lemon scented gum	1	-	-	-	-	-	-	-	-	1
Total	1,485	5,300	4,957	2,781	2,054	1,239	696	479	658	19,649
Broadleaf Evergreen Medium (BEM)										
Camphor tree	38	105	241	177	111	79	57	27	44	879
Yew podocarpus	18	64	58	12	7	2	-	-	-	161
Weeping bottlebrush	26	43	47	14	-	-	1	-	-	131
Mountain ebony	23	52	27	4	-	-	-	-	-	106
Fig	9	6	2	1	-	-	-	-	-	18
Surinam cherry	4	11	2	-	-	-	-	-	-	17
Carrotwood	6	2	1	-	-	-	-	-	-	9
Acacia	6	-	-	-	-	-	-	-	-	6
Sweetbay	2	2	2	-	-	-	-	-	-	6
Coral tree	4	-	-	-	-	-	-	-	-	4
Toog	-	-	-	1	-	-	-	-	-	1
Total	136	285	380	209	118	81	58	27	44	1,338
Broadleaf Evergreen Small (BES)										
Holly	133	927	605	26	2	-	-	-	-	1,693

Species	DBH class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Japanese privet	103	391	119	6	-	1	-	-	-	620
Carolina laurelcherry	70	154	217	64	10	2	1	-	1	519
Loquat tree	66	127	84	7	-	-	-	-	-	284
Citrus	51	100	55	4	-	-	-	-	-	210
Fraser photinia	8	24	83	12	-	-	-	-	-	127
Glossy privet	6	17	3	2	-	-	-	-	-	28
Viburnum	2	13	13	-	-	-	-	-	-	28
Southern bayberry	1	17	8	-	-	-	-	-	-	26
Papaya	7	10	3	1	-	-	-	-	-	21
Chinese holly	7	12	2	-	-	-	-	-	-	21
Oleander	5	15	1	-	-	-	-	-	-	21
Indian hawthorn	7	9	-	-	-	-	-	-	-	16
Purple glory tree	8	5	1	-	-	-	-	-	-	14
Bougainvillea	2	8	1	-	-	-	-	-	-	11
Mango	5	4	2	-	-	-	-	-	-	11
Orange-jessamine	8	3	-	-	-	-	-	-	-	11
Pagoda flower	7	2	-	-	-	-	-	-	-	9
Sea grape	2	5	2	-	-	-	-	-	-	9
Pink powder puff tree	4	4	-	-	-	-	-	-	-	8
Mexican holdback	4	3	-	-	-	-	-	-	-	7
Star fruit	2	2	-	-	-	-	-	-	-	4
Feijoa	4	-	-	-	-	-	-	-	-	4
Yaupon	1	-	3	-	-	-	-	-	-	4
Shooting star	-	3	-	-	-	-	-	-	-	3
Dwarf poinciana	-	1	1	-	-	-	-	-	-	2
Jatropha	2	-	-	-	-	-	-	-	-	2
Rusty pittosporum	-	2	-	-	-	-	-	-	-	2
Sweet viburnum	-	2	-	-	-	-	-	-	-	2
Bamboo	1	-	-	-	-	-	-	-	-	1
Datura	1	-	-	-	-	-	-	-	-	1
Photinia	-	1	-	-	-	-	-	-	-	1
Poonga oil tree	-	-	1	-	-	-	-	-	-	1
Total	517	1,861	1,204	122	12	3	1	-	1	3,721
Conifer Evergreen Large (CEL)										
Slash pine	81	131	348	317	64	4	-	-	-	945
Longleaf pine	1	15	24	39	58	12	2	-	-	151
Norfolk Island pine	46	54	46	3	-	-	-	-	-	149
Loblolly pine	1	9	27	25	8	3	-	-	-	73
Red cedar	17	19	8	1	-	-	-	-	-	45
Sugarberry	2	1	2	3	-	-	-	-	-	8
Chinese juniper	-	8	-	-	-	-	-	-	-	8
Pine	-	1	1	2	1	-	-	-	-	5
Sand pine	-	2	3	-	-	-	-	-	-	5
Shortleaf pine	-	-	5	-	-	-	-	-	-	5
Arizona cypress	1	1	2	-	-	-	-	-	-	4

