City of Indianapolis, Indiana
Municipal Forest Resource Analysis

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

Technical Report to:
Lindsey Purcell, Indianapolis City Forester
Parks and Recreation Department
City of Indianapolis, Indiana

—April 2008—



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Executive Summary

Indianapolis, the capital and largest city in the state of Indiana, maintains parks and street trees as an integral component of the urban infrastructure (*Figure 1*). Located along the original east-west National Road, the city is a transportation hub connecting to Chicago, Louisville, Cincinnati, Columbus, Detroit, Cleveland and St. Louis—a fitting capital for a state known as the "Crossroads of America."

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

- 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)



Figure 1—Trees shade Indianapolis neighborhoods. Street trees in Indianapolis provide great benefits, improving air quality, sequestering carbon dioxide, reducing stormwater runoff and beautifying the city. The trees of Indianapolis return $6.09 in benefits for every $1 spent on tree care.

Resource Structure

Indianapolis's tree inventory includes 117,525 publicly managed trees along street rights-of-way. These include 177 tree species with silver maple (*Acer saccharinum*), sugar maple (*Acer saccharum*), Northern hackberry (*Celtis occidentalis*), white ash (*Fraxinus americana*), and crabapple (*Malus species*) as 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 and distribution of trees among species.

There is approximately one street tree for every seven residents, and these trees shade approximately 0.74% of the city or 13.8% of the city's streets and sidewalks.

The age structure of Indianapolis's street tree population appears fairly close to the desired "ideal" distribution with the exception of young tree representation in the 0-6 inch DBH class (diameter at breast height or 4.5 ft above the ground [DBH]) where the proportion is 11% below the ideal. Among mature trees, Indianapolis street trees are heavily represented in largest size classes by four species—Siberian elm (*Ulmus pumila*), silver maple, white ash and Northern hackberry. Many of these are nearing the end of their natural life spans. Loss of these 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 the young trees survive and grow to full maturity, Indianapolis can look forward to greater benefits in the future, as long as young tree planting is increased in the near future.

Resource Function and Value

The street trees of Indianapolis provide great benefits to the citizens. Their ability to moderate climate—thereby reducing energy use—is substantial. Electricity saved annually in Indianapolis from both shading and climate effects of the street trees totals 6,447 MWh ($432,000), and annual natural gas saved totals 153,133 therms ($165,000) for a total energy cost savings of $597,000 or $5 per tree.

Citywide, annual carbon dioxide (CO_2) sequestration and emission reductions due to energy savings by street trees are 9,289 and 7,055 tons, respectively. CO_2 released during decomposition and tree-care activities is 2,198 tons. Net annual CO_2 reduction is 14,146 tons, valued at $94,495 or $0.80 per tree.

Net annual air pollutants removed, released, and avoided average 1.5 lbs per tree and are valued at $212,000 or $1.80 per tree. Ozone ($O_3$) is the most significant pollutant absorbed by trees, with 23.7 tons per year removed from the air ($38,859), while sulfur dioxide (SO_2) is the most economically significant air pollutant at 42.3 tons per year ($127,000).

Indianapolis's street trees intercept rain, reducing stormwater runoff by 318.9 million gallons annually, with an estimated value of $1.98 million. Citywide, the average tree intercepts 2,714 gallons of stormwater each year, valued at $16.83 per tree.

The estimated total annual benefits associated with aesthetics, property value increases, and other less tangible improvements are approximately $2.85 million or $24 per tree on average.

The grand total for all annual benefits—environmental and aesthetic—provided by street trees is $5.73 million, an average of $49 per street tree. The city's 16,371 silver maples produce the highest total level of benefits at $984,000, annually ($60 per tree, 17.2% of total benefits). On a per tree basis, Northern hackberry ($81 per tree) and Eastern cottonwood (*Populus deltoides*, $77 per tree) also produce significant benefits. Small-stature species, such as the crabapple ($19 per tree), Eastern redbud (*Cercis canadensis*, $18 per tree), and plum (*Prunus species*, $18 per tree) provide the lowest benefits.

Indianapolis spends approximately $940,130 in a typical year (2005) maintaining its street trees

($8.00/tree). The highest single cost is tree removal ($491,500), followed by contract or staff pruning ($129,700). Silver maple, due to age and structural problems, accounts for a significant proportion of maintenance costs associated with tree removal, storm cleanup, and property and infrastructure damage. It is important to note that the contract budget has been reduced by about $100,000 since 2005 and the Forestry Section experienced an staff reduction of 2.5 positions.

Subtracting Indianapolis's total expenditures on street trees from total costs shows that Indianapolis's municipal street tree population is a valuable asset, providing approximately $5.73 million or $49 per tree ($7.32 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 $6.09 in benefits for every $1 spent on tree care.** Indianapolis's benefit–cost ratio of 6.09 is the highest in 15 studies to date, similar to that for New York City (5.60), but significantly higher than those reported for Berkeley, CA (1.37), Charleston, SC (1.34), and Albuquerque (1.31), Fort Collins, CO (2.18), Cheyenne, WY (2.09), and Bismarck, ND (3.09).

A variety of factors can contribute to the benefit-cost ratio being higher than other communities, but on a per tree basis, Indianapolis spends the least on planting and managing trees compared to the other cities having average expenditures of $25 per tree. The benefits for Indianapolis, while significant, are also lower. The average benefit for 19 U.S. cities is $72 per tree compared to $49 per tree for Indianapolis. 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 a cities' trees and reflects their value over a lifetime. As a major component of Indianapolis's green infrastructure, the 117,525 street trees are estimated to have a replacement value of $113.1 million or $963 per tree.

Resource Management

Indianapolis'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.

In 2007, former Indianapolis Mayor Bart Peterson signed the U.S. Mayors Climate Protection Agreement. Current Mayor Gregory Ballard has endorsed this agreement and the Indy GreenPrint focused on creating a sustainable Indianapolis. The GreenPrint focuses on the role of "natural areas" for keeping air and water clean while contributing to vitality of neighborhoods. It is important to note, however, that street trees contribute more to reducing heat island effects, energy consumption, and ground-level ozone by shading the gray infrastructure than trees in backyards and parks. By acting now to implement the recommendations in this report, Indianapolis will be better able to meet its 7% emission reduction target by 2012, its GreenPrint goals, and generally benefit from a more functional and sustainable urban forest overall.

Management recommendations focused on sustaining existing benefits and increasing future benefits follow. These recommendations will also help Indianapolis meet its Climate Protection Agreement goals to reduce greenhouse gases and emissions and assist the city in creating a more sustainable envi-

ronment as it strives to meet its Greenprint planting goal (100,000 trees to be planted over 10 years):

1. Work together with the Tree Board and civic partnerships to develop a prioritized plan with targets and funding necessary to significantly increase shade tree planting along streets, in parking lots, and near buildings in and adjacent to public rights-of-way.
    - Revise, update, and enforce the current tree and landscape ordinance to create specific public and private street and parking lot shade guidelines promoting increased tree canopy and the associated benefits.
    - Specifically plan an increase in street tree stocking and canopy cover, setting an initial goal of planting 1 street tree for every 5 residents. This represents an increase of over 39,000 street trees (156,574 projected compared to 117,525 currently) for a 20% stocking level and 18.5% canopy cover over streets and sidewalks.
    - Increase stocking level with larger-growing shade tree species where conditions are suitable to maximize benefits. Continue planting a diverse mix of tree species, with a focus on native species, to guard against catastrophic losses due to storms, pests or disease.
    - Plan and fund inspection and pruning cycles to reduce street tree mortality rates and insure survival. 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., silver maples, hackberries, cottonwoods, American sycamores, and elms) 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 ensure that every removed tree is replaced and that current empty sites are planted.
2. Fund the updating, maintenance, and use of a working inventory of all public trees to properly assess, track, and manage the resource.
3. Adequately staff the Forestry Section to meet the planting and maintenance demands of the urban forest, increase the canopy along with associated environmental benefits, and ensure public safety.

The challenge is to better integrate the Indianapolis green infrastructure with its gray infrastructure. This can be achieved by including green space and trees in the planning phase of development projects, providing space for trees through adequate street design or property easements, planting that available space, and adequately funding the maintenance of those and prior plantings to maximize net benefits over the long term.

Chapter One—Introduction

Unlike most cities, Indianapolis was not established by settlers but by an 1816 U.S. Congress proclamation setting aside land for the capital of the Union's 19th state. Growth was slow until the National (or Cumberland) Road was routed through the city center in 1831, and subsequently, the building of the Madison & Indianapolis Railroad in 1847. Seven additional major rail lines were then built, providing the city access to the Ohio River. Today, Indianapolis is the capital and largest city in the state of Indiana and the 12th largest city in the country. It is the hub of commerce, banking and government for the state and region. During the late 1800s, palatial Victorian residences were built along North Meridian Street, and new neighborhoods and suburbs grew along tree-lined streets. Over the past century, Indianapolis residents and the city have continued planting trees on public and private properties. Indy Parks' Forestry Section actively manages more than 200,000 public trees in addition to over 14,000 acres of park property with over 38% forest canopy. (Pinco and Purcell 2008). 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 Indianapolis'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 Indianapolis 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 "nonessential," 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 Indianapolis'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 Indianapolis's urban forest.



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

- Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.
- Highlight the relevance and relationship of Indianapolis'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—Indianapolis's Municipal Street Tree Resource: Describes the current structure of the street tree resource.

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

Chapter Four—Benefits of Indianapolis'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—Replacement Values: Lists replacement values for the entire street tree population.

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

References—Lists publications cited in the study.

Chapter Two—Indianapolis's Municipal Tree Resource

Many Indianapolis 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. Today thousands of trees grace Indianapolis, earning the city recognition as a National Arbor Day Foundation "Tree City USA" for 20 consecutive years. Additionally, Indy has received the Foundation's Growth Award for six years and was awarded the Indiana Arborist Association's Gold Leaf Award for the 2007 Arbor Day Program.

The Forestry Section is responsible for the preservation, protection and management of more than 200,000 publicly owned trees in the City of Indianapolis and over 14,000 acres of Indianapolis Parks property. Forestry sponsors tree-planting events, workshops and seminars for tree professionals, the public, neighborhood groups, and staff.

Additionally, the Indianapolis/Marion County Tree Board was established by former Mayor Bart Peterson. Current Mayor Gregory Ballard has endorsed the U.S. Mayors Climate Protection Agreement and the Indy Greenprint. Cooperatively, citizens and the Forestry Section are striving to monitor and improve all aspects of their urban forest, continuing to make Indianapolis an enjoyable and healthy place to live.

Tree Numbers

The City of Indianapolis maintains an inventory of 210,229 street and park trees; the Center Township trees were re-inventoried in 2003. At the time of this study 117,525 street trees were tallied and were distributed through the nine Indianapolis townships as shown in *Figure 4*. This number includes 538 trees that were not assigned a township designation. In addition, the inventory listed 688 tree stumps and 10,109 available planting spaces.



Figure 3— Indianapolis's trees provides citizens with many environmental and aesthetic benefits.

The Indianapolis street tree population is dominated by deciduous trees (88.2% of the total). Conifers account for 11.8% of the street tree population, while broadleaf evergreen trees represent only 0.04%.

Street Tree Stocking Level

Although the inventory on which our study is based did not sample all current potential public right-of-way planting sites in Indianapolis, stocking level can be estimated based on total street miles and the city's inventory of 117,525 street trees. Assuming there are about 3,500 linear miles of streets in Indianapolis (Pinco 2007), on average there are 34 street trees per mile. A fully stocked city would have one tree on each side of the street every 50 feet or 211 trees per mile. By this measure, Indianapolis's street tree stocking level is 16%, and there is room, theoretically, for as many as another 620,975 trees.

The actual number of street tree plantings sites may be significantly less due to inadequate planting spaces, presence of privately owned trees, and utility conflicts. Indianapolis's current stocking level compares favorably with Fort Collins, CO (18%), Charlotte, NC (16%), and Boise, ID (14%), but is far less than other large cities like Minneapolis, MN (87%) and New York City (43%), as well as the mean stocking level for 22 U.S. cities (38.4%) (McPherson et al. 2005; McPherson and Rowntree 1989).

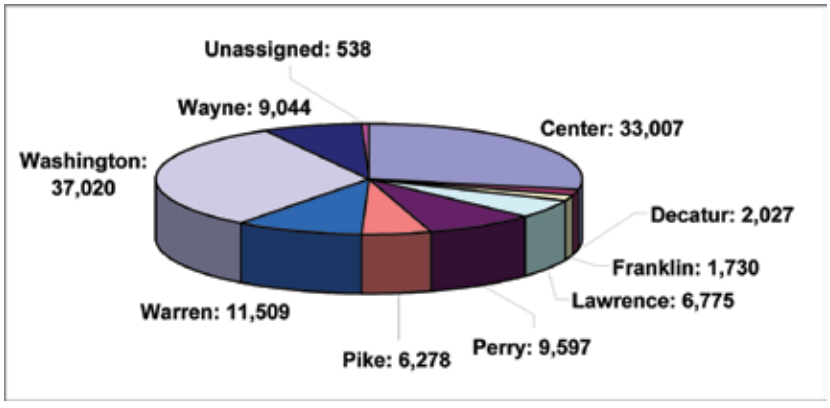


Figure 4—Urban forest management townships in Indianapolis with number of trees in each

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 782,871 (US Census Bureau 2005) and a street tree population of 117,525, Indianapolis's number of street trees per capita is 0.15—approximately one tree for every seven people—significantly below the mean ratio of 0.37 reported for 22 U.S. cities (McPherson and Rowntree 1989). More recent research shows Indianapolis's ratio is similar to Fort Collins, CO (0.12 or one tree per eight residents), but significantly lower than Minneapolis, MN (one tree per two residents) and Bismarck, ND (one tree per three residents) (McPherson et al. 2003, Peper et al. 2004a, b).

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 Indianapolis—likely represent less than 20% of the entire urban forest (Moll and Kollin 1993). The tree canopy in Indianapolis represented by street trees in the inventory is estimated at 1,758 acres and shades approximately 13.8% of public street and sidewalk surfaces.

Species Richness, Composition and Diversity

The street tree population in Indianapolis includes 177 different species and cultivars—over 3 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. This diversity is especially impressive considering the challenging growing conditions in a densely urbanized city.

The predominant municipal street tree species are silver maple (13.9%), sugar maple (6.0%), Northern hackberry (5.1%), white ash (4.9%), and crabapple (4.9%) (*Table 1*; see also *Appendix A*).

The Forestry Section, focused on species diversification, is working to conform to the general idea that no single species should represent more than 10% of the population and no genus more than

Table 1—*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)											
Silver maple	1,086	782	3,285	4,022	3,219	2,253	1,092	400	232	16,371	13.9
Sugar maple	535	765	1,839	1,794	1,397	538	134	29	11	7,042	6.0
Northern hackberry	266	644	1,822	1,195	768	519	321	215	190	5,940	5.1
White ash	689	785	1,589	1,195	682	385	202	101	89	5,717	4.9
Siberian elm	304	389	946	781	653	482	274	96	52	3,977	3.4
Norway maple	320	473	963	752	571	172	39	6	2	3,298	2.8
Red maple	658	722	810	518	238	133	42	9	5	3,135	2.7
Green ash	338	688	937	457	194	113	59	21	3	2,810	2.4
Black cherry	49	143	680	582	411	207	94	62	37	2,265	1.9
Ash	283	310	749	368	264	128	79	30	30	2,241	1.9
Northern red oak	292	259	332	388	268	175	119	55	52	1,940	1.7
Honeylocust	274	451	747	306	105	25	10	6	7	1,931	1.6
Eastern cottonwood	104	82	255	383	334	269	185	128	132	1,872	1.6
Pin oak	215	303	376	302	171	97	45	12	16	1,537	1.3
Black walnut	102	101	370	453	302	135	47	5	3	1,518	1.3
Sweetgum	149	240	413	474	157	36	7	2	-	1,478	1.3
Black locust	141	174	471	322	166	92	26	9	18	1,419	1.2
American sycamore	66	110	256	263	252	202	120	64	53	1,386	1.2
BDL other	1,736	1,451	2,668	1,894	1,144	709	523	256	207	10,588	9.0
Total	7,607	8,872	19,508	16,449	11,296	6,670	3,418	1,506	1,139	76,465	65.1
Broadleaf deciduous medium (BDM)											
Mulberry	439	455	999	542	294	180	91	57	50	3,107	2.6
Unknown medium	-	-	-	954	594	349	-	-	-	1,897	1.6
Callery pear	384	510	421	96	9	-	-	-	-	1,420	1.2
Boxelder	105	212	530	279	153	70	30	14	13	1,406	1.2
Slippery elm	136	303	475	190	71	34	14	4	6	1,233	1.0
Northern catalpa	68	51	186	190	206	226	143	75	43	1,188	1.0
BDM other	469	540	892	320	134	54	27	14	22	2,472	2.1
Total	1,601	2,071	3,503	2,571	1,461	913	305	164	134	12,723	10.8
Broadleaf deciduous small (BDS)											
Crabapple	1,539	1,498	1,936	541	184	56	24	18	7	5,803	4.9
Eastern redbud	452	369	715	273	95	37	19	9	3	1,972	1.7
Plum	550	416	476	161	78	24	12	7	6	1,730	1.5
Unknown small	211	290	1,214	-	-	-	-	-	-	1,715	1.5
BDS other	977	811	915	336	112	41	23	6	-	3,221	2.7
Total	3,729	3,384	5,256	1,311	469	158	78	40	16	14,441	12.3

***Table 1*, cont.**

Species	DBH Class (in) 0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	Total	% of Total
Broadleaf evergreen small (BES)											
BES other	12	17	15	-	1	-	-	-	-	45	0.0
Total	12	17	15	-	1	-	-	-	-	45	0.0
Conifer evergreen large (CEL)											
Eastern white pine	1,064	603	1,092	350	34	4	1	-	-	3,148	2.7
Blue spruce	756	762	939	174	17	1	2	-	3	2,654	2.3
Norway spruce	397	504	925	445	118	15	-	1	1	2,406	2.0
Scotch pine	145	242	596	209	34	9	2	1	1	1,239	1.1
CEL other	433	403	760	251	73	19	5	2	1	1,947	1.7
Total	2,795	2,514	4,312	1,429	276	48	10	4	6	11,394	9.7
Conifer evergreen medium (CEM)											
Eastern red cedar	142	315	625	170	35	16	16	5	1	1,325	1.1
CEM other	257	219	373	54	7	3	1	-	-	914	0.8
Total	399	534	998	224	42	19	17	5	1	2,239	1.9
Conifer evergreen small (CES)											
CES other	71	114	26	5	1	-	-	1	-	218	0.2
Total	71	114	26	5	1	-	-	1	-	218	0.2
Citywide total	16,214	17,506	33,618	21,989	13,546	7,808	3,828	1,720	1,296	117,525	100

20% (Clark et al. 1997). Silver maple is the only species exceeding the 10% species level, and only one genus, maple, surpasses the 20% threshold at 27.4%. Indy Parks' Forestry Section is aware of this and when maples die or require removal, the Forestry staff encourages replacement with non-maple species, thereby reducing the predominance of this genus. Forestry also currently emphasizes the use of native tree species and is clearly aware of the impact that drought, disease, pests, or other stressors can have on an urban forest dominated by one species or genus. Providing a wide variety of species will reduce the loss of canopy in case of such catastrophic events.

