City of Albuquerque, New Mexico Municipal Forest Resource Analysis

By
Kelaine E. Vargas
E. Gregory McPherson
James R. Simpson
Paula J. Peper
Shelley L. Gardner
James Ho
Qingfu Xiao

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

Technical Report to:
Martin J. Chavez, Mayor
City of Albuquerque, New Mexico

—August 2006—

Center for
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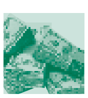
Areas of Research: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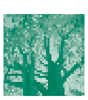
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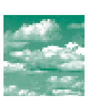
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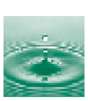
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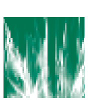
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Mission Statement

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

CITY OF ALBUQUERQUE, NEW MEXICO
MUNICIPAL FOREST RESOURCE ANALYSIS

Technical report to:
Martin J. Chavez, Mayor
City of Albuquerque, New Mexico

By
Kelaine E. Vargas[1]
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James Ho[1]
Qingfu Xiao[2]

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[1]Center for Urban Forest Research
USDA Forest Service, Pacific Southwest Research Station
c/o Dept. of Plant Science, MS-6
University of California
One Shields Ave.
Davis, CA 95616-8587

[2]Department of Land, Air, and Water Resources
University of California
Davis, CA

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Executive Summary

Albuquerque, a booming southwestern city appreciated for the beauty of its high desert surroundings and its bustling business culture maintains parks and natural areas as an integral component of the urban infrastructure (*Figure 1*). Recently, Albuquerque was honored by the Trust for Public Land for its excellent park system: it leads the nation in percentage of land protected as open space.

Trees are a critical component of these natural areas and 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 Albuquerque a more enjoyable place to live, work, and play, while mitigating the city's environmental impact. Over the years, the people of Albuquerque have invested millions of dollars in their municipal forest. The primary question that this study asks is *whether the accrued benefits from Albuquerque's municipal forest justify the annual expenditures?*

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information on the city-managed park and street 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)

Resource Structure

The city's tree inventory includes 21,519 publicly managed trees in Albuquerque, the majority of which are found in parks. The inventory contains 73 tree species with honeylocust (*Gleditsia triacanthos*), Modesto ash (*Fraxinus velutina* 'Modesto'), Siberian elm (*Ulmus*

Figure 1—Trees shade Albuquerque's historic Old Town Square. Public trees in Albuquerque provide great benefits, improving air quality, sequestering carbon dioxide, reducing stormwater runoff and beautifying the city. The trees of Albuquerque return $1.31 in benefits for every $1 spent on tree care.

pumila), London planetree (*Platanus* x *acerifolia*) and desert willow (*Chilopsis linearis*) the predominant species. The managers of Albuquerque's urban forest can commend themselves for the diversity of their urban forest, in terms of both the number of species and distribution of trees among the species.

The age structure of Albuquerque's municipal tree population appears fairly close to the desired distribution. The recent initiative by Mayor Martin Chavez to plant 2,000 trees per year means that the number of trees in the smallest size class (47%) will continue to grow. The larger size classes are represented almost entirely by Siberian elms, which were heavily planted in the first half of the 20th century and are nearing the end of their natural lifespans.

Resource Function and Value

The municipal trees of Albuquerque provide great benefits to the citizens. Their ability to moderate climate—thereby reducing energy use—is substantial. Electricity saved annually in Albuquerque from both shading and climate effects of trees totals 1,482 MWh ($116,847), and annual natural gas saved totals 48,708 therms ($53,579) for a total energy cost savings of $170,426 or $8 per tree.

Citywide, annual carbon dioxide (CO_2) sequestration and emission reductions due to energy savings by public trees are 735 tons and 1,725 tons, respectively. CO_2 released during decomposition and tree-care activities is 128 tons. Net CO_2 reduction is 2,332 tons, valued at $15,576 or $0.72 per tree.