	DBH class (in)									
Species	**0-3**	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**
Deodar cedar	-	-	1	-	-	-	-	-	-	1
Blue chinese fir	-	-	-	1	-	-	-	-	-	1
Total	149	241	467	391	131	19	2	-	-	1,400
Conifer Evergreen Medium (CEM)										
Southern redcedar	7	17	70	45	26	12	6	2	-	185
Juniper	9	34	7	3	-	1	-	-	-	54
Italian cypress	29	16	-	-	-	-	-	-	-	45
Leyland cypress	2	3	2	1	1	-	-	-	-	9
Total	47	70	79	49	27	13	6	2	-	293
Conifer Evergreen Small (CES)										
Oriental arborvitae	60	239	133	31	7	-	-	-	-	470
Total	60	239	133	31	7	-	-	-	-	470
Palm Evergreen Large (PEL)										
Queen palm	26	164	540	87	-	-	-	-	-	817
Canary island date palm	2	3	2	18	46	32	6	2	-	111
Senegal date palm	1	12	39	4	-	-	-	-	-	56
Coconut palm	-	-	3	-	-	-	-	-	-	3
Total	29	179	584	109	46	32	6	2	-	987
Palm Evergreen Medium (PEM)										
Cabbage palmetto	5	33	904	1,624	269	20	-	-	-	2,855
Date palm	-	2	3	76	197	16	1	1	-	296
Chinese fan palm	1	3	43	23	1	-	-	-	-	71
Foxtail palm	13	25	8	2	-	-	-	-	-	48
Toddy palm	-	-	13	17	14	2	-	-	-	46
Ribbon palm	-	-	9	4	-	-	-	-	-	13
Queen sago	-	-	1	1	-	-	-	-	-	2
Total	19	63	981	1,747	481	38	1	1	-	3,331
Palm Evergreen Small (PES)										
Mexican fan palm	5	6	247	777	339	9	1	-	-	1,384
Jelly palm	-	1	32	142	94	31	3	1	-	304
Pygmy date palm	2	128	30	-	-	-	-	-	-	160
Areca palm	16	35	-	-	-	-	-	-	-	51
Christmas palm	4	26	-	-	-	-	-	-	-	30
King palm	-	-	7	13	-	-	-	-	-	20
Paurotis palm	-	16	1	-	-	-	-	-	-	17
Mediterranean fan palm	-	11	6	-	-	-	-	-	-	17
Burmese fishtail palm	4	7	-	-	-	-	-	-	-	11
Bottle palm	-	1	3	3	-	-	-	-	-	7
Bismarckia palm	-	-	2	3	-	-	-	-	-	5
Pony-tail palm	-	4	-	-	-	-	-	-	-	4
Majesty palm	1	3	-	-	-	-	-	-	-	4
California palm	-	-	-	1	2	1	-	-	-	4
Triangle palm	-	-	2	1	-	-	-	-	-	3
Yucca	1	-	2	-	-	-	-	-	-	3
Grugru palm	-	-	1	-	-	-	-	-	-	1

Species	DBH class (in)									
	0-3	**3-6**	**6-12**	**12-18**	**18-24**	**24-30**	**30-36**	**36-42**	**>42**	**Total**
Carnauba wax palm	-	-	1	-	-	-	-	-	-	1
King sago	-	-	-	1	-	-	-	-	-	1
Unknown palm	-	-	-	1	-	-	-	-	-	1
Total	33	238	334	942	435	41	4	1	-	2,028
Citywide Total	8,733	19,725	15,295	9,601	6,120	3,831	2,302	1,303	1,301	68,211

Appendix B

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 municipal tree sampling, tree growth modeling, and the model inputs and calculations used to derive the aforementioned outputs.