Although street tree species diversity at the city level is good, at the township level there are areas for concern (*Table 2*; see *Figure 4* for townships). With the exception of Washington, every township has at least one species that exceeds the 10% species level. Wayne Township would be particularly hard hit were disease or insects to affect its silver maples, which constitute nearly one-third of all trees in the township.

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 (IV), a mean of three relative values, can in theory range between 0 and 100, where an IV of 100 implies total reliance on one species and an IV of 0 suggests no reliance. 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

Table 2—*Most abundant street tree species listed by township with percentage of totals in parenthesis*

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	No. of trees
Center	Silver maple (14)	Apple (8.6)	Green ash (7.2)	Sugar maple (5.3)	Norway maple (4.7)	33,007
Decatur	Ash (17.5)	Silver maple (12.4)	Northern hackberry (8.6)	Sugar maple (8.5)	Mulberry (4.7)	2,027
Franklin	N. hackberry (13)	Silver maple (10.2)	White ash (7.7)	Mulberry (7.4)	Ash (7.2)	1,730
Lawrence	Silver maple (13.9)	White ash (9.4)	Apple (8.3)	Unknown small (4.4)	Eastern white pine (3.7)	6,775
Perry	Silver maple (12)	N. hackberry (11.2)	White ash (4.9)	Ash (4.9)	Mulberry (4.6)	9,597
Pike	Ash (11)	Sugar maple (9.5)	N. hackberry (8)	Silver maple (5.4)	Plum (5.1)	6,278
Warren	Silver maple (22.7)	White ash (9.3)	Sugar maple (4.3)	Siberian elm (3.2)	Red maple (3.2)	11,509
Washington	Silver maple (8.9)	Sugar maple (7.5)	White ash (6.9)	N. hackberry (5.6)	Eastern white pine (4.5)	37,020
Wayne	Silver maple (31.9)	Sugar maple (5.7)	Northern hackberry (5.7)	Ash (4)	Unknown medium (3.5)	9,044
Unassigned	Silver maple (18)	Honeylocust (10)	Siberian elm (5.2)	White ash (5)	N. hackberry (4.3)	538
Citywide	Silver maple (13.9)	Sugar maple (6)	N. hackberry (5.1)	Apple (4.9)	White ash (4.9)	117,525

short-lived or poorly adapted trees can result in short rotations and increased long-term management costs.

The 33 most abundant street tree species listed in *Table 3* constitute 84% of the total population, 86% of the total leaf area, and 86% of total canopy cover, for an IV of 85. As *Table 3* illustrates, Indianapolis is relying most on the functional capacity of silver maple. Though the species accounts for nearly 14% of all public street trees, because of the trees' large size, the amount of leaf area and canopy cover provided is great, increasing their importance value to 25 when all components are considered. This makes them 3.8 times more significant than sugar maple and 4.5 times more significant than Northern hackberry, the next closest species. The main reason why silver maple is highest in importance value is that 44% of the trees are either mature or old; therefore, they have reached their full structural and functional capacity.

Maple, as a genus, contributes 43% of the leaf area and 41% of Indianapolis's canopy cover. Other large trees—sugar maple, hackberry, and white ash—appear to have significantly lower importance values; however, nearly half or more of their populations are younger trees (<12 inches DBH) and will continue to grow in importance as they age. For example, white ash's current importance value is only 4.9%, but with over half of its population less than 12 inches DBH, it is likely to become as important as the silver maple as the trees mature.

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

Citywide, the overall age structure, represented here in terms of DBH, for street trees in Indianapolis is nearly ideal with the exception of trees

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

Species	No. of trees	% of total trees	Leaf area (ft^2)	% of total leaf area	Canopy cover (ft^2)	% of total canopy cover	Importance value
Silver maple	16,371	13.9	84,310,504	31.4	22,906,126	29.9	25.1
Sugar maple	7,042	6.0	19,209,210	7.2	5,088,912	6.6	6.6
Northern hackberry	5,940	5.1	16,140,838	6.0	4,281,323	5.6	5.6
Crabapple	5,803	4.9	2,840,706	1.1	939,906	1.2	2.4
White ash	5,717	4.9	11,771,007	4.4	4,225,268	5.5	4.9
Siberian elm	3,977	3.4	866,977	0.3	427,974	0.6	1.4
Norway maple	3,298	2.8	7,234,597	2.7	2,670,746	3.5	3.0
Eastern white pine	3,148	2.7	2,910,397	1.1	674,933	0.9	1.5
Red maple	3,135	2.7	3,762,501	1.4	916,962	1.2	1.8
Mulberry	3,107	2.6	4,172,611	1.6	1,274,352	1.7	2.0
Green ash	2,810	2.4	4,814,476	1.8	1,600,468	2.1	2.1
Blue spruce	2,654	2.3	1,500,954	0.6	347,606	0.5	1.1
Norway spruce	2,406	2.0	2,314,964	0.9	507,300	0.7	1.2
Black cherry	2,265	1.9	10,244,533	3.8	2,832,390	3.7	3.1
Ash	2,241	1.9	4,796,474	1.8	1,565,487	2.0	1.9
Eastern redbud	1,972	1.7	3,075,339	1.1	860,098	1.1	1.3
Northern red oak	1,940	1.7	3,933,229	1.5	1,393,877	1.8	1.6
Honeylocust	1,931	1.6	2,837,524	1.1	632,372	0.8	1.2
Unknown medium	1,897	1.6	5,913,583	2.2	2,082,822	2.7	2.2
Eastern cottonwood	1,872	1.6	2,175,563	0.8	1,031,224	1.3	1.3
Plum	1,730	1.5	793,135	0.3	263,024	0.3	0.7
Unknown small	1,715	1.5	1,122,556	0.4	356,414	0.5	0.8
Pin oak	1,537	1.3	2,530,311	0.9	914,162	1.2	1.1
Black walnut	1,518	1.3	4,860,291	1.8	1,008,292	1.3	1.5
Sweetgum	1,478	1.3	3,757,004	1.4	1,126,872	1.5	1.4
Callery pear	1,420	1.2	1,233,688	0.5	449,862	0.6	0.8
Black locust	1,419	1.2	4,539,786	1.7	1,282,623	1.7	1.5
Boxelder	1,406	1.2	2,095,438	0.8	498,056	0.7	0.9
American sycamore	1,386	1.2	8,214,723	3.1	2,140,441	2.8	2.3
Eastern red cedar	1,325	1.1	1,234,019	0.5	245,660	0.3	0.6
Scotch pine	1,239	1.1	1,674,742	0.6	371,287	0.5	0.7
Slippery elm	1,233	1.0	158,390	0.1	80,870	0.1	0.4
Northern catalpa	1,188	1.0	4,478,688	1.7	1,072,721	1.4	1.4
Other trees	19,405	16.5	36,665,388	13.7	10,516,915	13.7	14.6
Total	117,525	100.0	268,184,048	100.0	76,587,344	100.0	100.0

in the 0-6 inch DBH class where the proportion is 11% below the ideal (*Figure 5*). The lack of representation currently in this size class suggests either a reduction in numbers of trees planted more recently or an increase in young-tree mortality, or both. Records maintained by the Forestry Section indicate mortality of new plantings in Indianapolis at around 2% per year for the first five years and 1.14% per year thereafter, suggesting that 50% of all trees planted do not live beyond 40 years (Pinco 2007). Many trees simply do not live long enough to grow large.

It is interesting to note that Indianapolis has a relatively high percentage of very old street trees (2.6% in DBH classes greater than 36 in). Silver maple, hackberry, white ash, and cottonwood (not all data shown), species that were heavily planted in the past, predominate.

Figure 6 shows age distribution of street trees by district. Generally, the same pattern holds true at the district level—a good distribution across size classes with the exception of young trees. Two townships that differ are Lawrence and Pike, where size classes above 18 inches DBH are under-represented. However, these same townships plus Center have had more trees planted (as a percentage of all trees in each township) in recent years than other townships, a clear effort on the part of Forestry to improve age distribution inequities.

Again, it is important to note that these findings are proportionate to the number of street trees present in each district, not the total number of street trees. Districts undergoing expansion, development, or infill have significantly fewer trees than older, established districts (*Figure 4*).

Tree Condition

Tree condition indicates both how well trees are managed and how well they perform given site-specific conditions. Condition was reported for trees only in the newest inventory (Center Township). However, our data collectors sampled trees throughout Indianapolis for this report and evaluated tree condition, allowing a comparison between Center Township and estimated condition for the entire city.

For the entire city, our estimates show 86% of the population is in fair or better condition with 38% in good condition. For Center Township, about 20% of street trees are in good or better condition,

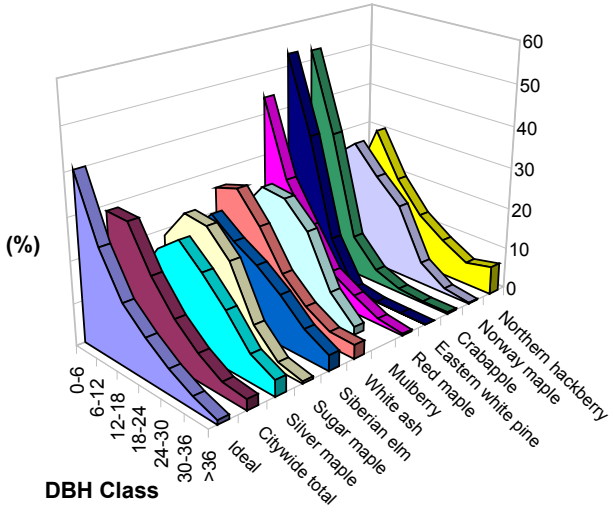


Figure 5—Relative age distribution for Indianapolis's 10 most abundant street tree species citywide shown with an ideal distribution

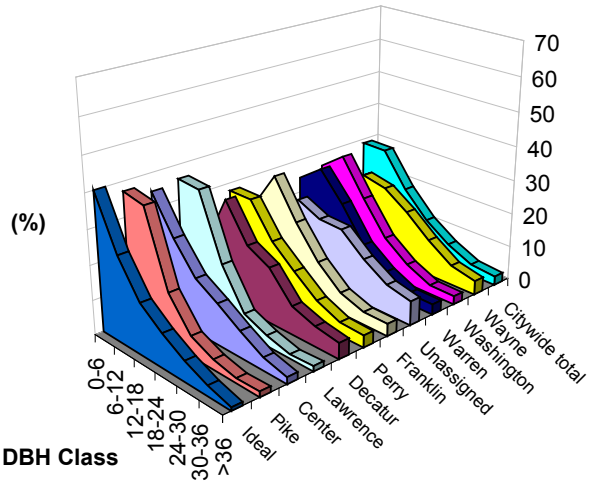


Figure 6—Relative age distribution of all street trees by management district

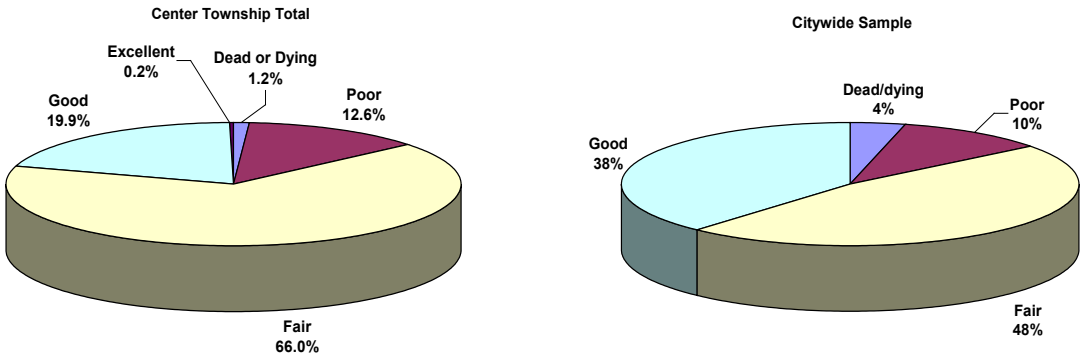


Figure 7—Indianapolis's Center Township and citywide sample tree conditions. In both cases, 86% of the trees are in fair or better condition

with nearly 14% in poor or worse condition (*Figure 7*). The bulk of the Center Township population (66%) is in fair condition. The tally of poor and worse condition trees remains the same for the city and the Center Township at 14%. Center Township, with fewer trees in good or better condition, reflects the greater difficulty of growing trees in a dense, urbanized environment where hardscapes, impervious pavement and buildings represent the highest percentage of land cover.

The relative performance index (RPI) of each species provides an indication of its suitability to local growing conditions, as well as its performance. A species whose trees are in average condition compared to all other species in the city has an RPI of 1.0. Species that perform above the average have an RPI greater than 1.0, and those species with below average performance have RPIs below 1.0. Again, this information was available only for Center Township, but if trees can do well in the harshest of environments, it is likely they will do well in other Indianapolis neighborhoods.

Condition varies greatly from species to species, however (*Table 4*). Looking at species representing 1% or more of the population, poor performers include mulberry and catalpa (*Catalpa speciosa*, 0.80), tree-of-heaven (*Ailanthus altissima,* 0.85), Siberian elm and silver maple (0.88). Species with the largest percentage of trees in good or better condition include blue spruce (*Picea pungens*, 1.3), Callery pear and sweetgum (*Liquidambar styraciflua,* 1.2). Note that these values reflect condition as reported in the 2003 inventory and may not reflect current condition for all species.

Care should be taken when analyzing RPI to ensure that relevant factors such as age are taken into consideration. For example, 50% or more of callery pear, blue spruce, and Austrian pine are young trees under 6 inches DBH. It is important to compare relative age (*Figure 5*) with RPI (*Table 4*) to determine whether various species have actually stood the test of time. Conclusions about their suitability to the region as ROW trees should be postponed until the trees have matured.

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. Arborists employ several methods 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 117,525 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 $113.1 million (*Table 5*; for complete list see *Appendix B*). Considered this way, we can

***Table 4**—Relative performance index (RPI) for Indianapolis's predominant street tree species in Center Township*

Species	Condition					RPI	# of trees	% of total population
	Dead or dying	Poor	Fair	Good	Excellent			
Silver maple	1.2	20.3	75.1	3.3	0.0	0.88	4,743	14.2
Crabapple	0.7	4.7	66.8	27.7	0.1	1.08	2,847	8.5
Green ash	0.6	8.7	65.5	25.0	0.1	1.05	2,404	7.2
Sugar maple	1.0	14.1	71.8	13.0	0.1	0.96	1,802	5.4
Norway maple	1.6	14.1	68.2	16.1	0.1	0.97	1,572	4.7
Siberian elm	0.6	21.4	75.7	2.3	0.0	0.88	1,543	4.6
Red maple	1.0	11.0	61.3	26.6	0.1	1.04	1,501	4.5
Honeylocust	0.8	4.0	74.4	20.7	0.0	1.05	1,270	3.8
Callery pear 'Bradford'	0.5	3.2	47.2	48.7	0.4	1.19	1,246	3.7
Mulberry	0.5	36.5	61.8	1.2	0.0	0.80	1,117	3.3
Northern hackberry	0.4	16.8	80.7	2.1	0.0	0.90	917	2.7
Littleleaf linden	0.4	11.1	65.8	22.7	0.0	1.03	810	2.4
Northern red oak	0.0	6.0	78.4	15.6	0.0	1.02	777	2.3
White ash	1.4	11.3	70.5	16.8	0.0	0.99	691	2.1
Blue spruce	0.2	3.2	35.1	58.5	3.0	1.27	626	1.9
Plum	0.4	5.0	49.8	44.8	0.0	1.16	516	1.5
Sweetgum	0.0	4.9	46.2	48.5	0.4	1.19	515	1.5
Northern catalpa	0.6	37.4	59.6	2.4	0.0	0.8	500	1.5
Pear	0.4	9.7	50.9	38.8	0.2	1.11	495	1.5
Tree of heaven	1.0	24.3	73.6	1.0	0.0	0.85	493	1.5
Eastern redbud	0.4	8.1	67.4	24.2	0.0	1.05	484	1.4
Eastern cottonwood	1.1	9.9	79.7	9.3	0.0	0.96	364	1.1
Eastern white pine	0.6	5.3	58.4	35.7	0.0	1.12	356	1.1
Ginkgo	0.0	3.7	63.0	32.8	0.6	1.12	354	1.1
Citywide total	1.2	12.6	66.0	19.9	0.2	1.0	117,525	100.0

see that Indianapolis's street trees are a valuable legacy and are a central component of the city's green infrastructure. The average replacement value per tree is $963. Silver maple trees account for 15% of the total.

Replacement value should be distinguished from the value of annual benefits produced by the ROW 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 Indianapolis's street tree population is many times greater than the value of annual benefits it produces.