Net annual air pollutants removed, released, and avoided average 1.04 lb per tree and are valued at $23,862 or $1.11 per tree. Ozone is the most significant pollutant intercepted by trees, with 7,929 lbs per year removed from the air ($4,837), while sulfur dioxide is the most economically significant air pollutant whose production is avoided at the power plant, due to reduced energy needs (6,818 lbs per year; $9,682).

Albuquerque's municipal trees intercept rain, reducing stormwater runoff by 11.1 million gallons annually, with an estimated value of $55,833. Citywide, the average tree intercepts 518 gallons of stormwater each year, valued at $2.59 per tree.

The estimated total annual benefits associated with aesthetics, property value increases, and other less tangible improvements are approximately $295,282 or $14 per tree on average.

Annual benefits total $560,979 and average $26 per tree. The city's 1,436 Siberian elms produce the highest total level of benefits ($98 per tree, 25% of total benefits). On a per tree basis, mountain cottonwoods (*Populus angustifolia*) are the next most valuable species, with benefits of $75 per tree. Species providing the least benefits on an individual tree basis include New Mexico olive (*Forestiera pubescens*) ($1) and pinyon pine (*Pinus edulis*) ($3).

Albuquerque spends approximately $428,500 in a typical year maintaining its public trees ($20/tree). Current expenses include an additional $600,000 for tree planting; these costs are not included in this analysis because the trees on which the funds are being spent were not included in the inventory analyzed here. The highest single cost in the tree care budget is for administration ($175,000), followed by pruning ($103,500).

Albuquerque's municipal trees are a valuable asset, providing approximately $132,399 or $6 per tree ($0.27 per capita) in net annual benefits to the community. Over the years, Albuquerque has invested millions in its urban forest. Citizens are now receiving a return on that investment—**trees are providing $1.31 in benefits for every $1 spent on tree care**. Albuquerque's benefit–cost ratio of 1.31 is similar to those reported for Berkeley, CA (1.37), and Charleston, SC (1.34); exceeds those for San Francisco (1.00); but is below those reported for Fort Collins, CO (2.18), Minneapolis, MN (1.57), Glendale, AZ (2.41), and Charlotte, NC (3.25). The value of Albuquerque's municipal urban forest will increase as the many recently planted trees mature.

Another way of describing the worth of trees is their replacement value, which assumes that the value of a tree is equal to the cost of replacing it in its current condition. Replacement value is a function of the number, stature, placement and condition of the cities' trees and reflects their value over a lifetime. As a central component of Albuquerque's green infrastructure, the 21,519 trees are estimated to have a replacement value of $40.6 million or $1,889 per tree.

Resource Management

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

1. Develop a strong young-tree care program that emphasizes reducing mortality. Irrigation, inspection and pruning on a two-year cycle will provide a good foundation for the many new trees being planted.

2. Sustain benefits by investing in intensive maintenance of mature trees to prolong the functional life spans of these heritage trees. Develop a plan to replace the aging Siberian elms with trees of similar stature gradually before they must be removed.

3. Conduct a canopy cover study of the city to identify and prioritize future planting. Streets, parking lots and schools may provide good opportunities for maximizing air quality, energy savings, and aesthetic benefits.

4. Track the success of the newly planted trees to determine those most adaptable to the difficult conditions. Maintain a diverse mix of tree species to guard against catastrophic losses due to storms, pests or disease while concentrating on those that have proven most successful.

5. Plant large species where conditions are suitable to maximize benefits.

The challenge ahead is to better integrate Albuquerque's green infrastructure with its gray infrastructure. This can be achieved by including green space and trees in the planning phase of development projects, providing adequate space for trees, and designing and maintaining plantings to maximize net benefits over the long term. By acting now to implement these recommendations, Albuquerque will benefit from a more functional and sustainable urban forest in the future.


Figure 2—Trees in the high desert are a symbol of water and life.