Growth Modeling

A stratified random sample of 895 street trees, drawn from Orlando's 2007 tree database containing 85,093 records (street and park trees plus empty planting spaces), 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 20 of the most abundant species; from these data, growth of all trees was inferred. The species were as follows:

- Red maple (*Acer rubrum*)
- Camphor tree (*Cinnamomum camphora*)
- Loquat tree (*Eriobotrya japonica*)
- Southern redcedar (*Juniperus virginiana* var. *silicicola*)
- Chinese raintree (*Koelreuteria elegans*)
- Common crapemyrtle (*Lagerstroemia indica*)
- Sweetgum (*Liquidambar styraciflua*)
- Southern magnolia (*Magnolia grandiflora*)
- Slash pine (*Pinus elliottii*)
- American sycamore (*Platanus occidentalis*)
- Carolina laurel cherry (*Prunus caroliniana*)
- Laurel oak (*Quercus laurifolia*)
- Shumard oak (*Quercus shumardii*)
- Live oak (*Quercus virginiana*)
- Cabbage palmetto (*Sabal palmetto*)
- Queen palm (*Syagrus romanzoffiana*)
- Oriental arborvitae (*Platycladus orientalis*)
- Tallowtree (*Triadica sebifera*)
- Chinese elm (*Ulmus parvifolia*)
- Mexican fan palm (*Washingtonia robusta*)

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

- 0–3 in (0–7.6 cm)
- 3–6 in (7.6–15.2 cm)
- 6–12 in (15.2–30.5 cm
- 12–18 in (30.5–45.7 cm)
- 18–24 in (45.7–61.0 cm)
- 24–30 in (61.0–76.2 cm)
- 30–36 in (76.2–91.4 cm)
- 36–42 in (91.4–106.7 cm)
- >42 in (>106.7 cm)

Thirty to sixty 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 municipal tree managers. Fieldwork was conducted in June and July 2008.

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 and non-linear regression was used to fit predictive models—with DBH as a function of age—for each of the 20 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. 2003).

Replacement Value

The monetary worth, or value, of a tree is based on people's perception of it (Cullen 2000). There are several approaches that arborists use to develop a fair and reasonable perception of value (CTLA 1992, Watson 2002). The cost approach is widely used today and assumes that the cost of production equals value (Cullen 2002).

The trunk formula method (CTLA 1992), also called depreciated replacement cost, is a commonly used approach for estimating tree value in terms of cost. It assumes that the benefits inherent in a tree are reproduced by replacing the tree, and therefore, replacement cost is an indication of value. Replacement cost is depreciated to reflect differences in the benefits that would flow from an "idealized" replacement compared to the imperfect appraised tree.

We regard the terms "replacement value" and "replacement cost" as synonymous indicators of the urban forest's value. Replacement value is indicated by the cost of replacing existing trees with trees of similar size, species, and condition if all were destroyed, for example, by a catastrophic storm. Replacement cost should be distinguished from the value of annual benefits produced by the urban forest. The latter is a "snapshot" of benefits during one year, while the former accounts for the long-term investment in trees now reflected in their number, stature, placement, and condition. Hence, the replacement value of a street tree population is many times greater than the value of the annual benefits it produces.

The trunk formula method uses tree size, species, condition, and location factors to determine tree replacement value. Tree size is measured as trunk area (TA, cross-sectional area of the trunk based on DBH), while the other factors are assessed subjectively relative to a "high-quality" specimen and expressed as percentages. The equation is

Replacement value = Basic value × Condition% × Location%

Basic value = Replacement cost + (Basic price × [TAA−TAR] × Species%)

where

Condition% = Rating of structural integrity and health; a higher percentage indicates better condition (CTLA 1992)

Location% = Rating of the site itself (relative market value), contribution of the tree in terms of its aesthetic and functional attributes, and placement, which reflects the effectiveness of realizing benefits; location is the sum of site, contribution, and placement divided by three (CTLA 1992). A higher percentage indicates better location.