Table 5— *Replacement values, summed by DBH class, for the 20 most valuable species of street trees in Indianapolis. See Appendix B for complete listing*

Species	DBH Class (in)								Total	% of total
	0–6	6–12	12–18	18–24	24–30	30–36	36–42	>42		
Silver maple	488,223	1,353,486	2,882,429	3,777,901	4,016,896	2,742,687	1,288,711	829,113	17,379,444	15.4
No. hackberry	284,328	1,087,427	1,454,545	1,649,465	1,758,614	1,562,960	1,358,479	1,336,704	10,492,522	9.3
Sugar maple	430,736	1,187,879	2,351,248	3,223,753	1,956,694	701,763	196,513	82,987	10,131,573	9.0
White ash	436,030	825,144	1,176,551	1,147,443	1,006,010	752,208	485,865	475,983	6,305,233	5.6
Crabapple	978,511	1,170,114	641,618	378,741	180,407	110,788	107,432	46,483	3,614,095	3.2
E. cottonwood	48,957	120,602	344,490	514,093	643,502	631,081	564,045	646,719	3,513,490	3.1
Siberian elm	183,906	360,953	488,336	647,021	712,527	563,717	252,419	151,369	3,360,247	3.0
Unknown med.	-	-	1,050,236	1,137,572	1,047,258	-	-	-	3,235,066	2.9
No. red oak	176,601	200,659	460,162	551,644	563,772	548,145	328,266	345,303	3,174,553	2.8
Norway maple	237,528	500,072	740,390	960,690	449,438	145,725	28,863	10,696	3,073,402	2.7
Mulberry	285,333	479,288	440,162	385,320	355,552	252,276	202,062	196,447	2,596,441	2.3
Ash	175,504	403,465	383,720	474,880	359,280	317,323	155,626	173,097	2,442,897	2.2
Red maple	407,471	420,621	510,002	400,428	347,531	156,809	43,295	26,741	2,312,898	2.0
Black cherry	52,566	280,174	417,100	482,361	369,063	236,680	199,750	132,229	2,169,922	1.9
Green ash	282,619	443,152	411,048	298,605	270,319	201,287	92,539	14,698	2,014,267	1.8
Black walnut	59,878	206,482	498,697	578,362	405,100	202,251	27,823	18,575	1,997,167	1.8
Amer. sycamore	47,718	113,276	212,519	341,816	421,687	354,805	244,108	224,538	1,960,467	1.7
Unknown large	-	-	-	-	-	931,881	542,105	430,024	1,904,009	1.7
Pin oak	170,351	227,253	358,168	351,982	312,491	207,549	71,622	106,247	1,805,662	1.6
Eastern redbud	262,544	461,845	357,797	219,224	134,568	99,744	60,987	22,633	1,619,343	1.4
Other trees	4,388,501	6,482,055	5,157,103	3,902,455	3,180,129	2,120,715	1,410,939	1,410,728	28,052,625	24.8
Citywide total	9,397,305	16,323,948	20,336,320	21,423,753	18,490,837	12,840,394	7,661,448	6,681,316	113,155,321	100.0

Chapter Three—Costs of Managing Indianapolis's Street Trees

The benefits Indianapolis's street trees provide come, of course, at a cost. This chapter presents a break-down of annual expenditures for fiscal year 2005 which was considered a typical year. However, it is important to note that since then the Forestry Section's budget has since been reduced by about $100,000 and staff has been reduced by 2.5 employees. *Table 6* shows that total annual tree-related expenditures for Indianapolis's street trees are approximately $940,130 (Pinco 2007). This represents 0.17% of the City of Indianapolis's total operating budget ($548 million) or $1 per person. Actual Forestry program expenditures account for $762,025 of the total city expenditures on street trees, with the remaining $178,105 paid by other divisions within the city.

The city spends about $8 per street tree on average during the year, less than half the 1997 mean value of $19 per tree reported for 256 California cities after adjusting for inflation (Thompson and Ahern 2000) and less than one-quarter of the $25 per tree average for the 19 U.S. cities we have studied to date. The Indianapolis figure includes non-program expenditures (e.g., sidewalk repair, litter clean-up) that were not included in the California survey. Indianapolis's annual expenditure is also the lowest of any city studied to date at $5 per tree less than Albuquerque, NM ($13 per tree). It is far less than Santa Monica, CA ($53), Minneapolis, MN ($46), and Fort Collins, CO ($32), and less than half the amount spent by Cheyenne, WY ($19), Bismarck, ND ($18) and Boulder, CO ($21) (McPherson et al. 2005a, e).

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 average DBH of new trees is 1.75 inches. In a typical year, about 385 street trees are planted (*Figure 8*). Planting activities including materials, labor, administration, and equipment costs, account for 4% of the program budget or approximately $40,000. Tree planting funds are entirely dependent upon annual donations or grants, not annually allocated funding.

Pruning, Removals, and General Tree Care

Contract and internal-crew pruning activity accounts for about 13% of the annual expenditures, at $129,700 ($1.04 per tree). New trees receive structural pruning by volunteers and staff at time

Table 6—*Indianapolis's annual municipal forestry-related expenditures for street trees*

Expenditures	Total ($)	$/tree	$/capita	% of total
Purchasing trees and planting	40,000	0.34	0.05	4.3
Contract pruning	121,696	1.04	0.16	12.9
Pest management	9,600	0.08	0.01	1.0
Irrigation	9,105	0.08	0.01	1.0
Removal	491,489	4.18	0.63	52.3
Administration	71,000	0.60	0.09	7.6
Inspection/service	11,440	0.10	0.01	1.2
Infrastructure repairs	110,500	0.94	0.14	11.8
Litter clean-up	75,300	0.64	0.10	8.0
Other cost	-	-	-	-
Total expenditures	940,130	8.00	1.20	100.0

of planting. Otherwise, Indianapolis does not have a planned cyclical pruning program. All pruning is reactive to customer service and inspection requests, on an as-needed basis. Tree care activity is scheduled and prioritized based upon public safety concerns and citizens requests for service. Since 2005, the "typical" year used here, the contract pruning budget has been reduced.

Tree and stump removal accounts for about 52% of tree-related expenses ($491,500 or $4 per tree). About 580 street trees are removed each year. Approximately 84% of the removals are chipped and used as mulch by Indy Parks, other departments and partners. Savings to the city exceed the cost of mulching by $30 per ton. Stump removal is a service no longer offered by the department.

Inspecting trees for damage and disease costs $11,440 annually with expenditures for pest control at $9,800. Storm and debris cleanup for street trees costs the Forestry Section approximately $16,800 annually and other city departments about $58,500 for a total $0.64 per tree.

Administration and Other Tree-Related Expenditures

About $71,000 (8%) is spent on administrative expenses including administrative salary, meetings, continuing education, and in-house safety inspections.

In a typical year, other costs external to the Forestry program budget include about $110,500 (12%) for infrastructure repair associated with damage from trees and $9,105 for street tree irrigation during tree establishment in the downtown area.



Figure 8—Young ginkgo trees thriving in downtown Indianapolis

Chapter Four—Benefits of Indianapolis'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 Indianapolis'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 Indianapolis—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 C*.

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., 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 C* provides additional infor-



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

mation on specific contributions that trees make toward energy savings.

Electricity and Natural Gas Results

Electricity and natural gas saved annually in Indianapolis from both shading and climate effects equal 6,447 MWh ($431,935) and 153,133 therms ($164,777), respectively, for a total retail savings of $596,712 or a citywide average of $5.08 per tree (*Table 7*). Silver maple provides 20.2% of the energy savings although it accounts for only 13.9% of total tree numbers, as expected for a tree species with such a high importance value (IV). Sugar maple (8.2%) and Northern hackberry (7.0%) make the next greatest contributions to overall energy savings. On a per tree basis, American syca-

***Table 7**—Net annual energy savings produced by Indianapolis street trees*

	Electricity		Natural gas			% of total	
Species	**MWh**	**$**	**Therms**	**$**	**Total ($)**	**trees**	**Avg. $/tree**
Silver maple	1,220	81,750	35,935	38,667	120,417	13.9	7.36
Sugar maple	467	31,291	16,325	17,566	48,857	6.0	6.94
Northern hackberry	464	31,058	10,014	10,775	41,833	5.1	7.04
Crabapple	133	8,937	4,547	4,893	13,830	4.9	2.38
White ash	338	22,613	10,688	11,501	34,113	4.9	5.97
Siberian elm	314	21,036	4,325	4,654	25,690	3.4	6.46
Norway maple	183	12,286	5,115	5,504	17,790	2.8	5.39
Eastern white pine	70	4,683	−2,005	−2,157	2,525	2.7	0.80
Red maple	142	9,545	4,779	5,142	14,687	2.7	4.68
Mulberry	190	12,728	5,567	5,990	18,718	2.6	6.02
Green ash	139	9,292	3,810	4,100	13,393	2.4	4.77
Blue spruce	23	1,525	−677	−728	797	2.3	0.30
Norway spruce	35	2,322	−906	−975	1,348	2.0	0.56
Black cherry	187	12,516	5,576	6,000	18,516	1.9	8.17
Ash	138	9,237	3,995	4,298	13,535	1.9	6.04
Eastern redbud	46	3,095	−352	−378	2,717	1.7	1.38
Northern red oak	162	10,832	5,155	5,547	16,379	1.6	8.44
Honeylocust	109	7,284	−692	−745	6,539	1.6	3.39
Eastern cottonwood	151	10,147	5,080	5,466	15,613	1.6	8.34
Plum	34	2,256	−211	−227	2,029	1.5	1.17
Unknown small	39	2,637	−301	−324	2,313	1.5	1.35
Pin oak	102	6,862	3,157	3,397	10,259	1.3	6.67
Black walnut	114	7,628	−1,082	−1,164	6,464	1.3	4.26
Sweetgum	84	5,620	2,335	2,512	8,133	1.3	5.50
Callery pear	22	1,507	468	503	2,010	1.2	1.42
Black locust	90	5,997	2,580	2,776	8,773	1.2	6.18
Boxelder	84	5,638	2,789	3,001	8,639	1.2	6.14
American sycamore	131	8,806	4,040	4,347	13,153	1.2	9.49
Eastern red cedar	29	1,911	−736	−792	1,119	1.1	0.84
Scotch pine	40	2,668	−1,119	−1,204	1,464	1.0	1.18
Slippery elm	51	3,449	363	391	3,840	1.0	3.11
Northern catalpa	73	4,867	2,035	2,190	7,057	1.0	5.94
Unknown medium	148	9,898	3,423	3,684	13,582	1.6	7.16
Other street trees	896	60,015	19,112	20,566	80,581	16.5	4.15
Citywide total	6,446	431,935	153,133	164,777	596,712	100.0	5.08

mores (*Platanus occidentalis*) are the greatest contributors, reducing energy needs by approximately $9.49 per tree annually. Northern red oak (*Quercus rubra*) and Eastern cottonwood (*Populus deltoides*) provide the next greatest savings on a per tree basis ($8.44 and $8.34).

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 silver maple ($9.49) are so much greater than, for instance, another large-growing species like green ash ($4.77). Nearly 44% of Indianapolis's silver maples were greater than 18 inches DBH, while the green ash had mostly been planted in recent years and are currently smaller in size. As these younger species age and their size increases, the benefits that they provide will increase as well.

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

Avoided and Sequestered Carbon Dioxide

Citywide, Indianapolis's street trees reduce atmospheric CO_2 by a net of 14,146 tons annually (*Table 8*). This benefit was valued at $94,495 or $0.80 per tree and is equivalent to storing enough CO_2 in 2005 (year of the Center Township inventory) to offset CO_2 production for 2,338 vehicles each year (based on the EPA assumption that the average vehicle produces 12,100 lbs of CO_2 per year).

Reduced CO_2 emissions from power plants due to cooling energy savings totaled 7,055 tons, while CO_2 sequestered by trees was 9,289 tons. Carbon dioxide released through decomposition and tree care activities totaled 2,198 tons, or 13.4% of the net total benefit. Net sequestration was nearly equal to avoided emissions. This is largely due to the relatively high CO_2-emitting fuel mix for electrical generation in Indianapolis; over 99% of energy is provided by coal (Indianapolis Power and Light 2007).

On a per tree basis, Northern red oak ($1.89), pin oak (*Quercus palustris*, $1.54) and black cherry (*Prunus serotina*, $1.22) provide the greatest CO_2 benefits (*Table 8*). Because of its importance, the silver maple population provides the greatest total CO_2 benefits, accounting for nearly 14% of citywide CO_2 reduction.

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 vola-

Table 8—*CO_2 reductions, releases, and net benefits produced by street trees*

Species	Sequestered (lb)	Decomp. release (lb)	Maint. release (lb)	Avoided (lb)	Net total (lb)	Total ($)	% of trees	% of total $	Avg. $/tree
Silver maple	3,990,821	−807,362	−143,431	2,670,677	5,710,705	19,074	13.9	20.2	1.17
Sugar maple	1,066,027	−266,894	−49,033	1,022,241	1,772,341	5,920	6.0	6.3	0.84
Northern hackberry	1,539,290	−251,413	−47,864	1,014,626	2,254,640	7,531	5.1	8.0	1.27
Crabapple	397,098	−49,171	−20,422	291,949	619,453	2,069	4.9	2.2	0.36
White ash	1,152,282	−234,533	−37,394	738,735	1,619,090	5,408	4.9	5.7	0.95
Siberian elm	931,014	−183,592	−32,292	687,220	1,402,350	4,684	3.4	5.0	1.18
Norway maple	300,202	−59,985	−20,495	401,368	621,090	2,074	2.8	2.2	0.63
Eastern white pine	50,346	−5,844	−10,168	152,976	187,310	626	2.7	0.7	0.20
Red maple	240,213	−43,069	−14,935	311,811	494,020	1,650	2.7	1.8	0.53
Mulberry	308,092	−58,427	−19,257	415,799	646,207	2,158	2.6	2.3	0.69
Green ash	474,383	−71,953	−14,525	303,575	691,479	2,310	2.4	2.4	0.82
Blue spruce	43,816	−3,061	−8,109	49,825	82,471	275	2.3	0.3	0.10
Norway spruce	64,145	−6,678	−10,448	75,870	122,890	410	2.0	0.4	0.17
Black cherry	555,667	−121,836	−18,571	408,876	824,136	2,753	1.9	2.9	1.22
Ash	429,666	−84,236	−14,169	301,756	633,017	2,114	1.9	2.2	0.94
Eastern redbud	47,041	−9,039	−1,486	101,110	137,626	460	1.7	0.5	0.23
Northern red oak	958,490	−202,822	−14,655	353,875	1,094,888	3,657	1.6	3.9	1.89
Honeylocust	305,625	−39,909	−8,667	237,960	495,010	1,653	1.6	1.8	0.86
Eastern cottonwood	273,711	−73,843	−18,850	331,500	512,519	1,712	1.6	1.8	0.91
Plum	33,829	−6,105	−1,303	73,688	100,109	334	1.5	0.3	0.19
Unknown small	56,164	−5,038	−1,292	86,155	135,988	454	1.5	0.5	0.26
Pin oak	589,791	−94,921	−9,284	224,171	709,757	2,371	1.3	2.5	1.54
Black walnut	286,625	−61,187	−11,352	249,197	463,283	1,547	1.3	1.6	1.02
Sweetgum	296,508	−38,738	−8,393	183,615	432,992	1,446	1.3	1.5	0.98
Callery pear	64,729	−4,905	−1,070	49,231	107,985	361	1.2	0.4	0.25
Black locust	290,357	−50,619	−9,068	195,900	426,571	1,425	1.2	1.5	1
Boxelder	133,200	−26,639	−8,564	184,197	282,193	943	1.2	1.0	0.67
American sycamore	342,008	−103,035	−13,276	287,670	513,368	1,715	1.2	1.8	1.24
Eastern red cedar	54,219	−5,985	−5,810	62,435	104,859	350	1.1	0.4	0.26
Scotch pine	28,059	−3,787	−5,478	87,151	105,945	354	1.0	0.4	0.29
Slippery elm	242,144	−24,905	−6,022	112,678	323,894	1,082	1.0	1.1	0.88
Northern catalpa	115,809	−42,899	−12,488	159,011	219,433	733	1.0	0.8	0.62
Unknown medium	177,132	−47,318	−18,187	323,369	434,997	1,453	1.6	1.5	0.77
Other street trees	2,738,502	−595,393	−94,287	1,960,626	4,009,448	13,392	16.5	14.2	0.69
Citywide total	18,577,002	−3,685,139	−710,644	14,110,841	28,292,060	94,495	100.0	100.0	0.80

tile 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.