Chapter One—Introduction

Albuquerque is a booming, vibrant high desert city, recently named the "third smartest place to live in America" (Ryan and Wood 2006). Trees, a symbol of water and life in the desert (*Figure 2*), are maintained as an integral component of the urban infrastructure. The City's Open Space Division of the Parks and Recreation Department actively manages more than 20,000 trees, and a recent initiative by Albuquerque Mayor Martin J. Chavez funds the planting of 2,000 more each year. The City believes that the public's investment in stewardship of the urban forest produces benefits that far outweigh the costs to the community. Investing in Albuquerque's green infrastructure makes sense economically, environmentally, and socially.

Research indicates that 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 urban forest makes Albuquerque a more enjoyable place to live, work and play, while mitigating the city's environmental impact (*Figure 3*).

In an era of decreasing public funds and rising costs, however, there is a need to scrutinize public expenditures that are often viewed as "nonessential," such as planting and maintaining street and park trees. 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 Albuqerque's urban trees justify the annual expenditures*?

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

- Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for Albuquerque's urban forest.
- Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.
- Highlight the relevance and relationship of Albuquerque's municipal 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—Albuquerque's Municipal Tree Resource: Describes the current structure of the street and park tree resource.

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

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

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

Appendix B—Replacement Values: Lists replacement values for the entire municipal tree population.

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

References—Lists publications cited in the study.

Figure 3—Large green ash trees (*Fraxinus pennsylvanica*) shade Albuquerque's Old Town Plaza.

Chapter Two—Albuquerque's Municipal Tree Resource

As might be expected in a city in the middle of a desert, the citizens of Albuquerque are passionate about their trees, believing that they add character, beauty, and serenity to the city (*Figure 3*). According to the Trust for Public Land, Albuquerque leads the nation in open space preservation, with more than one-quarter of its land protected as public open space.

In recent years, Albuquerque's mayor, Martin Chavez, has focused attention on the city's urban forest. The bosque, or riparian forest, that runs through the center of the city is being restored and cleared of non-native plants. Streets and interstate medians are being planted with xeriscape vegetation. An Urban Forest Master Plan for Parks and Recreation Facilities was completed in 2005 and included an inventory of municipal trees, a community survey, and recommendations for priority locations for future planning (Urban Forest Master Plan for Parks and Recreation Facilities 2005, hereafter Master Plan). As a result of the Master Plan and the Mayor's focus on the urban forest, over the next several years 2,000 trees will be planted annually.

Tree Numbers

The Albuquerque municipal tree inventory was begun in November 2004 and completed in May 2005 and included 21,519 trees at the time of this study (*Figure 4*). The majority of trees are located in parks (approximately 75%) and the remainder are planted in medians along streets. Albuquerque's Open Space Division is also responsible for additional trees in a few parks and facilities that could not be inventoried for logistical reasons.

The municipal tree population is dominated by deciduous trees (84% of the total). Deciduous trees are advantageous in climates like Albuquerque's because their leaves provide protection against the harsh summer sun

Council district	No. of trees
1	1,594
2	2,286
3	6,149
4	2,016
5	2,316
6	2,154
7	2,247
8	1,380
9	1,173
Not in city	204
Total	21,519