Replacement cost = Sum of the cost of the replacement tree (of size TAR) and its installation

Basic price = Cost of the largest available transplantable tree divided by TAR ($/in2)

TAA = Trunk area of appraised tree (in2) or height of clear trunk (linear ft) for palms

TA_R = Trunk area of replacement tree (in^2) or height of clear trunk (linear ft) for palms

Species% = Rating of the species' longevity, maintenance requirements, and adaptability to the local growing environment (CTLA 1992)

In this study, data from the Florida International Society of Arboriculture "2001 Tree Species Ratings for Florida" were used for species ratings while unit and installed tree cost data were supplied by Earth Advisors, Inc. after evaluating cost survey data from arborists in Central Florida. Together, these data were used to calculate replacement value (Florida ISA Chapter 2001). Tree condition ratings were based on the inventory (or set at 70% when no data were available) and location ratings were arbitrarily set at 70%, indicative of a tree located in a typical park. TA_R is 7.065 in^2 for a 3-in caliper tree representing the largest tree that is normally available from wholesalers; TA_A is calculated using the midpoint for each DBH class. The basic price was \$45/in^2 TA, based on the wholesale cost of a 6-in caliper tree. Replacement costs equaled the cost for a 6-in tree plus installation.

Replacement values were calculated using the trunk formula equation for each species by DBH class, then summed across DBH classes and species to derive total replacement value for the population.

Identifying and Calculating Benefits

Annual benefits for Orlando's municipal trees were estimated for the fiscal year 2007-08. 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 Orlando, 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 that outside air moves into a building can increase substantially with wind speed. In cold, Orlando 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 20 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 Orlando's climate based on consultation with forestry supervisor (Kittsley 2009).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to Orlando (i.e.,

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**		**Institu- tional/**
	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	Trans-portation
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	14%	63%	76%	14%	63%	76%	14%	63%	76%	14%	63%	76%	14%	63%	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	59%	23%	5%	59%	23%	5%	59%	23%	5%	59%	23%	5%	59%	23%	5%	9%	9%	9%
None	27%	14%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	5%	5%
Adjusted cooling saturation	28%	69%	77%	28%	69%	77%	28%	69%	77%	28%	69%	77%	28%	69%	77%	88%	88%	88%

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 2008.

Land use (single-family residential, multifamily residential, commercial/industrial, other) for right-of-way trees was based on the same tree sample. 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 for Orlando (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 Orlando were used (National Oceanic and Atmospheric Administration 2007). Dollar values for energy savings were based on electricity and natural gas prices of $0.132/kWh (Orlando Utilities Commission 2009) and $0.268/therm (Peoples Gas 2009), respectively.

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 modify 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