Deposition and Interception

Each year 42.3 tons ($77,753) 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 Indianapolis (*Table 9*). Trees are most effective at removing O_3 and PM_{10}, with an implied annual value of $58,716. Due to their substantial leaf area and predominance, sil-

Table 9—*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. $/tree
Species	O_3	NO_2	PM_{10}	SO_2	Total ($)	NO_2	PM_{10}	VOC	SO_2	Total ($)	(lb)	($)	(lb)	($)		
Silver maple	8,961	1,840	3,820	1,422	14,772	3,988	1,246	1,239	14,603	26,780	−4,052	−1,215	33,068	40,336	13.9	2.46
Sugar maple	3,370	692	1,436	535	5,554	1,553	479	475	5,590	10,274	−3,679	−1,104	10,450	14,725	6.0	2.09
Northern hackberry	3,519	723	1,500	558	5,801	1,478	471	469	5,548	10,140	0	0	14,265	15,941	5.1	2.68
Crabapple	951	195	405	151	1,567	442	137	136	1,596	2,933	−8	−3	4,005	4,498	4.9	0.78
White ash	2,454	504	1,046	389	4,045	1,111	345	343	4,039	7,415	0	0	10,231	11,459	4.9	2.00
Siberian elm	2,458	505	1,048	390	4,052	976	317	316	3,757	6,845	0	0	9,767	10,897	3.4	2.74
Norway maple	1,325	272	565	210	2,184	596	187	186	2,195	4,022	−568	−171	4,968	6,036	2.8	1.83
Eastern white pine	544	137	300	117	1,031	187	68	69	836	1,496	−721	−216	1,537	2,311	2.7	0.73
Red maple	1,007	207	429	160	1,659	472	146	145	1,705	3,132	−471	−141	3,798	4,650	2.7	1.48
Mulberry	1,404	288	598	223	2,314	621	194	193	2,273	4,169	−465	−139	5,329	6,344	2.6	2.04
Green ash	963	178	371	133	1,503	451	141	141	1,660	3,041	0	0	4,038	4,545	2.4	1.62
Blue spruce	184	46	102	40	349	61	22	22	272	487	−390	−117	359	719	2.3	0.27
Norway spruce	273	69	151	58	517	94	34	34	415	743	−539	−162	588	1,098	2.0	0.46
Black cherry	1,337	248	515	185	2,087	611	191	190	2,236	4,101	0	0	5,512	6,187	1.9	2.73
Ash	978	181	377	135	1,526	450	141	140	1,650	3,025	0	0	4,052	4,551	1.9	2.03
Eastern redbud	347	71	148	55	571	134	46	46	553	998	0	0	1,399	1,569	1.7	0.80
Northern red oak	1,268	260	541	201	2,090	532	165	164	1,935	3,552	−1,808	−542	3,259	5,100	1.7	2.63
Honeylocust	827	170	353	131	1,364	316	108	108	1,301	2,350	−359	−108	2,955	3,606	1.6	1.87
Eastern cottonwood	1,125	231	480	179	1,855	501	155	154	1,813	3,330	−5,189	−1,557	−551	3,628	1.6	1.94
Plum	254	52	108	40	418	98	33	34	403	728	0	0	1,022	1,146	1.5	0.66
Pin oak	778	160	332	123	1,282	336	105	104	1,226	2,249	−1,026	−308	2,137	3,223	1.3	2.10
Black walnut	690	103	239	82	1,010	327	113	113	1,362	2,457	−159	−48	2,871	3,420	1.3	2.25
Sweetgum	573	106	221	79	894	273	86	85	1,004	1,840	0	0	2,426	2,734	1.3	1.85
Callery pear	159	33	68	25	262	72	23	23	269	492	0	0	671	754	1.2	0.53
Black locust	628	116	242	87	980	292	91	91	1,071	1,964	0	0	2,618	2,944	1.2	2.07
Boxelder	596	122	254	94	982	278	86	86	1,007	1,850	−284	−85	2,239	2,746	1.2	1.95
American sycamore	970	180	374	134	1,513	431	134	134	1,573	2,886	0	0	3,929	4,400	1.2	3.17
Eastern red cedar	232	58	128	50	440	77	28	28	341	611	−314	−94	629	957	1.1	0.72
Other street trees	9,214	1,871	3,910	1,447	15,130	3,941	1,264	1,259	14,921	27,241	−4,011	−1,203	33,814	41,168	23.0	1.56
Citywide total	47,389	9,619	20,057	7,433	77,753	20,699	6,558	6,525	77,153	141,151	−24,044	−7,213	171,388	211,691	100.0	1.80

ver maple contributes the most to pollutant uptake, removing 38,068 lbs each year.

Avoided Pollutants

Energy savings result in reduced air pollutant emissions of NO_2, PM_{10}, volatile organic compounds (VOCs), and SO_2 (*Table 9*). Together, 55.5 tons of pollutant emissions are avoided annually with an implied value of $141,151. In terms of amount and dollar, avoided emissions of SO_2 are greatest (38.6 tons, $115,729). Silver maples have the greatest impact on reducing energy needs; by moderating the climate they account for 10.5 tons of pollutants whose production is avoided in power plants each year.

BVOC Emissions

Biogenic volatile organic compound (BVOC) emissions from trees must be considered. At a total of 12 tons, these emissions offset about one-eighth of air quality improvements and are calculated as a cost to the city of $7,213. Eastern cottonwood and silver maple are the highest emitters of BVOCs among Indianapolis's predominant tree species, accounting for 22% and 17% of the urban forest's total annual emissions, respectively.

Net Air Quality Improvement

Net air pollutants removed, released, and avoided are valued at $211,691 annually. The average benefit per street tree is $1.80 (1.5 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 silver maples are classified as moderate BVOC emitters, the large amount of leaf area associated with the silver maple population results in substantial net air quality benefits ($40,366 total; $2.46 per tree).

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.

Indianapolis's street trees intercept 318.9 million gallons of stormwater annually, or 2,714 gal per tree on average (*Table 10*). The total value of this benefit to the city is $1,977,467 or $16.83 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 Eastern cottonwood ($29.02 per tree), Northern hackberry ($26.13 per tree), Northern red oak ($25.80 per tree), American sycamore ($25.24) and silver maple ($24.91). Interception by silver maple alone accounts for nearly 21% of the total dollar benefit from street trees.

Comparatively poor performers are species with relatively small leaf and stem surface areas, such as crabapple (*Malus* species), Callery pear (*Pyrus calleryana*), and blue spruce (*Picea pungens*). Smaller species like the plum and crabapple simply do not intercept as much due to less leaf and bark surface area. Although large-growing, the blue spruce trees are currently young and small. Their stormwater benefit value will increase as they mature.

Table 10—*Annual stormwater reduction benefits of Indianapolis's street trees by species*

Species	Rainfall interception (gal)	Total ($)	% of trees	% of $	Avg. $/tree
Silver maple	65,761,612	407,750	13.9	20.6	24.91
Northern hackberry	25,031,216	155,204	5.1	7.8	26.13
Sugar maple	24,285,602	150,581	6.0	7.6	21.38
Siberian elm	16,924,802	104,941	3.4	5.3	26.39
White ash	16,660,232	103,301	4.9	5.2	18.07
Mulberry	10,913,572	67,669	2.6	3.4	21.78
Norway maple	8,952,331	55,508	2.8	2.8	16.83
Eastern cottonwood	8,761,273	54,324	1.6	2.8	29.02
Northern red oak	8,073,630	50,060	1.6	2.5	25.80
Black cherry	7,732,553	47,945	1.9	2.4	21.17
Red maple	6,585,174	40,831	2.7	2.1	13.02
American sycamore	5,642,380	34,985	1.2	1.8	25.24
Ash	5,608,512	34,775	1.9	1.8	15.52
Green ash	5,465,493	33,888	2.4	1.7	12.06
Pin oak	4,777,489	29,622	1.3	1.5	19.27
Eastern white pine	4,483,051	27,797	2.7	1.4	8.83
Crabapple	4,418,403	27,396	4.9	1.4	4.72
Black walnut	4,373,648	27,119	1.3	1.4	17.86
Honeylocust	4,343,538	26,932	1.6	1.4	13.95
Boxelder	3,933,109	24,387	1.2	1.2	17.34
Northern catalpa	3,699,501	22,939	1.0	1.2	19.31
Black locust	3,602,428	22,337	1.2	1.1	15.74
Sweetgum	3,270,624	20,279	1.3	1.0	13.72
Slippery elm	2,717,840	16,852	1.0	0.9	13.67
Norway spruce	2,683,870	16,641	2.0	0.8	6.92
Scotch pine	2,583,370	16,018	1.0	0.8	12.93
Eastern redbud	1,952,518	12,106	1.7	0.6	6.14
Blue spruce	1,884,198	11,683	2.3	0.6	4.40
Eastern red cedar	1,859,647	11,531	1.1	0.6	8.70
Plum	1,412,918	8,761	1.5	0.4	5.06
Callery pear	895,748	5,554	1.2	0.3	3.91
Unknown medium	6,409,253	39,740	1.6	2.0	20.95
Unknown small	1,674,414	10,382	1.5	0.5	6.05
Other street trees	41,550,080	257,628	16.5	13.0	13.28
Citywide total	318,924,000	1,977,467	100.0	100.0	16.83

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, 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 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 C* for more details).

The estimated total annual benefit associated with property value increases and other less tangible benefits attributable to Indianapolis street trees is $2,848,008 or $24.23 per tree on average (*Table 11*). Generally, the larger the tree, the more benefits provided. Therefore, the Indianapolis street tree species that produce the highest average annual benefits are among the largest trees currently in the population. These include slippery elm ($45.32 per tree), northern hackberry ($44.27 per tree), and Siberian elm ($39.65).

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

Total annual benefits produced by Indianapolis's municipal street trees are estimated at $5,728,373 ($48.74 per tree, $7.32 per capita) (*Table 12*). Over the same period, tree-related expenditures are estimated to be $940,130 ($8.00 per tree, $1.20 per capita). Net annual benefits (benefits minus costs) are $4,788,243 or $40.74 per tree and $6.12 per capita. Indianapolis's street trees currently return $6.09 to the community for every $1 spent on their management. Indianapolis's benefit-cost ratio of 6.09 is similar to New York City at 5.60, but significantly higher than those reported for 19 other cities we have studied to date, including Charleston, SC (1.34), Albuquerque, NM (1.31), Fort Collins, CO (2.18), Cheyenne, WY (2.09), and Bismarck, ND (3.09) (Maco et al. 2005; Vargas et al. 2006; McPherson et al. 2006, 2005a). That said, it is also important to note that at $49 per tree, Indianapolis's benefits are nearly one-third less than the $72 per tree average across 19 cities studied thus far.

Indianapolis's street trees have beneficial effects on the environment. Half (50%) of the annual benefits provided to residents of the city are environmental services. Stormwater runoff reduction represents 69% of environmental benefits, with energy savings accounting for another 21%. Air quality improvement (7%) and carbon dioxide reduction (3%) provide the remaining environmental benefits. Non-environmental benefits associated with annual



Figure 10—Trees add beauty and value to residential property

increases in property value by street trees provide the remaining 50% of total annual benefits.

Table 13 shows the distribution of total annual benefits in dollars for the predominant municipal street tree species in Indianapolis. On a per tree basis, Eastern cottonwood ($77 per tree) and Siberian elm ($76 per tree) produced second and third largest benefits after Northern hackberry at $81. Four species account for over 38% of all benefits—silver maple (17.2%), Northern hackberry (8.4%), sugar maple (7.2%), and Siberian elm (5.3%). It should be noted again that this analysis provides benefits for a snapshot in time. Hackberry and white ash are the third and fourth most predominant tree species, but with most trees measuring less than 12 inches DBH, they are poised to become the city's most beneficial species in the future. Benefit production should increase each year for these species. Note

Table 11—*Total annual increases in property value produced by street trees*

Species	Total ($)	% of trees	% of total $	Avg. $/tree
Silver maple	396,391	13.9	13.9	24.21
Northern hackberry	262,939	5.1	9.2	44.27
Sugar maple	189,503	6.0	6.7	26.91
Siberian elm	157,672	3.4	5.5	39.65
White ash	148,522	4.9	5.2	25.98
Mulberry	108,723	2.6	3.8	34.99
Red maple	78,530	2.7	2.8	25.05
Norway maple	72,641	2.8	2.5	22.03
Green ash	69,791	2.4	2.5	24.84
Northern red oak	69,608	1.6	2.4	35.88
Eastern cottonwood	69,595	1.6	2.4	37.18
Crabapple	64,605	4.9	2.3	11.13
Black cherry	60,222	1.9	2.1	26.59
Slippery elm	55,884	1.0	2.0	45.32
Ash	54,982	1.9	1.9	24.53
Honeylocust	53,736	1.6	1.9	27.83
Pin oak	53,044	1.3	1.9	34.51
Eastern white pine	47,756	2.7	1.7	15.17
Sweetgum	40,538	1.3	1.4	27.43
Black walnut	39,444	1.3	1.4	25.98
Blue spruce	38,471	2.3	1.4	14.50
Boxelder	38,264	1.2	1.3	27.21
Black locust	36,975	1.2	1.3	26.06
Norway spruce	32,383	2.0	1.1	13.46
American sycamore	31,294	1.2	1.1	22.58
Callery pear	27,608	1.2	1.0	19.44
Eastern red cedar	20,426	1.1	0.7	15.42
Scotch pine	20,315	1.0	0.7	16.40
Eastern redbud	18,536	1.7	0.6	9.40
Plum	18,218	1.5	0.6	10.53
Northern catalpa	18,347	1.0	0.6	15.44
Unknown medium	28,164	1.6	1.0	14.85
Unknown small	17,792	1.5	0.6	10.37
Other street trees	407,089	16.5	14.3	20.98
Citywide total	2,848,008	100.0	100.0	24.23

Table 12—*Benefit–cost summary for all street trees*

Benefits	Total ($)	$/tree	$/capita
Energy	596,712	5.08	0.76
CO_2	94,495	0.80	0.12
Air quality	211,691	1.80	0.27
Stormwater	1,977,467	16.83	2.53
Aesthetic/other	2,848,008	24.23	3.64
Total Benefits	5,728,373	48.74	7.32
Costs			
Planting	40,000	0.34	0.05
Contract pruning	121,696	1.04	0.16
Pest management	9,600	0.08	0.01
Irrigation	9,105	0.08	0.01
Removal	491,489	4.18	0.63
Administration	71,000	0.60	0.09
Inspection/service	11,440	0.10	0.01
Infrastructure repairs	110,500	0.94	0.14
Litter clean-up	75,300	0.64	0.10
Other costs	-	0.00	0.00
Total costs	940,130	8.00	1.20
Net benefits	4,788,243	40.74	6.12
Benefit-cost ratio		6.09	

that smaller species, such as crabapple ($19 per tree), Eastern redbud ($18 per tree), and plum ($18 per tree), will provide correspondingly lower benefits despite increased new plantings. Crabapples are the fourth most predominant tree in the inventory but 13th in dollar value of benefits produced.

Figure 11 illustrates the average annual benefits per tree by township and reflects differences in tree types and ages. The street trees of Decatur, Wayne, and Franklin Townships provide $57.94, $55.27, and $52.27 in benefits on average each year, which can be attributed to the relative abundance of mature, larger-stature trees from the predominant species (see *Table 2*). Lawrence Township's street trees, in contrast, provide only $40.58 in benefits on average, due to high percentage (12.7%) of small trees, relative to other townships. Only Pike and Center count small trees among their top five species, but at lower percentages than Lawrence—5.1 and 8.6%. The higher small-tree representation in Center is counteracted by the predominance of large trees and large tree numbers overall.

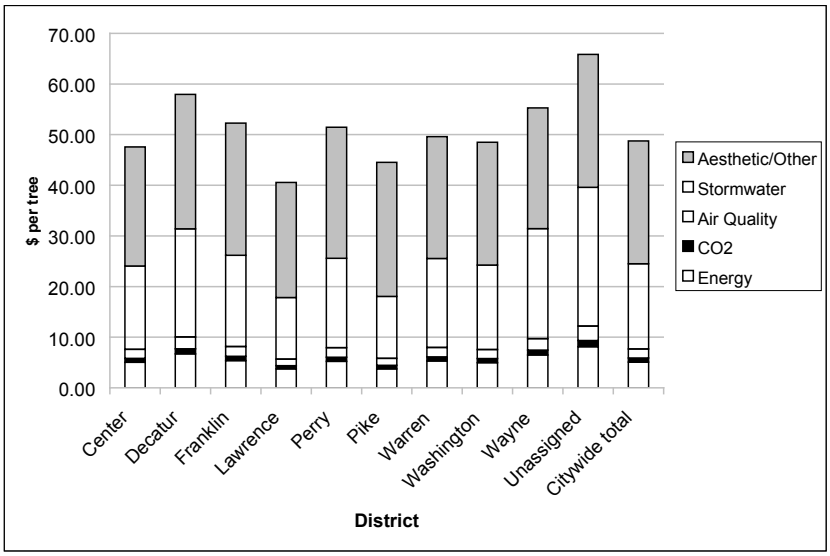


Figure 11—Average annual street tree benefits per tree by township

Table 13—*Average annual benefits ($ per tree) of street trees by species*

Species	Energy	CO_2	Air quality	Stormwater	Aesthetic/other	Total ($)	% of total $	$/tree
Northern hackberry	7.04	1.27	2.68	26.13	44.27	483,448	8.44	81.39
Eastern cottonwood	8.34	0.91	1.94	29.02	37.18	144,872	2.53	77.39
Siberian elm	6.46	1.18	2.74	26.39	39.65	303,883	5.30	76.41
Northern red oak	8.44	1.89	2.63	25.80	35.88	144,805	2.53	74.64
Mulberry	6.02	0.69	2.04	21.78	34.99	203,611	3.55	65.53
Slippery elm	3.11	0.88	1.41	13.67	45.32	79,394	1.39	64.39
Pin oak	6.67	1.54	2.10	19.27	34.51	98,520	1.72	64.10
American sycamore	9.49	1.24	3.17	25.24	22.58	85,547	1.49	61.72
Silver maple	7.36	1.17	2.46	24.91	24.21	983,968	17.18	60.10
Black cherry	8.17	1.22	2.73	21.17	26.59	135,623	2.37	59.88
Sugar maple	6.94	0.84	2.09	21.38	26.91	409,586	7.15	58.16
Boxelder	6.14	0.67	1.95	17.34	27.21	74,979	1.31	53.33
White ash	5.97	0.95	2.00	18.07	25.98	302,803	5.29	52.97
Black walnut	4.26	1.02	2.25	17.86	25.98	77,994	1.36	51.38
Black locust	6.18	1.00	2.07	15.74	26.06	72,453	1.26	51.06
Sweetgum	5.50	0.98	1.85	13.72	27.43	73,130	1.28	49.48
Ash	6.04	0.94	2.03	15.52	24.53	109,958	1.92	49.07
Honeylocust	3.39	0.86	1.87	13.95	27.83	92,466	1.61	47.89
Norway maple	5.39	0.63	1.83	16.83	22.03	154,049	2.69	46.71
Red maple	4.68	0.53	1.48	13.02	25.05	140,348	2.45	44.77
Green ash	4.77	0.82	1.62	12.06	24.84	123,926	2.16	44.10
Northern catalpa	5.94	0.62	2.06	19.31	15.44	51,524	0.90	43.37
Scotch pine	1.18	0.29	1.06	12.93	16.40	39,464	0.69	31.85
Eastern red cedar	0.84	0.26	0.72	8.70	15.42	34,383	0.60	25.95
Eastern white pine	0.80	0.20	0.73	8.83	15.17	81,014	1.41	25.74
Callery pear	1.42	0.25	0.53	3.91	19.44	36,286	0.63	25.55
Norway spruce	0.56	0.17	0.46	6.92	13.46	51,881	0.91	21.56
Blue spruce	0.30	0.10	0.27	4.40	14.50	51,946	0.91	19.57
Crabapple	2.38	0.36	0.78	4.72	11.13	112,398	1.96	19.37
Eastern redbud	1.38	0.23	0.80	6.14	9.40	35,388	0.62	17.95
Plum	1.17	0.19	0.66	5.06	10.53	30,488	0.53	17.62
Unknown medium	7.16	0.77	2.55	20.95	14.85	87,784	1.53	46.28
Unknown small	1.35	0.26	0.78	6.05	10.37	32,275	0.56	18.82
Other street trees	4.15	0.69	1.52	13.28	20.98	788,182	13.76	40.62



Old trees grace a residential neighborhood in Indianapolis

Chapter Five—Management Implications

Indianapolis'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 Indianapolis'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 Indianapolis Parks and Recreation Department, Forestry Section is to be commended for its commitment to increasing the diversity of the urban forest. The number of street tree species (177) is excellent, particularly considering the extent of urbanization within the community. It is evident that there has been increased effort to diversify the species structure of the public right-of-way trees. The distribution of trees across species, with only one species representing more than 10% of the total—silver maple at about 14%—is fairly unusual among the cities we have studied. However, there is reason to remain concerned over the predominance of maples generally. As a genus, these trees represent over 27% of the total ROW tree population and produce 29.5% of all benefits enjoyed by residents of Indianapolis. Sugar maple, northern hackberry and white ash represent another 16% of the population and currently produce 21% of the benefits. As previously mentioned, with over 40% of these four species under 12-inch DBH, they are poised to become the next generation of major benefit producers within the city. The green ash and red maple with 70% of their populations under 12 inches DBH have the potential to become yet a third generation of primary benefit producers.

Care must be taken to maintain and monitor the maples and ashes to protect them from disease and pest infestations now occurring. Indiana and Marion County, specifically, are under quarantine for emerald ash borer (EAB). EAB have killed more than 20 million ash trees in Michigan, Ohio, and Indiana. Although Illinois has deregulated all quarantine zones for the Asian longhorn beetle (ALB) maple tree infestation, it remains a potential problem for any community in the country that serves as a transportation hub. Ash trees account for about 9.3% (approximately 11,000 trees) of the Indianapolis street tree population.

Figure 12 displays large- and medium-growing trees in the smallest DBH size classes, indicating

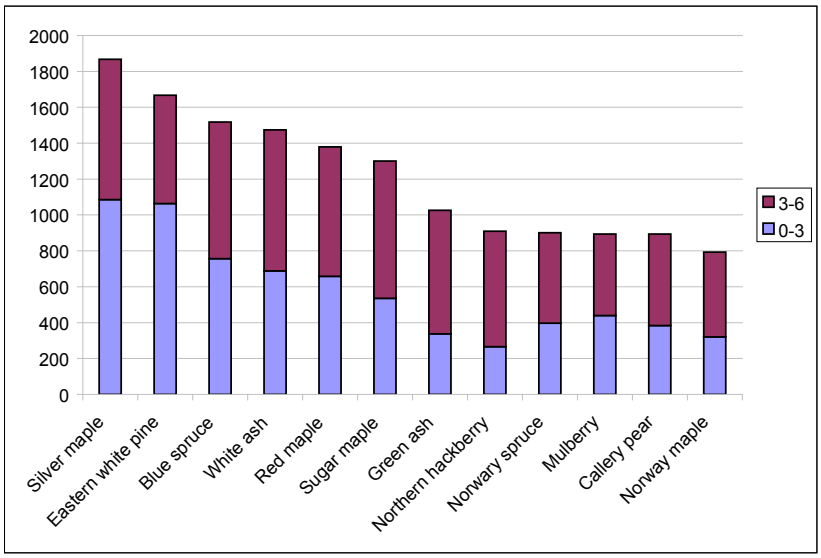


Figure 12—Predominant large- and medium-growing species in the smallest diameter classes (0-6" DBH) indicating relatively recent tree planting and survival trend

trends in new and replacement trees. Silver maples predominate, but still only account for 6.7% of all relatively recent plantings (0-3 inch DBH). The maple genus accounts for 16% of all relatively recent plantings and ash, as a genus, composes another 8.1%. It appears that the Forestry Section is adhering to the rule of thumb of not planting more than 10% of any one species or 20% of a single genus.

The percentage of recent transplants in small, medium and large tree categories is 24, 11, and 65%, respectively. This suggests that the street tree population is being downsized given that overall inventory representation for small, medium, and large-growing trees is 12%, 13%, and 75%. However, it is important to note that the majority of the inventory is at least 20 years old. The newer, Center Township inventory indicates planting proportions of 39% small, 18% medium and 43% large trees. This reflects recent planting programs focused on downtown areas, and many of these areas are adjacent to buildings and surrounded by concrete infrastructure that may limit large-tree planting.

Nevertheless, New York City's Manhattan Island is considered an urban canyon, with a high percentage of impervious land-cover. However, the city foresters have long been conscious of the fact that trees can help counteract the urban heat island effect while also providing stormwater runoff reduction benefits. The percentage of small, medium and large-growing trees in Manhattan is 4, 27, and 69%, respectively. This suggests that planning in Indianapolis for planting the largest possible tree in a given space can be improved to include fewer small trees and more medium- to large trees.

Over 57% of the Indianapolis street tree population is relatively young compared to a desired ideal of 65%. More trees need to be planted to ensure a flow of benefits through time.

Increasing the planting of high benefit species like Northern red oak, pin oak (*Quercus palustris*) and American sycamore/London planetree (*Platanus occidentalis*/*P. hybrida*) is possible. All had above-average relative performance indices in the Center Township and produced significant benefits, although they remain relatively young populations. Expanding upon the planting of species with high relative performance and leaf area but low susceptibility to pests and disease will be vital to maintaining the flow of benefits through time as well as ensuring the health of the urban forest.

Resource Extent

Canopy cover, or more precisely the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As 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 Indianapolis's canopy cover.

Tree planting in Indianapolis is not a fiscally allocated line item in the Forestry Section's annual budget. Planting is entirely dependent upon annual grants and donations. Normally, Forestry can count upon about $50,000 annually in grants and donations for tree planting. At a cost of $104 per tree, about 385 street trees and 96 park trees are planted. Given that the current street tree mortality rate is 50% over the first 40 years of growth, we would expect about 192 of these trees to die before reaching maturity, leaving 192 to continue growing and producing benefits.

The largest portion of the Forestry Section's budget is spent on tree removal, at the rate of 724 trees in 2005. The Center Township inventory lists 1.2% or 396 trees as dead or dying. The stratified random sample we collected throughout the city estimates that 4% or about 4,701(±31) trees are dead or dying and need removal. In addition, another 10% citywide (11,752 trees ±119) are in poor condition; 4,159 of these are in Center Township. These numbers indicate a 7-year backlog of dead trees to be removed. Without the resources—fiscal and

staffing—necessary to provide systematic maintenance for these trees, many more trees will require removal over the next 10 years. The city needs to (1) remove dead and risk trees which are a liability and produce little or no benefit, (2) replace each removal, and (3) plant additional empty sites.

Without implementing programmed pruning cycles and without establishing and adequately funding a tree planting and care plan, this net loss in street trees will be exacerbated in the future. Street tree canopy and the associated benefits will be lost. It is important to note that although Indianapolis has the highest benefit-cost ratio of any city studied to date, it is in large part due to the fact that the city spends relatively little on their trees compared to any other study city.

Indianapolis is the 12th largest city in the nation. Examining results of previous studies conducted in cities with populations exceeding 375,000, we can see that each one expends more on their tree populations and, with the exception of Albuquerque, receives more benefits in return (*Table 14*). The benefit of added expenditure is revealed in overall tree condition for these cities, which ranges from 92 to 98% in fair or better condition compared to Indy's 86%. Healthy trees provide more benefits, and well-maintained trees live longer, allowing those benefits to accrue over a longer period.

In 2007, former Indianapolis Mayor Bart Peterson joined 400 other mayors across 50 states in signing the U.S. Mayors Climate Protection Agreement, thereby promising that Indy will strive to meet or exceed a 7% reduction from the 1990 greenhouse gas emission level through such measures as energy-efficient building practices, alternative fuels, improved transportation, and improved land-use planning.

Table 14—*Benefits and costs per tree and benefit-cost ratio for cities with populations over 375,000*

City	Benefit/ tree ($)	Cost/ tree ($)	BCR
Albuquerque	26.06	19.91	1.31
Charlotte	69.42	21.37	3.25
Honolulu	89.53	30.02	2.98
Indianapolis	48.74	8.00	6.09
Lisbon	204.45	45.64	4.48
Minneapolis	125.53	46.05	2.73
New York City	216.12	37.28	5.80

Current Mayor Gregory Ballard continues to endorse the Mayors Climate Protection Agreement and the Indy Greenprint. Urban forestry is one component of the Greenprint, with a goal of planting 100,000 trees in parks and on streets over 10 years and preserving as many existing trees as possible (Indy Greenprint 2008). This goal is listed under the Natural Resource Stewardship Action Plan addressing land conservation, urban forestry and water quality. Although the street trees of Indianapolis are often not native or part of the community's original natural resource, they are contributing significantly to improving the quality of life in neighborhoods and, particularly, water quality through rainfall interception and stormwater runoff reduction with each tree intercepting an average 2,714 gallons of rainfall.

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 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/ft^2. In areas with on-street parking, trees can have an additional benefit of reducing pollutant emis-sions 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 in-creasing 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.

The city's street tree stocking level citywide (34 trees/mile; 1 tree for approximately every 7 citizens), is one of the lowest among large cities studied thus far. The tree canopy currently shades 13.8% of the city's streets and sidewalks. We recommend that within the existing goal of planting 100,000 trees over the next 10 years, the city specifically address increasing street tree stocking and canopy cover, setting an initial goal of planting 1 street tree for every 5 residents. This represents an increase of over 39,000 street trees (156,574 projected compared to 117,525 currently) for a 20% stocking level and 18.5% canopy cover over streets and sidewalks. The median stocking level for cities studied to date is 28.3%.

Maintenance

Indianapolis's maintenance challenges in the coming years will be to establish and care for the new trees being planted and to preserve and, eventually, remove the older silver maples, American sycamores, cottonwoods, and elms as they continue to decline and become safety hazards. With at least 385 new trees planted each year, a strong young-tree care program is imperative to ensure, 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 a significant challenge, the Forestry Section, Tree Board and citizens should work to secure funding to allow increasing the young tree maintenance cycle to at least two visits during the first 5 years of establishment. Funding for establishment irrigation should also be strongly considered.

The older silver maples, hackberries, cottonwoods, American sycamores, and elms are reaching the end of their natural life spans and are in decline. Like people, older trees tend to develop problems that younger trees do not; for example, silver maples often develop significant internal decay that can result in dangerous loss of large branches. Silver maples also cause significant damage when planted too near built infrastructure because they have shallow root systems and large root crowns. The city's silver maples will require increased maintenance as they age and eventually need removal. The future of these species, which provide a large share of the benefits of the urban forest, 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.

Other Management Implications

There are several difficulties inhibiting the creation of a sustainable forest in Indianapolis. First, a complete, updated inventory of all public trees

is recommended, but only if funding is provided for updating and using the inventory as a working management tool. This inventory should tally available planting spaces and note the maximum tree size suitable for each space. In this way, spaces for large trees could be filled first, providing the most benefits in a cost-effective way. At a minimum, if funding is not made available, a sample inventory should be conducted.

Second, the street tree population in Indy is at a critical juncture. The Forestry Section, along with partners and the community, is doing an admirable job of finding new ways to get more trees planted, but the fact remains that street tree removals continue to outpace planting rates. Young trees are not receiving enough care during the first five years of establishment. Mature trees provide many of the benefits now enjoyed by the community but they are not receiving the care necessary to support them into maturity, ensuring that citizens reap a higher level of benefits over a longer period. The budget for providing these trees with minimal care (supporting a reactive rather than pro-active pruning program) has been further eroded in the past few years. The Indy GreenPrint and Mayors Climate Action Agreement speak to tree planting, but the act of planting trees is not enough to ensure an increase in canopy and benefits. Indianapolis needs to establish stable funding for a long-range planting and care program providing adequate care and maintenance to reduce high street tree mortality rates, ensure survival of new plantings, and improve the health of established plantings.

Lastly, new plantings should be closely monitored. Fewer than half the trees planted appear to reach their full mature stature, and the reason for this remains unclear. Pest problems, poor species selection, lack of irrigation, 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 Forestry Section determine what changes need to be made to ensure trees grow to their full size and provide maximum benefits.



Tree leaves help clean the air by absorbing pollutants, reduce stormwater runoff by intercepting rainfall, and reduce energy use by shading homes and businesses

Chapter Six—Conclusion

This analysis describes structural characteristics of the municipal tree population and uses tree growth and geographic data for Indianapolis 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 Indianapolis that can be used to make informed decisions.

The 117,525 street trees in the City of Indianapolis are a valuable asset, providing over $5.7 million ($49 per tree) in annual benefits. Benefits to the community are most pronounced for stormwater runoff reduction, 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 14*). Indianapolis spends approximately $940,000 maintaining these trees or $8.00 per tree.

After expenditures are taken into account, Indianapolis's street tree resource currently provides approximately $4.8 million or $40.74 per tree ($6.12 per capita) in net annual benefits to the community. Over the years, Indianapolis has invested millions of dollars in these trees. Citizens are seeing a return on that investment—receiving $6.09 in benefits for every $1 spent on tree care. Over 57% of the tree population is relatively young—less than 12 inches DBH—and nearly 81% of these trees are medium to large-growing trees. The value of Indianapolis's ROW trees will increase if the many young trees planted can survive and mature. As the resource grows, continued investment in management is critical, ensuring that the trees are properly cared for so residents receive a high return on investment in the future.

The street trees of Indianapolis 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 Forestry Section has been able to sustain the street tree population as effectively as it has, given fiscal reductions that include loss of personnel and contract 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 Indianapolis meet its Climate Protection Agreement goals to reduce greenhouse gases and emissions and assist the city in creating a more sustainable environment through the Greenprint (100,000 trees to be planted over 10 years):

1. Work together with the Tree Board and civic partnerships to develop a prioritized plan with targets and funding necessary to significantly increase shade tree planting along streets, in parking lots, and near buildings in and adjacent to public rights-of-way.
    - Revise, update, and enforce the current tree and landscape ordinance to create specific public and private street and parking lot shade guidelines promoting increased tree canopy and the associated benefits.
    - Specifically plan an increase in street tree stocking and canopy cover, setting an initial goal of planting 1 street tree for every 5 residents. This represents an increase of over 39,000 street trees (156,574 projected compared to 117,525 currently) for a 20% stocking level and 18.5% canopy cover over streets and sidewalks.

- Increase stocking level with larger-growing shade tree species where conditions are suitable to maximize benefits. Continue planting a diverse mix of tree species, with a focus on native species, to guard against catastrophic losses due to storms, pests or disease.
- Plan and fund inspection and pruning cycles to reduce street tree mortality rates and ensure survival. Plans should address:
    - o An improved young-tree care program that details inspections and structural pruning at least twice during the initial 5 years after planting to reduce young-tree mortality and provide a good foundation for the trees.
    - o Planned inspection and pruning cycles for mature trees (e.g., silver maples, hackberries, cottonwoods, American sycamores, and elms) to prolong the functional life spans of these trees and increase current benefits.
    - o 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 ensure that every removal is replaced and that current empty sites are planted.

2. Fund the updating, maintenance, and use of a working inventory of all public trees to properly assess, track, and manage the resource.
3. Adequately staff the Forestry Section to meet the planting and maintenance demands of the urban forest, grow the canopy along with associated environmental benefits, and insure public safety.

These recommendations build on a history of dedicated management and commitment to natural resource preservation. Indianapolis 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)										
Acer saccharinum	1,086	782	3,285	4,022	3,219	2,253	1,092	400	232	16,371
Acer saccharum	535	765	1,839	1,794	1,397	538	134	29	11	7,042
Celtis occidentalis	266	644	1,822	1,195	768	519	321	215	190	5,940
Fraxinus americana	689	785	1,589	1,195	682	385	202	101	89	5,717
Ulmus pumila	304	389	946	781	653	482	274	96	52	3,977
Acer platanoides	320	473	963	752	571	172	39	6	2	3,298
Acer rubrum	658	722	810	518	238	133	42	9	5	3,135
Fraxinus pennsylvanica	338	688	937	457	194	113	59	21	3	2,810
Prunus serotina	49	143	680	582	411	207	94	62	37	2,265
Fraxinus species	283	310	749	368	264	128	79	30	30	2,241
Quercus rubra	292	259	332	388	268	175	119	55	52	1,940
Gleditsia triacanthos	274	451	747	306	105	25	10	6	7	1,931
Populus deltoides	104	82	255	383	334	269	185	128	132	1,872
Quercus palustris	215	303	376	302	171	97	45	12	16	1,537
Juglans nigra	102	101	370	453	302	135	47	5	3	1,518
Liquidambar styraciflua	149	240	413	474	157	36	7	2	-	1,478
Robinia pseudoacacia	141	174	471	322	166	92	26	9	18	1,419
Platanus occidentalis	66	110	256	263	252	202	120	64	53	1,386
Liriodendron tulipifera	194	92	228	289	191	102	34	6	3	1,139
Ulmus americana	70	118	356	190	127	91	45	21	15	1,033
Carya ovata	32	65	314	294	100	38	6	4	2	855
Ailanthus altissima	110	109	179	136	84	60	27	9	7	721
Pyrus species	145	184	228	44	7	2	1	1	-	612
Ginkgo biloba	222	110	141	31	17	14	5	-	-	540
Quercus macrocarpa	32	39	105	98	93	57	36	25	42	527
Tilia americana	18	33	114	113	89	71	33	13	20	504
Quercus alba	66	30	73	92	48	45	19	21	26	420
Betula nigra	238	48	38	40	16	7	2	4	-	393
Acer nigrum	32	44	153	91	36	23	4	-	-	383
Alnus glutinosa	127	151	61	3	1	-	-	-	-	343
Platanus hybrida	23	27	48	77	59	29	43	17	2	325
Unknown large	-	-	-	-	-	-	178	80	57	315
Ulmus species	20	37	99	39	23	17	12	4	3	254
Populus nigra	90	60	66	17	3	-	-	-	1	237
Betula papyrifera	37	61	63	16	13	1	-	-	-	191
Quercus muehlenbergii	8	6	39	39	37	9	7	13	4	162
Fagus grandifolia	4	7	21	33	24	31	25	10	2	157
Quercus velutina	28	12	43	24	15	5	5	2	1	135
Maclura pomifera	1	15	41	19	16	10	6	6	3	117
Populus species	23	26	23	23	12	5	-	1	-	113
Quercus bicolor	1	6	19	25	27	19	6	4	4	111