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		Institu-tional/
	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**	**Transpor-tation**
Equipment efficiencies																		
Natural gas (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
Heat pump (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
Electric resistance (HSPF)	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41	3.41
Electric Heating saturations																		
Electric resistance	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	4.9%	4.9%	4.9%
Heat pump	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	5.4%	5.4%	5.4%
Adj elec heat saturations	2.7%	4.2%	9.7%	2.7%	4.2%	9.7%	2.7%	4.2%	9.7%	2.7%	4.2%	9.7%	2.7%	4.2%	9.7%	1.7%	1.7%	1.7%
Natural Gas and other heating																		
Natural gas	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	89.7%	89.7%	89.7%
Oil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other	9.1%	11.3%	4.8%	9.1%	11.3%	4.8%	9.1%	11.3%	4.8%	9.1%	11.3%	4.8%	9.1%	11.3%	4.8%	0.0%	0.0%	0.0%
NG Heat saturations:	82%	73%	33%	82%	73%	33%	82%	73%	33%	82%	73%	33%	82%	73%	33%	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		Institu- tional
	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**	**Transpor-tation**
Vintage distribution by building type	5.4%	40.4%	54.1%	1.1%	38.6%	60.3%	5.4%	40.4%	54.1%	7.2%	46.1%	46.7%	1.7%	31.4%	66.9%	100.0%	100.0%	100.0%
Tree distribution by vintage and building type	4.6%	34.7%	46.5%	0.1%	2.6%	4.0%	0.4%	3.0%	4.0%	1.8%	11.5%	11.6%	1.3%	23.5%	50.2%	63.0%	37.0%	100.0%
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	1.29%	23.43%	35.17%	0.02%	1.74%	3.04%	0.10%	1.79%	2.69%	0.37%	5.74%	6.52%	0.14%	6.51%	15.58%	19.4%	5.7%	0.0%
Cooling factor: climate	1.32%	23.97%	35.98%	0.02%	1.70%	2.97%	0.09%	1.68%	2.53%	0.23%	3.57%	4.05%	0.17%	7.48%	17.90%	17.4%	34.1%	0.0%
Combined vintage, equipment saturation factors for heating																		
Heating factor, nat. gas: shade	3.71%	24.87%	15.15%	0.06%	1.84%	1.31%	0.28%	1.90%	1.16%	1.07%	6.09%	2.81%	0.42%	6.91%	6.71%	19.7%	5.8%	0.0%
Heating factor, electric: shade	0.12%	1.42%	4.42%	0.00%	0.11%	0.38%	0.01%	0.11%	0.34%	0.04%	0.35%	0.82%	0.01%	0.40%	1.96%	0.38%	0.11%	0.00%
Heating factor, nat. gas: climate	3.80%	25.44%	15.50%	0.03%	1.03%	0.73%	0.31%	2.11%	1.28%	0.63%	3.60%	1.66%	0.51%	8.41%	8.16%	68.0%	133.1%	0.0%
Heating factor, electric: climate	0.13%	1.46%	4.52%	0.00%	0.06%	0.21%	0.01%	0.12%	0.37%	0.02%	0.21%	0.48%	0.02%	0.48%	2.38%	1.30%	2.55%	0.00%

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 were estimated as a function of neighborhood canopy cover 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 C3*). Heating loads were converted to fuel use based on efficiencies in *Table C2*. 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 C3*).

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 roofs are exposed and could be shaded by a tree, while a PSF of 0 indicates that no shading is possible (e.g., 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 the 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 McHale et al. (2009) and 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 with results reduced by 20% to reflect lower woody and higher foliar biomass partitioning of open-grown trees (Tritton and Hornbeck 1982; Ter-Mikaelian and Korzukhin 1997; Jenkins et al. 2004).

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 Orlando was 1.0% per year for the first five years after planting for street trees and 1.0% every year thereafter (Aldridge 2009). Finally, CO_2 released during tree maintenance was estimated to be 0.34 lb CO_2 per inch DBH based on the expenditure survey results for gas (6,180 gal), diesel fuel (11,667 gal) and biodiesel fuel (4,064 gal).

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 Orlando. The fuel mix for electrical generation included coal (97.89%), biomass (1.85%), oil (0.18%) and natural gas (0.08%) (U.S. EPA 2007).

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 $6.68/ton based on the average value in Pearce (2003).

	Emission Factor		
	Electricity (lb/MWh)[a]	Natural gas (lb/MBtu)[b]	Implied value ($/lb)[c]
CO_2	2,037	118	0.0033
NO_2	2.808	0.1020	2.20
SO_2	2.257	0.0006	2.01
PM_{10}	0.985	0.0075	2.10
VOC's	0.984	0.0054	1.03

[a]USEPA, eGRID 2002, except Ottinger et al. 1990 for VOC's
[b]U. S. Environmental Protection Agency 1998.
[c]CO_2 from Pearce (2003); value for all other pollutants based on the methods of Wang and Santini (1995) using emissions concentrations from US EPA (2005) and population estimates from the U.S. Census Bureau (2003)

Table B4—*Emissions factors and monetary implied values for CO2 and criteria air pollutants.*

Improving Air Quality

Calculating 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. b 2009). The prices 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. (2009b), and population estimates for the city of Orlando from the US Census Bureau (2009).