Species	DBH Class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Populus alba	38	6	25	18	8	6	1	-	2	104
Tilia species	29	5	10	17	14	15	3	5	3	101
Aesculus hippocastanum	18	17	31	20	10	2	-	-	-	98
Gymnocladus dioicus	14	17	25	15	11	4	4	-	-	90
Quercus species	25	4	15	3	7	4	6	2	1	67
Taxodium distichum	21	19	8	10	3	2	1	-	-	64
Quercus prinus	7	4	11	9	9	13	2	4	4	63
Fraxinus excelsior 'Hessei'	8	19	1	14	12	1	-	-	-	55
Zelkova serrata	6	15	26	4	-	-	-	-	-	51
Quercus coccinea	3	14	6	7	7	3	5	2	1	48
Quercus imbricaria	12	3	6	11	3	1	1	-	-	37
Fraxinus quadrangulata	1	2	11	5	9	4	1	-	1	34
Tilia tomentosa 'Sterling Silver'	14	14	-	-	-	-	-	-	-	28
Fagus species	1	-	12	4	1	5	-	2	-	25
Carya cordiformis	-	1	3	5	4	5	3	-	-	21
Carya glabra	2	1	2	10	1	4	-	-	-	20
Platanus species	2	-	2	2	2	3	1	-	1	13
Betula alleghaniensis	3	7	2	-	-	-	-	-	-	12
Larix species	2	6	4	-	-	-	-	-	-	12
Acer pseudoplatanus	1	4	2	3	1	-	-	-	-	11
Tilia tomentosa	3	1	4	1	-	-	-	-	1	10
Quercus robur	-	6	1	-	-	-	-	-	1	8
Larix decidua	1	2	1	-	1	-	-	-	-	5
Metasequoia glyptostroboides	1	-	2	1	1	-	-	-	-	5
Fagus sylvatica 'Purpurea'	1	-	1	-	-	-	1	-	-	3
Fraxinus nigra	-	1	1	1	-	-	-	-	-	3
Paulownia species	2	-	1	-	-	-	-	-	-	3
Cercidiphyllum japonicum	-	1	-	-	1	-	-	-	-	2
Fagus sylvatica	-	-	1	-	-	1	-	-	-	2
Oxydendrum arboreum	-	1	1	-	-	-	-	-	-	2
Ulmus parvifolia	-	-	1	-	1	-	-	-	-	2
Carya laciniosa	-	-	-	1	-	-	-	-	-	1
Magnolia acuminata	-	1	-	-	-	-	-	-	-	1
Total	7,607	8,872	19,508	16,449	11,296	6,670	3,418	1,506	1,139	76,465
Broadleaf deciduous medium (BDM)										
Morus species	439	455	999	542	294	180	91	57	50	3,107
Unknown medium	-	-	-	954	594	349	-	-	-	1,897
Pyrus calleryana	384	510	421	96	9	-	-	-	-	1,420
Acer negundo	105	212	530	279	153	70	30	14	13	1,406
Ulmus rubra	136	303	475	190	71	34	14	4	6	1,233
Catalpa speciosa	68	51	186	190	206	226	143	75	43	1,188
Tilia cordata	159	261	427	103	25	17	4	2	2	1,000
Salix species	48	43	88	46	38	12	18	9	17	319
Acer species	36	64	91	34	8	7	-	1	1	242
Acer campestre	49	28	86	10	2	-	-	-	-	175

Species	DBH Class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Aesculus glabra	14	19	42	52	18	13	2	2	2	164
Fraxinus oxycarpa 'Aureafolia'	38	21	24	5	-	-	-	-	-	88
Sorbus alnifolia	38	20	11	5	-	2	-	-	-	76
Aesculus species	8	14	14	14	8	1	3	-	-	62
Diospyros virginiana	20	13	9	4	5	1	-	-	-	52
Carpinus caroliniana	6	13	18	7	1	-	-	-	-	45
Ostrya virginiana	2	9	20	7	2	-	-	-	-	40
Sassafras albidum	13	10	9	4	1	-	-	-	-	37
Eucommia ulmoides	-	-	-	8	18	-	-	-	-	26
Betula species	6	2	8	5	2	-	-	-	-	23
Carpinus species	7	4	8	1	1	-	-	-	-	21
Juglans cinerea	5	5	1	6	-	-	-	-	-	17
Castanea mollissima	6	3	6	1	-	-	-	-	-	16
Carpinus betulus 'Fastigiata'	1	3	8	-	-	-	-	-	-	12
Juglans species	4	1	1	3	1	1	-	-	-	11
Juglans regia	1	2	1	4	1	-	-	-	-	9
Nyssa sylvatica	-	1	5	1	1	-	-	-	-	8
Paulownia tomentosa	2	1	5	-	-	-	-	-	-	8
Fraxinus ornus	2	1	4	-	-	-	-	-	-	7
Phellodendron amurense	2	2	1	-	1	-	-	-	-	6
Sophora japonica	-	-	4	-	1	-	-	-	-	5
Cladrastis kentukea	2	-	1	-	-	-	-	-	-	3
Total	1,601	2,071	3,503	2,571	1,461	913	305	164	134	12,723
Broadleaf deciduous small (BDS)										
Malus species	1,539	1,498	1,936	541	184	56	24	18	7	5,803
Cercis canadensis	452	369	715	273	95	37	19	9	3	1,972
Prunus species	550	416	476	161	78	24	12	7	6	1,730
Unknown small	211	290	1,214	-	-	-	-	-	-	1,715
Crataegus species	162	261	324	172	60	21	16	4	-	1,020
Cornus florida	247	174	164	18	3	-	-	-	-	606
Cornus species	149	59	73	18	7	3	-	-	-	309
Magnolia species	50	28	95	62	17	10	2	-	-	264
Crataegus phaenopyrum	36	48	23	-	3	1	-	-	-	111
Acer palmatum	51	20	31	2	-	-	-	-	-	104
Cornus racemosa	36	24	32	7	2	-	-	-	-	101
Elaeagnus angustifolia	28	20	27	11	1	-	1	-	-	88
Acer ginnala	32	21	27	4	-	1	1	-	-	86
Koelreuteria paniculata	20	24	14	12	3	1	-	-	-	74
Rhus typhina	28	20	15	1	-	1	-	-	-	65
Syringa species	31	29	5	-	-	-	-	-	-	65
Albizia julibrissin	16	13	23	-	1	-	-	-	-	53
Magnolia soulangiana	4	4	15	14	11	1	-	-	-	49
Cotinus coggygria	18	6	17	4	2	-	1	-	-	48
Crataegus crusgalli 'Inermis'	7	11	3	3	-	-	-	1	-	25
Crataegus × *Lavallei*	9	9	5	-	-	-	-	-	-	23

Species	DBH Class (in)									Total
	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	>42	
Amelanchier × *Grandiflora* 'Autumn'	-	20	-	-	-	-	-	-	-	20
Amelanchier canadensis	14	4	-	-	-	-	-	-	-	18
Lonicera species	8	3	2	1	-	-	2	-	-	16
Hibiscus species	11	3	-	-	-	-	-	-	-	14
Prunus subhirtella	4	3	6	1	-	-	-	-	-	14
Rhamnus cathartica	1	5	4	-	1	-	-	-	-	11
Aralia spinosa	8	-	1	-	-	-	-	-	-	9
Asimina triloba	2	-	2	1	-	-	-	-	-	5
Prunus pennsylvanica	-	-	2	1	-	-	-	1	-	4
Crataegus viridis 'Winter King'	1	-	-	2	-	-	-	-	-	3
Prunus hally	1	-	1	-	-	1	-	-	-	3
Corylus americana	-	-	-	1	1	-	-	-	-	2
Euonymus species	2	-	-	-	-	-	-	-	-	2
Magnolia stellata	-	-	1	-	-	1	-	-	-	2
Frangula alnus	-	-	1	1	-	-	-	-	-	2
Robinia viscosa	-	2	-	-	-	-	-	-	-	2
Elaeagnus species	1	-	-	-	-	-	-	-	-	1
Spirea species	-	-	1	-	-	-	-	-	-	1
Viburnum species	-	-	1	-	-	-	-	-	-	1
Total	3,729	3,384	5,256	1,311	469	158	78	40	16	14,441
Broadleaf evergreen small (BES)										
Ilex opaca	12	14	11	-	-	-	-	-	-	37
Elaeagnus umbellata	-	-	3	-	1	-	-	-	-	4
Ligustrum species	-	3	-	-	-	-	-	-	-	3
Buxus species	-	-	1	-	-	-	-	-	-	1
Total	12	17	15	-	1	-	-	-	-	45
Conifer evergreen large (CEL)										
Pinus strobus	1,064	603	1,092	350	34	4	1	-	-	3,148
Picea pungens	756	762	939	174	17	1	2	-	3	2,654
Picea abies	397	504	925	445	118	15	-	1	1	2,406
Pinus sylvestris	145	242	596	209	34	9	2	1	1	1,239
Pinus resinosa	149	88	244	105	22	6	1	-	-	615
Pinus nigra	41	169	154	51	8	-	-	-	-	423
Picea species	105	50	93	17	4	1	1	1	-	272
Abies fraseri	7	20	60	45	32	11	1	-	-	176
Picea glauca	58	30	43	4	4	-	-	-	-	139
Pseudotsuga menziesii	27	12	51	18	-	-	1	-	-	109
Pinus banksiana	1	9	65	7	2	-	-	-	-	84
Abies species	13	6	14	2	-	-	1	-	-	36
Pinus virginiana	7	3	20	1	1	1	-	-	-	33
Abies concolor	8	9	11	-	-	-	-	-	-	28
Abies balsamea	10	4	3	-	-	-	-	1	1	19
Picea mariana	2	3	2	1	-	-	-	-	-	8
Picea rubens	4	-	-	-	-	-	-	-	-	4

	DBH Class (in)									
Species	**0–3**	**3–6**	**6–12**	**12–18**	**18–24**	**24–30**	**30–36**	**36–42**	**>42**	**Total**
Pinus ponderosa	1	-	-	-	-	-	-	-	-	1
Total	2,795	2,514	4,312	1,429	276	48	10	4	6	11,394
Conifer evergreen medium (CEM)										
Juniperus virginiana	142	315	625	170	35	16	16	5	1	1,325
Thuja occidentalis	165	148	276	41	5	2	1	-	-	638
Tsuga canadensis	92	71	97	13	2	1	-	-	-	276
Total	399	534	998	224	42	19	17	5	1	2,239
Conifer evergreen small (CES)										
Juniperus species	46	64	14	0	0	0	0	1	0	125
Taxus species	16	46	6	4	0	0	0	0	0	72
Pinus mugo	8	1	4	0	1	0	0	0	0	14
Taxus canadensis	0	2	1	1	0	0	0	0	0	4
Juniperus conferta	1	1	0	0	0	0	0	0	0	2
Juniperus procumbens	0	0	1	0	0	0	0	0	0	1
Total	71	114	26	5	1	0	0	1	0	218
Citywide total	16,214	17,506	33,618	21,989	13,546	7,808	3,828	1,720	1,296	117,525

Appendix B—Replacement Values

Table B1*— Replacement value for Indianapolis's street trees*

Species	DBH Class (in)								Total	% of total
	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42		
Silver maple	488,223	1,353,486	2,882,429	3,777,901	4,016,896	2,742,687	1,288,711	829,113	17,379,444	15.4
Northern hackberry	284,328	1,087,427	1,454,545	1,649,465	1,758,614	1,562,960	1,358,479	1,336,704	10,492,522	9.3
Sugar maple	430,736	1,187,879	2,351,248	3,223,753	1,956,694	701,763	196,513	82,987	10,131,573	9.0
White ash	436,030	825,144	1,176,551	1,147,443	1,006,010	752,208	485,865	475,983	6,305,233	5.6
Crabapple	978,511	1,170,114	641,618	378,741	180,407	110,788	107,432	46,483	3,614,095	3.2
Eastern cottonwood	48,957	120,602	344,490	514,093	643,502	631,081	564,045	646,719	3,513,490	3.1
Siberian elm	183,906	360,953	488,336	647,021	712,527	563,717	252,419	151,369	3,360,247	3.0
Unknown medium	0	0	1,050,236	1,137,572	1,047,258	0	0	0	3,235,066	2.9
Northern red oak	176,601	200,659	460,162	551,644	563,772	548,145	328,266	345,303	3,174,553	2.8
Norway maple	237,528	500,072	740,390	960,690	449,438	145,725	28,863	10,696	3,073,402	2.7
Mulberry	285,333	479,288	440,162	385,320	355,552	252,276	202,062	196,447	2,596,441	2.3
Ash	175,504	403,465	383,720	474,880	359,280	317,323	155,626	173,097	2,442,897	2.2
Red maple	407,471	420,621	510,002	400,428	347,531	156,809	43,295	26,741	2,312,898	2.0
Black cherry	52,566	280,174	417,100	482,361	369,063	236,680	199,750	132,229	2,169,922	1.9
Green ash	282,619	443,152	411,048	298,605	270,319	201,287	92,539	14,698	2,014,267	1.8
Black walnut	59,878	206,482	498,697	578,362	405,100	202,251	27,823	18,575	1,997,167	1.8
American sycamore	47,718	113,276	212,519	341,816	421,687	354,805	244,108	224,538	1,960,467	1.7
Unknown large	0	0	0	0	0	931,881	542,105	430,024	1,904,009	1.7
Pin oak	170,351	227,253	358,168	351,982	312,491	207,549	71,622	106,247	1,805,662	1.6
Eastern redbud	262,544	461,845	357,797	219,224	134,568	99,744	60,987	22,633	1,619,343	1.4
Bur oak	23,422	72,185	140,653	237,790	230,987	209,652	189,604	354,821	1,459,114	1.3
Northern catalpa	31,099	70,970	118,802	204,114	334,089	294,725	197,202	125,171	1,376,171	1.2
Tulip tree	73,345	114,778	286,354	328,899	275,078	131,418	29,994	16,687	1,256,553	1.1
Boxelder	87,290	250,664	250,946	235,498	167,454	102,634	61,692	63,692	1,219,870	1.1
Honeylocust	197,832	353,295	275,232	161,616	59,805	34,137	26,440	34,296	1,142,652	1.0
American elm	51,356	168,370	170,895	195,478	217,690	153,167	92,539	73,491	1,122,987	1.0
Sweetgum	106,041	195,328	426,340	241,654	86,119	23,836	8,813	0	1,088,133	1.0
Norway spruce	201,502	360,822	328,869	148,971	29,406	0	3,609	4,012	1,077,189	1.0
Eastern white pine	342,210	394,093	234,875	38,636	7,027	2,478	0	0	1,019,319	0.9
American basswood	15,561	63,619	124,399	170,444	213,053	142,382	72,339	123,834	925,631	0.8
White oak	29,607	47,153	120,576	110,766	163,664	99,860	142,302	196,151	910,081	0.8
Black locust	83,508	179,713	201,337	164,480	136,001	53,679	23,664	52,397	894,780	0.8
Unknown small	150,541	677,485	0	0	0	0	0	0	828,027	0.7
Blue spruce	319,878	338,876	116,767	19,318	1,757	4,956	0	10,740	812,291	0.7
Shagbark hickory	26,717	148,506	264,438	153,920	90,904	20,527	17,626	9,799	732,437	0.6
Plum	252,508	181,621	100,669	77,286	35,479	24,795	18,406	17,466	708,228	0.6
Littleleaf linden	127,416	238,292	113,390	47,878	51,013	17,146	11,129	12,383	618,647	0.5
Callery pear	266,429	218,619	94,518	15,142	0	0	0	0	594,708	0.5
Hawthorn	114,531	143,365	138,986	81,385	43,839	47,512	15,257	0	584,875	0.5
Tree of heaven	57,693	68,299	85,037	83,231	88,696	55,724	23,664	20,377	482,721	0.4
Slippery elm	116,116	152,299	84,072	44,394	29,546	16,303	5,778	9,512	458,020	0.4
Eastern red cedar	93,052	183,083	82,755	27,216	18,645	26,162	10,405	2,305	443,623	0.4
London planetree	13,362	21,239	62,220	80,028	60,539	127,145	64,841	8,473	437,849	0.4
American beech	3,376	12,533	40,167	51,546	105,043	122,182	63,185	14,071	412,103	0.4
Scotch pine	81,791	175,476	98,579	25,076	9,828	3,039	1,929	2,134	397,853	0.4