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 Orlando were obtained from the Environmental Protection Agency (U.S. EPA 2007). The year 2007 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 Scott 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 Orlando during July 2008. 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 2007 described in the pollutant uptake section were used as model inputs (Renewable Resource Data Center 2007). Hourly emissions were summed to get annual totals.

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 0.1°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 benefits that result from reduced surface 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), the depth of water captured by the canopy surface, and the surface water storage capacity of the tree crown. 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 2008 at the Orlando International Airport (ORL) (Latitude: 28.433° N, Longitude: -81.333°, Elevation: 27.4 m (90') above sea level, CoopID: 086628) in Orlando, Florida, were used in this simulation. The year 2008 was chosen because it closely approximated the long time average rainfall of 48.35 in (1,228.1 mm). Annual precipitation at ORL during 2008 was 53.8 in (1,366.5 mm). Storm events less than 0.1 in (2.5 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 City of Orlando spends approximately $36.5 million annually on operations and maintenance of its stormwater management system (City of Orlando 2008-09). To calculate annual runoff we assigned curve numbers for each land use (USDA SCS 1986). Land use percentages were obtained from the city land use GIS layers (2009). We calculated runoff depth for each land use (12.4 in, citywide) and found the citywide total to be 37,374 acre-feet. The annual stormwater control cost was estimated to be $0.003 per gallon of runoff.

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 material, 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 (25-year-old laurel oak, average leaf surface area 5,248 ft2) 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 Orlando, each large tree would be worth $1,542 based on the 4th quarter, 2008, median single-family-home resale price in Orlando ($175,200) (National Association of Realtors 2009). 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 reduction factor (0.83) 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 reduction factor reflects the distribution of municipal trees in Orlando by land use. The overall reduction factor for street trees reflects tree distribution by land use. Reduction factors were single-home residential (100%), multi-home residential (75%), small commercial (66%), industrial/institutional/large commercial (50%), vacant/other (50%) (McPherson et al. 2001). Trees in parks were assigned a reduction factor of 0.50.

Estimating Magnitude of Benefits

Resource units describe the absolute value of the benefits of Orlando'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 Orlando 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 the 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 DBH classes described at the beginning of this chapter.

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 London planetrees citywide in the 30–36 in DBH class. The interpolated electricity and natural gas resource unit values for the class midpoint (33 in) were 199.3 kWh and 6,487.9 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: 59,790 kWh of electricity saved and 1,946,370 kBtu of natural gas saved.

Matching Significant Species with Modeled Species

To extrapolate from the 20 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 >50 ft, 35–50 ft, and <35 ft in mature height, respectively. A typical tree was chosen to represent each of the above 12 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = Laurel oak (*Quercus laurifolia*)

BDM Other = Chinese elm (*Ulmus parvifolia*)

BDS Other = Crapemyrtle (*Lagerstroemia indica*)

BEL Other = Southern magnolia (*Magnolia grandiflora*)

BEM Other = Camphor tree (*Cinnamomum camphora*)

BES Other = Loquat (*Eriobotrya japonica*)

CEL Other = Slash pine (*Pinus elliottii*)

CEM Other = Southern redcedar (*Juniperus virginiana* var. *silicicola*)

CES Other = Oriental arborvitae (*Platycladus orientalis*)

PEL Other = Cabbage palmetto (*Sabal palmetto*)

PEM Other = Queen palm (*Syagrus romanzoffiana*)

PES Other = Mexican fan palm (*Washingtonia robusta*)

When local data were not measured for certain categories, growth data from similar-sized species in a different region were used. Tree ages for the sample were determined by the urban forester (Kittsley 2009).

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.

Orlando 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 city-wide 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:

Equation 3

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

where

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

a = price of annual net air quality improvement = PM10 interception + NO2 and O3 absorption + avoided power plant emissions – BVOC emissions

c = price of annual carbon dioxide reductions = CO2 sequestered – releases + CO2 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 (Aldridge 2009). Annual costs for the municipality (*C*) were summed:

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

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

cl = 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:

Citywide Net Benefits = B – C *Equation 4*

BCR = B / C *Equation 5*

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