Species	DBH Class (in)								Total	% of total
	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42		
Black maple	24,960	92,473	107,925	74,101	74,096	18,499	0	0	392,053	0.3
Ginkgo	102,760	96,935	44,492	43,467	56,734	29,347	0	0	373,735	0.3
Chinkapin oak	4,453	25,192	51,114	85,382	32,733	36,509	88,092	30,177	353,651	0.3
Pear	106,952	128,330	46,700	12,664	5,612	3,965	5,161	0	309,384	0.3
Swamp white oak	2,511	13,062	35,881	69,036	76,996	34,877	30,337	33,792	296,491	0.3
Willow	26,403	37,850	32,983	43,601	20,655	43,341	27,687	57,934	290,456	0.3
Red pine	48,736	93,463	77,442	27,924	11,870	2,865	0	0	262,299	0.2
Flowering dogwood	133,198	99,121	21,348	6,175	0	0	0	0	259,842	0.2
Ohio buckeye	10,865	26,257	64,912	39,294	44,580	9,756	12,745	14,185	222,593	0.2
Magnolia	22,274	53,016	68,254	32,557	30,007	8,621	0	0	214,729	0.2
Northern white cedar	62,684	102,252	29,497	6,214	3,882	2,813	0	0	207,341	0.2
River birch	71,115	17,972	35,978	24,627	16,745	6,842	17,626	0	190,907	0.2
Elm	15,279	37,774	24,386	22,789	25,131	24,667	10,517	8,733	169,276	0.1
Maple	30,463	50,783	37,430	15,321	21,005	0	5,565	6,192	166,759	0.1
Basswood	9,220	5,581	18,715	26,811	45,011	12,883	27,823	18,575	164,619	0.1
Dogwood	63,848	44,121	21,348	14,409	9,665	0	0	0	153,389	0.1
Austrian pine	46,717	55,577	34,225	9,091	0	0	0	0	145,610	0.1
Chestnut oak	3,441	6,648	10,674	18,525	41,880	9,351	23,874	26,562	140,955	0.1
Black oak	12,357	24,203	25,473	27,137	14,031	20,088	10,321	5,737	139,345	0.1
Osage orange	4,566	18,142	15,353	21,703	20,876	17,881	22,885	12,710	134,116	0.1
European alder	90,579	36,868	3,558	2,058	0	0	0	0	133,064	0.1
Fraser fir	5,939	21,653	30,198	36,363	19,324	2,532	0	0	116,010	0.1
Kentucky coffeetree	10,168	16,148	19,659	25,384	14,548	20,846	0	0	106,753	0.1
Spruce	31,584	33,563	11,408	4,545	1,757	2,532	3,222	0	88,611	0.1
Black poplar	39,112	28,199	12,960	3,795	0	0	0	3,905	87,971	0.1
Eastern hemlock	35,512	35,420	8,635	2,226	1,711	0	0	0	83,504	0.1
Horsechestnut	11,258	18,736	23,720	20,584	6,443	0	0	0	80,741	0.1
Paper birch	26,189	24,038	10,004	12,881	1,478	0	0	0	74,591	0.1
Hedge maple	19,950	40,674	8,994	3,078	0	0	0	0	72,697	0.1
Oak	7,165	7,094	2,698	10,774	9,569	20,527	8,813	4,899	71,540	0.1
Buckeye	7,258	7,880	14,859	14,473	2,806	11,983	0	0	59,258	0.1
Scarlet oak	4,792	2,746	5,976	10,135	6,720	15,942	8,221	4,568	59,100	0.1
Cottonwood	12,958	8,776	14,381	11,890	7,391	0	2,629	0	58,025	0.1
Baldcypress	12,918	5,500	14,352	7,671	8,105	5,922	0	0	54,467	0.0
Gray dogwood	18,925	19,341	8,302	4,117	0	0	0	0	50,684	0.0
Pyramid magnolia	2,361	8,371	15,412	21,066	3,001	0	0	0	50,211	0.0
White poplar	11,187	8,777	9,610	6,464	7,042	1,599	0	4,496	49,175	0.0
Hesse ash	8,256	519	13,784	20,190	2,613	0	0	0	45,361	0.0
Douglas fir	7,910	19,535	13,276	0	0	2,865	0	0	43,585	0.0
Blue ash	826	5,202	4,497	13,853	9,569	3,384	0	4,899	42,230	0.0
Amur maple	15,269	15,068	4,404	0	3,001	4,358	0	0	42,098	0.0
Beech	259	6,929	4,636	2,031	15,973	0	11,883	0	41,712	0.0
White spruce	17,994	15,518	2,684	4,545	0	0	0	0	40,742	0.0
Washington hawthorn	22,569	10,177	0	4,069	2,088	0	0	0	38,903	0.0
Goldenrain tree	11,884	7,048	11,890	5,166	2,697	0	0	0	38,684	0.0
Japanese maple	19,967	16,098	1,969	0	0	0	0	0	38,034	0.0
Shingle oak	4,513	3,626	13,046	6,175	3,222	4,676	0	0	35,258	0.0
Hardy rubber tree	0	0	7,196	27,706	0	0	0	0	34,901	0.0
Bitternut hickory	293	1,419	4,497	6,157	11,961	10,151	0	0	34,478	0.0

Species	DBH Class (in)								Total	% of total
	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42		
Russian olive	12,527	10,302	6,878	991	0	2,088	0	0	32,785	0.0
Eastern hophornbeam	3,855	12,919	9,174	4,615	0	0	0	0	30,563	0.0
Golden desert ash	15,267	10,985	4,269	0	0	0	0	0	30,521	0.0
Juniper	22,166	4,237	0	0	0	0	2,269	0	28,673	0.0
Korean mountain ash	14,996	4,532	3,583	0	3,566	0	0	0	26,677	0.0
Jack pine	2,174	19,138	3,302	1,475	0	0	0	0	26,089	0.0
Smoke tree	6,073	8,040	3,598	3,078	0	3,458	0	0	24,248	0.0
Japanese zelkova	6,434	13,501	3,938	0	0	0	0	0	23,874	0.0
Yew	17,314	2,838	3,598	0	0	0	0	0	23,750	0.0
Common persimmon	8,594	3,708	2,867	5,868	1,783	0	0	0	22,820	0.0
Lilac	19,289	3,022	0	0	0	0	0	0	22,311	0.0
American hornbeam	5,203	7,965	5,656	1,356	0	0	0	0	20,180	0.0
Skunkbush sumac	12,511	5,266	534	0	1,174	0	0	0	19,485	0.0
Pignut hickory	773	885	8,081	1,356	8,350	0	0	0	19,446	0.0
Sycamore	485	885	1,616	2,713	6,263	3,001	0	4,237	19,200	0.0
Mimosa	9,139	9,124	0	812	0	0	0	0	19,074	0.0
Sassafras	6,046	4,257	3,598	1,539	0	0	0	0	15,440	0.0
American holly	8,463	6,648	0	0	0	0	0	0	15,111	0.0
Cockspur hawthorn	4,934	1,510	2,973	0	0	0	4,999	0	14,415	0.0
Fir	3,867	5,052	1,342	0	0	2,478	0	0	12,739	0.0
Virginia pine	2,033	6,775	605	1,003	1,535	0	0	0	11,951	0.0
Birch	2,040	3,296	3,583	2,347	0	0	0	0	11,266	0.0
Balsam fir	2,833	1,083	0	0	0	0	3,222	3,580	10,717	0.0
Silver linden	1,113	2,232	1,101	0	0	0	0	6,192	10,637	0.0
English oak	2,193	646	0	0	0	0	0	7,544	10,383	0.0
Hornbeam	2,851	3,540	808	1,356	0	0	0	0	8,555	0.0
Sterling silver linden	8,264	0	0	0	0	0	0	0	8,264	0.0
Sycamore maple	1,577	1,116	3,303	1,915	0	0	0	0	7,911	0.0
White fir	3,615	4,214	0	0	0	0	0	0	7,828	0.0
Butternut	2,903	403	3,814	0	0	0	0	0	7,119	0.0
Carriere hawthorn	4,777	2,212	0	0	0	0	0	0	6,990	0.0
Black tupelo	335	2,984	1,217	2,148	0	0	0	0	6,684	0.0
Walnut	1,404	422	2,081	1,101	1,644	0	0	0	6,652	0.0
Honeysuckle	2,840	641	442	0	0	2,347	0	0	6,271	0.0
Utah serviceberry	5,860	0	0	0	0	0	0	0	5,860	0.0
Chinese chestnut	2,320	2,655	808	0	0	0	0	0	5,783	0.0
English walnut	890	422	2,775	1,101	0	0	0	0	5,188	0.0
Copper Beech	261	558	0	0	0	4,263	0	0	5,082	0.0
Higan cherry	1,829	2,289	625	0	0	0	0	0	4,744	0.0
Hornbeam ‘Fastigiata’	1,107	3,540	0	0	0	0	0	0	4,647	0.0
Eastern serviceberry	4,528	0	0	0	0	0	0	0	4,528	0.0
European buckthorn	1,642	1,526	0	991	0	0	0	0	4,159	0.0
Japanese pagoda tree	0	2,232	0	1,915	0	0	0	0	4,147	0.0
Pin cherry	0	763	625	0	0	0	2,629	0	4,018	0.0
Dawn redwood	265	1,039	985	1,682	0	0	0	0	3,970	0.0
Amur corktree	1,291	604	0	2,058	0	0	0	0	3,954	0.0
Larch	2,208	1,733	0	0	0	0	0	0	3,941	0.0
Sweet mountain pine	1,695	1,249	0	894	0	0	0	0	3,838	0.0
Rosemallow	3,602	0	0	0	0	0	0	0	3,602	0.0

Species	DBH Class (in)								Total	% of total
	0-6	6-12	12-18	18-24	24-30	30-36	36-42	>42		
European beech	0	558	0	0	3,001	0	0	0	3,559	0.0
Star magnolia	0	558	0	0	3,001	0	0	0	3,559	0.0
Yellow birch	2,721	824	0	0	0	0	0	0	3,545	0.0
Royal paulownia	774	2,060	0	0	0	0	0	0	2,834	0.0
American hazlenut	0	0	991	1,722	0	0	0	0	2,713	0.0
European larch	819	442	0	1,356	0	0	0	0	2,618	0.0
Flowering ash	773	1,831	0	0	0	0	0	0	2,604	0.0
Black spruce	1,079	766	738	0	0	0	0	0	2,582	0.0
Devils walking stick	2,032	321	0	0	0	0	0	0	2,353	0.0
Hally jolivette cherry	247	397	0	0	1,631	0	0	0	2,274	0.0
Autumn olive	0	1,145	0	991	0	0	0	0	2,136	0.0
Green hawthorn	240	0	1,799	0	0	0	0	0	2,039	0.0
Pawpaw	491	824	717	0	0	0	0	0	2,032	0.0
Chinese elm	0	473	0	1,539	0	0	0	0	2,012	0.0
Canada yew	586	473	899	0	0	0	0	0	1,958	0.0
Black ash	326	539	1,043	0	0	0	0	0	1,907	0.0
Katsura tree	293	0	0	1,539	0	0	0	0	1,832	0.0
Yellowwood	530	519	0	0	0	0	0	0	1,049	0.0
Glossy buckthorn	0	382	625	0	0	0	0	0	1,007	0.0
Sourwood	335	597	0	0	0	0	0	0	932	0.0
Paulownia	491	412	0	0	0	0	0	0	903	0.0
Shellbark hickory	0	0	899	0	0	0	0	0	899	0.0
Privet	808	0	0	0	0	0	0	0	808	0.0
Red spruce	765	0	0	0	0	0	0	0	765	0.0
Clammy locust	557	0	0	0	0	0	0	0	557	0.0
Narrow-leaved gimlet	508	0	0	0	0	0	0	0	508	0.0
Viburnum	0	458	0	0	0	0	0	0	458	0.0
Boxwood	0	442	0	0	0	0	0	0	442	0.0
Shore juniper	399	0	0	0	0	0	0	0	399	0.0
Van houtt’s spirea	0	382	0	0	0	0	0	0	382	0.0
Cucumber tree	329	0	0	0	0	0	0	0	329	0.0
Japanese garden juniper	0	303	0	0	0	0	0	0	303	0.0
Elaeagnus	248	0	0	0	0	0	0	0	248	0.0
Ponderosa pine	189	0	0	0	0	0	0	0	189	0.0
Citywide total	9,397,305	16,323,948	20,336,320	21,423,753	18,490,837	12,840,394	7,661,448	6,681,316	113,155,321	100.0

Appendix C—Methodology and Procedures

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

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

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

Growth Modeling

A stratified random sample of 878 street trees, drawn from Indianapolis's Center Township tree database containing 129,267 records, was studied to establish relations between tree age, size, leaf area and biomass; subsequently, estimates for determining the magnitude of annual benefits in relation to predicted tree size were derived. The sample was composed of the 20 most abundant species; from these data, growth of all trees was inferred. The species were as follows:

- Norway maple (*Acer platanoides*)
- Red maple (*Acer rubrum*)
- Silver maple (*Acer saccharinum*)
- Sugar maple (*Acer saccharum*)
- Northern catalpa (*Catalpa speciosa*)
- Eastern redbud (*Cercis canadensis*)
- Northern hackberry (*Celtis occidentalis*)
- White ash (*Fraxinus americana*)
- Green ash (*Fraxinus pennsylvanica*)
- Honeylocust (*Gleditsia triacanthos*)
- Black walnut (*Juglans nigra*)
- Apple (*Malus* sp.)
- Mulberry (*Morus* sp.)
- Blue spruce (*Picea pungens*)
- Eastern white pine (*Pinus strobus*)
- Eastern cottonwood (*Populus deltoides*)
- Callery pear 'Bradford' (*Pyrus calleryana* 'Bradford')
- Northern red oak (*Quercus rubra*)
- Littleleaf linden (*Tilia cordata*)
- Siberian elm (*Ulmus pumila*)

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 study, 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 August 2006.

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 1 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 × [$TA_A - TA_R$] × 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 TA_R) and its installation

Basic price = Cost of the largest available transplantable tree divided by TA_R ($/in^2)

TA_A = Trunk area of appraised tree (in^2) 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 Southern region of the "2006 Species Rating Guide and Appraisal Factors for Illinois" were used for species ratings while unit and installed tree cost data were taken from the Minnesota ISA ratings guide after evaluating cost survey data from arborists in Illinois, Ohio, and Indiana. Together, these data were used to calculate replacement value (Pacific Northwest ISA Chapter 2006). 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 \$66/in^2 TA, based on the wholesale cost of a 3-in caliper tree. Replacement costs equaled the cost for a 3-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 Indianapolis's municipal trees were estimated for the fiscal year 2007. 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 Indianapolis, 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, windy weather, the entire volume of air, even in newer or tightly sealed homes, may change every two to three hours. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed reduces heat transfer through conductive materials as well. Cool winter winds, blowing against single-pane windows, can contribute significantly to the heating load of homes and buildings

Calculating Electricity and Natural Gas Benefits

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate, and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per-tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950–1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same floor area, and other construction characteristics. Shading effects for each of the 19 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 Indianapolis's climate based on consultation with forestry supervisors (Pinco 2007).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to Indianapolis (i.e., frequency of trees located at different distances from buildings [setbacks] and tree orientation with respect to buildings). Setbacks were assigned to four distance classes: 0–20 ft, 20–40 ft, 40–60 ft

and >60 ft. It was assumed that street trees within 60 ft of buildings provided direct shade on walls and windows. Savings per tree at each location were multiplied by tree distribution to determine location-weighted savings per tree for each species and DBH class, independent of location. Location-weighted savings per tree were multiplied by the number of trees of each species and DBH class and then summed to find total savings for the city. Tree locations were based on the stratified random sample conducted in summer 2005.

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 Indianapolis (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 C1*).

Weather data for a typical meteorological year (TMY2) from Indianapolis were used National Renewable Energy Laboratory 2008). Dollar values for energy savings were based on electricity and natural gas prices of $0.067/kWh (Indianapolis Power and Light 2007) and $1.0704/therm (Citizens Gas 2007), 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:

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

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):

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

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

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

Table C1*—Saturation adjustments for cooling (%)/*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Instit./ Trans-porta-tion
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Cooling equipment factors																		
Central air/ heat pump	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Evaporative cooler	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Wall/window unit	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling saturations																		
Central air/ heat pump	13	35	69	13	35	69	13	35	69	13	35	69	13	35	69	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	37	23	25	37	23	25	37	23	25	37	23	25	37	23	25	9	9	9
None	51	42	6	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
Adjusted cooling saturation	22	41	75	22	41	75	22	41	75	22	41	75	22	41	75	88	88	88

approximately 6% and 5% 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 C1*) or heating (*Table C2*) 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 PSFs were unavailable for multi-family structures, a multi-family PSF value of 0.80 was selected (less than single-family detached PSF of 1.0 and greater than small commercial PSF 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.

***Table C2**—Saturation adjustments for heating (%, except AFUE [fraction] and HSPF [kBtu/kWh).*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Equipment efficiencies																		
AFUE	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.78	0.78	0.78
HSPF	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	8	8	8
HSPF	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412
Electric heat saturations																		
Electric resistance	2.4	10.9	21.4	2.4	10.9	21.4	2.4	10.9	21.4	2.4	10.9	21.4	2.4	10.9	21.4	4.9	4.9	4.9
Heat pump	0.4	1.8	3.6	1.4	1.8	3.6	0.4	1.8	3.6	0.4	1.8	3.6	0.4	1.8	3.6	5.4	5.4	5.4
Adjusted electric heat saturations	0.4	1.7	2.9	0.4	1.7	2.9	0.4	1.7	2.9	0.4	1.7	2.9	0.4	1.7	2.9	1.7	1.7	1.7
Natural gas and other heating saturations																		
Natural gas	69.0	60.8	50.0	69.0	60.8	50.0	69.0	60.8	50.0	69.0	60.8	50.0	69.0	60.8	50.0	89.7	89.7	89.7
Oil	18.3	19.0	0.0	18.3	19.0	0.0	18.3	19.0	0.0	18.3	19.0	0.0	18.3	19.0	0.0	0.0	0.0	0.0
Other	9.9	7.6	25.0	9.9	7.6	25.0	9.9	7.6	25.0	9.9	7.6	25.0	9.9	7.6	25.0	0	0	0
NG heat saturations	97	87	75	97	87	75	97	87	75	97	87	75	97	87	75	90	90	90

***Table C3**—Building vintage distribution and combined vintage/saturation factors for heating and air conditioning.*

	Single family detached			Mobile homes			Single-family attached			Multi-family 2-4 units			Multi-family 5+ units			Commercial/ industrial		Institutional/ Transportation
	pre-1950	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**pre-1950**	**1950-1980**	**post-1980**	**Small**	**Large**	
Vintage distribution by building type	24.9	42.6	32.4	2.2	37.0	60.8	24.9	42.6	32.4	26.6	47.8	25.6	10.4	49.1	40.5	100	100	100
Tree distribution by vintage and building type	22.0	37.6	28.6	0.1	1.5	2.5	1.9	3.3	2.5	8.1	14.5	7.7	7.2	34.2	28.3	63.0	37.0	100
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	4.69	15.10	20.94	0.02	0.62	1.86	0.36	1.17	1.62	1.27	4.31	4.20	0.63	5.64	8.49	19.4	5.7	0.0
Cooling factor: climate	4.80	15.45	21.42	0.02	0.61	1.82	0.34	1.10	1.52	0.79	2.68	2.61	0.73	6.48	9.76	17.4	34.1	0.0
Combined vintage, equipment saturation for heating																		
Heating factor, natural gas: shade	20.88	32.06	20.94	0.09	1.32	1.86	1.61	2.48	1.62	5.66	9.15	4.20	2.82	11.98	8.49	19.7	5.8	0.0
Heating factor, electric: shade	0.08	0.61	0.81	0.00	0.03	0.07	0.01	0.05	0.06	0.02	0.17	0.16	0.01	0.23	0.33	0.38	0.11	0.00
Heating factor, natural gas: climate	21.36	32.80	21.42	0.05	0.74	1.04	1.79	2.75	1.80	3.35	5.41	2.48	3.43	14.57	10.33	68.0	133.1	0.0
Heating factor, electric: climate	0.08	0.62	0.83	0.00	0.01	0.04	0.01	0.05	0.07	0.01	0.10	0.10	0.01	0.28	0.40	1.30	2.55	0.0

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. (in press) 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).

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 Indianapolis was 2.0% per year for the first five years after planting for street trees and 1.14% every year thereafter (Pinco 2007). Finally, CO_2 released during tree maintenance was estimated to be 0.50 lb CO_2 per inch DBH based on the expenditure survey results for gas (6,460 gal) and diesel fuel (21,355 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 Indianapolis. The fuel mix for electrical generation included coal (99.8%), oil (0.12%) and natural gas (0.08%) (U.S. EPA 2006).

Emissions factors for electricity (lb/MWh) and natural gas (lb/MBtu) fuel mixes are given in *Table C4*. The monetary value of avoided CO_2 was $6.68/ton based on the average value in Pearce (2003).

Improving Air Quality

Calculating Avoided Emissions

Reductions in building energy use also result in

***Table C4**—Emissions factors and monetary implied values for CO_2 and criteria air pollutants.*

	Emission factor		
	Electricity (lb/MWh)[a]	Natural gas (lb/MBtu)[b]	Implied value[b] ($/lb)
CO_2	2,189	118	0.00334
NO_2	2.986	0.1020	0.82
SO_2	11.966	0.0006	1.50
PM_{10}	1.00	0.0075	0.99
VOCs	0.999	0.0054	0.30

[a]USEPA 1998, 2003, except Ottinger et al. 1990 for VOCs
[b]CO_2 from Pearce (2003), values for all other pollutants are based on methods of Wang and Santini (1995) using emissions concentrations from U.S. EPA (2006) and population estimates from the U.S. Census Bureau (2006)

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. EPA 2006). 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. EPA (2007), and population estimates for the city of Indianapolis from the US Census Bureau (2007).

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 $V_d = 1/(R_a+R_b+R_c)$, pollutant concentration (C), canopy projection (CP) area, and time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances R_a, R_b, and R_c 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 Indianapolis 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 Indianapolis during August 2006. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data for 2003 described in the pollutant uptake section were used as model inputs. Hourly emissions were summed to get annual totals.

The 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. Simula-

tion 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 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 2005 at the Indianapolis International Airport (IND) (Latitude: 39.717°, Longitude: -86.267°, Elevation: 241 m, CoopID: 124259) in Indianapolis, Indiana, were used in this simulation. The year 2005 was chosen because it closely approximated the long time average rainfall of 40.95 in (1,040.1 mm). Annual precipitation at IND during 2005 was 43.5 in (1,101.3 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 Indianapolis spends approximately $21 million annually on operations and maintenance of its stormwater management system (Brian M Brown, PE, AMEC Earth & Environmental, Inc, 2007). In addition, the Clean Streams-Healthy Neighborhoods program is an investment of more than $3 billion over 20 years (Ray 2007). Thus, total annual expenditures including capital improvements are $171 million. 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 (2007). We calculated runoff depth for each land use (5.7 in, citywide) and found the citywide total to be 84,956 acre-feet. The annual stormwater control cost was estimated to be $0.006 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 qual-

ity 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 (30-year-old green ash, average leaf surface area 4,076 ft^2) was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the city of Indianapolis, each large tree would be worth $1,050 based on the 3rd quarter, 2006, median single-family-home resale price in Indianapolis ($119,300) (National Association of Realtors 2007). 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 (0.86) 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 Indianapolis 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 Indianapolis'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 Indianapolis 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 = Green ash (*Fraxinus pennsylvanica*)

BDM Other = Littleleaf linden (*Tilia cordata*)

BDS Other = Eastern redbud (*Cercis canadensis*)

BEL Other = Not available

BEM Other = Not available

BES Other = American holly (*Ilex opaca*)

CEL Other = Eastern white pine (*Pinus strobus*)

CEM Other = Austrian pine (*Pinus nigra*)

CES Other = Bolander beach pine (*Pinus contorta* 'Bolander')

PEL Other = Not applicable

PEM Other = Not applicable

PES Other = Not applicable

When local data were not measured for certain categories, growth data from similar-sized species in a different region were used. Similarly, adequate tree age data was not available for 10 species. To determine what other region's tree aging data could be substituted, we compared data for aged species with same species in other regions and determined that aging from either Fort Collins, Colorado or Indianapolis, Idaho could be substituted for missing age data. Mean growth rates (dbh vs. age) were nearly identical and all were well within confidence intervals.

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.

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

Net Benefits and Costs Methodology

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

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 = PM_{10} interception + NO_2 and O_3 absorption + avoided power plant emissions – BVOC emissions

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

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

p = price of aesthetics = annual increase in property value

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

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

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*

References

Akbari, H.; Davis, S.; Dorsano, S.; Huang, J.; Winnett, S., eds. 1992. Cooling our communities: a guidebook on tree planting and light-colored surfacing. Washington, DC: U.S. Department of the Interior, U.S. Environmental Protection Agency. 26 p.

Alden, H.A. 1995. Hardwoods of North America. Gen. Tech. Rep. FPL-83. Madison, WI: U.S. Department of Agriculture, Forest Service. 136 p.

Alden, H.A. 1997. Softwoods of North America. Gen. Tech. Rep. FPL-102. Madison, WI: U.S. Department of Agriculture, Forest Service. 151 p.

Anderson, L.M.; Cordell, H.K. 1988. Residential property values improve by landscaping with trees. Southern Journal of Applied Forestry. 9: 162–166.

Benjamin, M.T.; Winer, A.M. 1998. Estimating the ozone-forming potential of urban trees and shrubs. Atmospheric Environment. 32: 53–68.

Chandler, T.J. 1965. The climate of London. London: Hutchinson. 292 p.

Citizens Gas. 2007. Natural gas rates for Marion County. http://www.citizensgas.com/newsinfo/rates-marion.html . (3 May 2007.)

Clark, J.R.; Matheny, N.P.; Cross, G.; Wake, V. 1997. A model of urban forest sustainability. Journal of Arboriculture. 23(1): 17–30.

Council of Landscape & Tree Appraisers [CTLA]. 1992. Guide for plant appraisal (8th ed.). Champaign, IL: International Society of Arboriculture. 103p.

Cullen, S. 2000. Tree appraisal: what is the trunk formula method? 9th ed. Arboricultural Consultant 30(5): 3.

Cullen, S. 2002. Tree appraisal: Can depreciation factors be rated greater than 100%? Journal of Arboriculture 28(3): 153–158.

Dwyer, J.F.; McPherson, E.G.; Schroeder, H.W.; Rowntree, R.A. 1992. Assessing the benefits and costs of the urban forest. Journal of Arboriculture. 18(5): 227–234.

Dwyer, J.F.; Nowak, D.J; Noble, M.H.; Sisinni, S.M. 2000. Connecting people with ecosystems in the 21st century: an assessment of our nation's urban forests. Gen. Tech. Rep. 490. Portland, OR: US Department of Agriculture, Forest Service, PNW Research Station.

Hammond J.; Zanetto, J.; Adams, C. 1980. Planning solar neighborhoods. Sacramento, CA: California Energy Commission. 179 p.

Heisler, G.M. 1986. Energy savings with trees. Journal of Arboriculture. 12(5): 113–125.

Heisler, G. M. 1990. Mean wind speed below building height in residential neighborhoods with different tree densities. ASHRAE Transactions 96(1): 1389–1396.

Hull, R.B. 1992. How the public values urban forests. Journal of Arboriculture. 18(2): 98–101.

Illinois Arborist Associaton. 2006. Species ratings and appraisal factors for Illinois. http://www.illinoisarborist.org/SpeciesRating.htm. (8 Feb 2008.)

Indianapolis Power and Light. 2007. Rate schedule. http://www.aes.com/pub-sites/IPL/content/staging/0205017431b9010a483052b3006d66/resident.pdf . (3 May 2007).

Indy Greenprint. 2008. http://www.indygov.org/NR/exeres/D085F058-05EB-4A78-A47C-ABC-D36ADC24E.htm. (4 March 2008.)

Kaplan, R. 1992. Urban forestry and the workplace. In: Gobster, P.H., ed. Managing urban and high-use recreation settings. Gen. Tech. Rep. NC-163. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station:41–45.

Kaplan, R.; Kaplan, S. 1989. The experience of nature: a psychological perspective. Cambridge, United Kingdom: Cambridge University Press. 360 p.

Lewis, C.A. 1996. Green nature/human nature: the meaning of plants in our lives. Chicago: University of Illinois Press. 176 p.

Maco, S.E.; McPherson, E.G. 2003. A practical approach to assessing structure, function, and value of street tree populations in small communities. Journal of Arboriculture. 29(2): 84–97.

Maco, S.E.; McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Xiao, Q. 2005. City of Berkeley, California, Municipal Tree Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service.

McHale, M. (in press). Volume equations for 11 urban tree species in Fort Collins, Colorado. Urban Forestry and Urban Greening.

McPherson, E.G. 1984. Planting design for solar control. In: McPherson, E.G., ed. Energy-conserving site design. Washington, DC: American Society of Landscape Architects: 141–164. Chapter 8.

McPherson, E.G. 1993. Evaluating the cost effectiveness of shade trees for demand-side management. The Electricity Journal. 6(9): 57–65.

McPherson, E.G.; Mathis, S., eds. 1999. Proceedings of the Best of the West summit. Sacramento, CA: Western Chapter, International Society of Arboriculture. 93 p.

McPherson, E.G.; Muchnick, J. 2005. Effects of tree shade on asphalt concrete pavement performance. Journal of Arboriculture. 31(6): 303–309.

McPherson, E.G.; Rowntree, R.A. 1989. Using structural measures to compare twenty-two U.S. street tree populations. Landscape Journal 8: 13–23.

McPherson, E.G.; Simpson, J.R. 1999. Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 p.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Xiao, Q. 2001. Tree Guidelines for Inland Empire Communities. Sacramento, CA: Local Government Commission. 124 p.

McPherson, E.G., Simpson, J.R.; Xiao, Q.; Peper, P.J.; Maco, S.E. 2003. Benefit–cost analysis of Fort Collins' municipal forest. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 39 p.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Maco, S.E.; Xiao, Q. 2005a. Municipal forest benefits and costs in five U.S. cities. Journal of Forestry 103(8):411–416.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Maco, S.; Gardner, S.L.; Cozad, S.K.; Xiao, Q. 2005b. City of Minneapolis, MN, Municipal Tree Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Maco, S.; Xiao, Q. 2005c. City of Glendale, AZ, Municipal Forest Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service. 46 p.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Gardner, S.L.; Vargas, K.E.; Ho, J.; Maco, S.; Xiao, Q. 2005d. City of Charlotte, North Carolina, Municipal Forest Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service. 57 p.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Gardner, S.L.; Vargas, K.E.; Ho, J.; Maco, S.; Xiao, Q. 2005e. City of Boulder, Colorado, Municipal Forest Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Gardner, S.L.; Vargas, K.E.; Ho, J.; Maco, S., Xiao, Q. 2006. City of Charleston, South Carolina, Municipal Tree Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service. 57 p.

Miller, R.W. 1997. Urban forestry: planning and managing urban greenspaces. 2nd. ed. Upper Saddle River: Prentice-Hall; 502 p.

Moll, G.; Kollin, C. 1993. A new way to see our city forests. American Forests. 99(9–10): 29–31.

National Association of Realtors. 2007. Median sales price of existing single-family homes. http://www.

realtor.org/Research.nsf/files/MSAPRICESF.pdf/$FILE/MSAPRICESF.pdf. (3 May 2007.)

National Solar Radiation Data Base (1961–1990). 2007. http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/. (3 May 2007.)

Pacific Northwest Chapter International Society of Arboriculture. 2006. 2006 Draft species evaluation guide. http://www.pnwisa.org/DraftSpeciesRating06.xls. (10 Oct 2006.)

Parsons, R.; Tassinary, L.G.; Ulrich, R.S.; Hebl, M.R.; Grossman-Alexander, M. 1998. The view from the road: implications for stress recovery and immunization. Journal of Environmental Psychology. 18(2): 113–140.

Pearce, D. 2003. The social cost of carbon and its policy implications. Oxford Review of Economic Policy. 19(3): 362–384.

Peper, P.J.; McPherson, E.G. 2003. Evaluation of four methods for estimating leaf area of isolated trees. Urban Forestry and Urban Greening. 2(1): 19–29.

Peper, P.J.; McPherson, E.G.; Mori, S.M. 2001. Equations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees. Journal of Arboriculture. 27(6): 306–317.

Peper, P.J., McPherson, E.G., J.R. Simpson, S.E. Maco, Q. Xiao. 2004a. City of Cheyenne, Wyoming Municipal Tree Resource Analysis. Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station.

Peper, P.J.; McPherson, E.G.; Simpson, J.R.; Maco, S.; Xiao, Q. 2004b. City of Bismarck, North Dakota, Street Tree Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 64 p.

Pinco, P. 2006. Personal communication re foliation periods for Indy trees. August 2006.

Pinco, P. , Purcell, L. 2008. Personal communications re budget expenditures and canopy coverage. February-April 2008.

Pillsbury, N.H.; Reimer, J.L.; Thompson, R.P. 1998. Tree volume equations for fifteen urban species in California. Tech. Rep. 7. San Luis Obispo, CA: Urban Forest Ecosystems Institute, California Polytechnic State University. 56 p.

Platt, R.H.; Rowntree, R.A.; Muick, P.C., eds. 1994. The ecological city. Boston, MA: University of Massachusetts. 292 p.

Ray, C. 2007. Indianapolis takes on the largest investment in clean-water infrastructure in city history. Stormwater. 8(5):12–14.

Renewable Resource Data Center. 1995. National Solar Radiation Data Base Typical Year Data. http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/. (July 2007.)

Richards, N.A. 1982/83. Diversity and stability in a street tree population. Urban Ecology 7: 159–171.

Ritschard, R.L.; Hanford, J.W.; Sezgen, A.O. 1992. Single-family heating and cooling requirements: assumptions, methods, and summary results. Publication GRI-91/0236. Chicago: Gas Research Institute. 97 p.

Schroeder, H.W.; Cannon, W.N. 1983. The esthetic contribution of trees to residential streets in Ohio towns. Journal of Arboriculture. 9: 237–243.

Scott, K.I.; McPherson, E.G.; Simpson, J.R. 1998. Air pollutant uptake by Sacramento's urban forest. Journal of Arboriculture. 24(4): 224–234.

Scott, K.I.; Simpson, J.R.; McPherson, E.G. 1999. Effects of tree cover on parking lot microclimate and vehicle emissions. Journal of Arboriculture. 25(3): 129-142.

Simpson, J.R. 1998. Urban forest impacts on regional space conditioning energy use: Sacramento County case study. Journal of Arboriculture. 24(4): 201–214.

Simpson, J.R. 2002. Improved estimates of tree shade effects on residential energy use. Energy and Buildings. 34(10): 173–182.

Sullivan, W.C.; Kuo, E.E. 1996. Do trees strengthen urban communities, reduce domestic violence? Arborist News. 5(2): 33–34.

Taha, H. 1996. Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. Atmospheric Environment. 30: 3423–3430.

Ter-Mikaelian, M.T.; Korzukhin, M.D. 1997. Biomass equations for sixty-five North American tree species. Forest Ecology and Management. 97: 1–24.

Thompson, R.P.; Ahern, J.J. 2000. The State of Urban and Community Forestry in California: Status in 1997 and Trends since 1988. California Dept. of Forestry and Fire Protection, Technical Report No. 9. Urban Forest Ecosystems Institute, Cal Poly State University, San Luis Obispo, CA. pp. 48.

Tretheway, R.; Manthe, A. 1999. Skin cancer prevention: another good reason to plant trees. In: McPherson, E.G.; Mathis, S., eds. Proceedings of the Best of the West summit. Davis, CA: University of California: 72–75.

Tritton, L.M.; Hornbeck, J.W. 1982. Biomass equations for major tree species of the Northeast. Gen. Tech. Rep. NE-69. Broomall, PA: U.S. Department of Agriculture Forest Service. 46 p.

Ulrich, R. S. 1985. Human responses to vegetation and landscapes. Landscape and Urban Planning. 13: 29–44.

U.S. Census Bureau. 2007. Population finder. http://www.census.gov/population/www/estimates/CBSA-est2006-annual.html. (21 May 2007.)

U.S. Department of Agriculture, Soil Conservation Service. 1986. Urban hydrology for small watersheds. Tech. Rel. no. 55, 2nd ed. Washington, D.C.

U.S. Environmental Protection Agency [U.S.EPA]. 1998. Ap-42 Compilation of air pollutant emission factors. 5th ed. Volume I. Research Triangle Park, NC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 2007. Air Quality System reports. http://www.epa.gov/air/data/reports.html. (5 May 2007.)

Vargas, K.E.; McPherson, E.G.; Simpson J.R.; Peper, P.J.; Gardner, S.L.; Xiao, Q. 2006. City of Albuquerque, New Mexico, Municipal Forest Resource Analysis. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 51 p.

Wang, M.Q.; Santini, D.J. 1995. Monetary values of air pollutant emissions in various U.S. regions. Transportation Research Record 1475: 33–41.

Watson, G. 2002. Comparing formula methods of tree appraisal. Journal of Arboriculture. 28(1): 11–18.

WC-ISA. 2004. Species classification and group assignment. Cohasset, CA: Western Chapter, International Society of Arboriculture.

Wilkinson, D. 1991. Can photographic methods be used for measuring the light attenuation characteristics of trees in leaf? Landscape and Urban Planning. 20: 347–349.

Wolf, K.L. 1999. Nature and commerce: human ecology in business districts. In: C. Kollin, ed. Building cities of green: proceedings of the 1999 National Urban Forest Conference. Washington, D.C.: American Forests: 56–59.

Xiao, Q.; McPherson, E.G.; Simpson, J.R.; Ustin, S.L. 1998. Rainfall interception by Sacramento's urban forest. Journal of Arboriculture. 24(4): 235–244.

Xiao, Q.; McPherson, E.G.; Simpson, J.R.; Ustin, S.L. 2000. Winter rainfall interception by two mature open grown trees in Davis, California. Hydrological Processes. 14(4): 763–784.



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