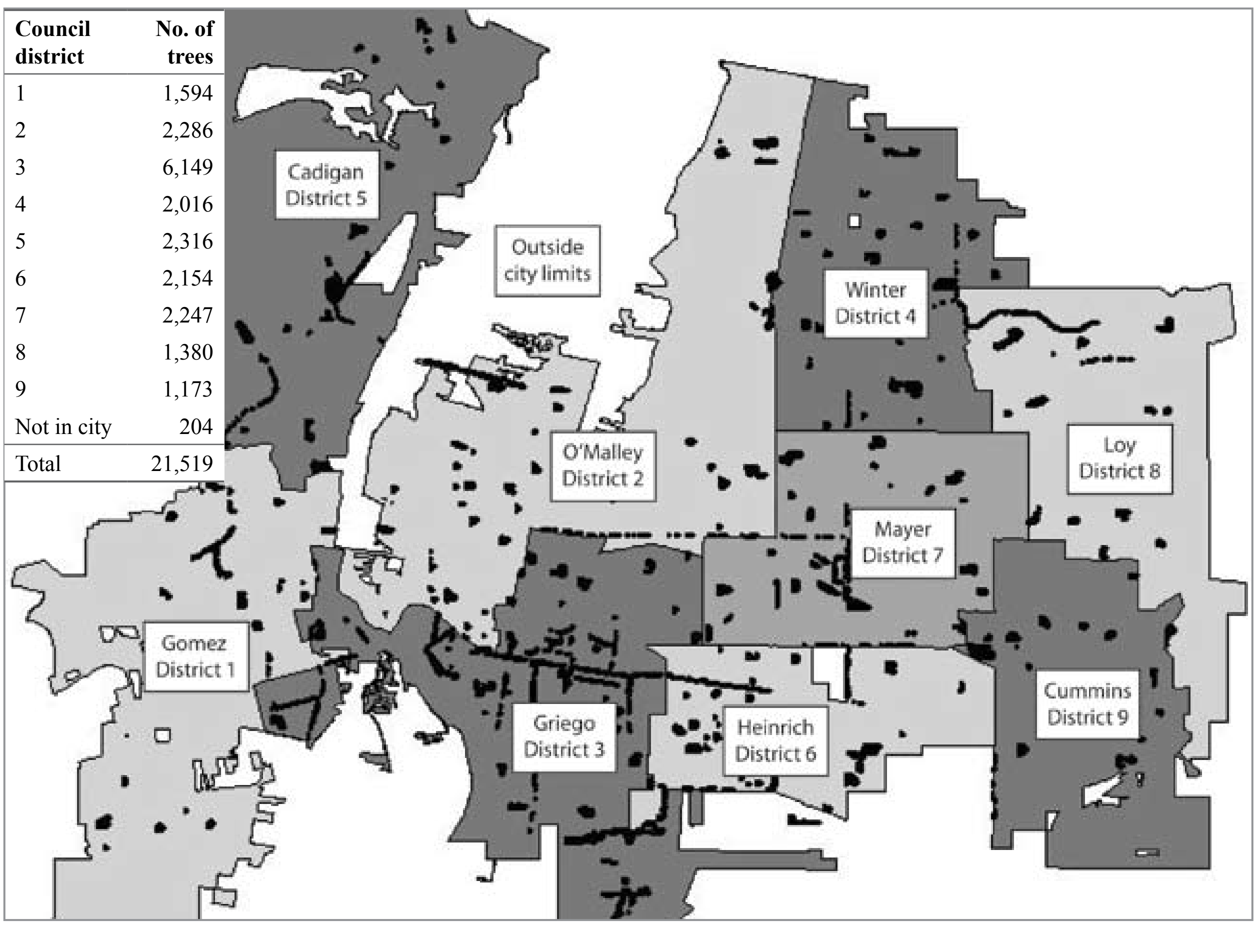

Figure 4—Municipal trees of Albuquerque by city council district. Inventoried trees are marked with dots.

Table 1—Most abundant park tree species in order of predominance by DBH class and tree type.

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)											
Honeylocust	208	573	1,084	210	42	17	0	5	2	2,141	9.9
Modesto ash	207	374	765	162	53	20	10	5	0	1,596	7.4
Siberian elm	52	97	156	141	150	286	214	198	142	1,436	6.7
London planetree	59	293	637	306	75	15	1	0	0	1,386	6.4
Green ash	42	291	415	110	48	15	2	0	0	923	4.3
White ash	66	106	178	45	11	3	0	1	0	410	1.9
Valley cottonwood	8	17	69	69	35	48	45	70	49	410	1.9
Mountain cottonwood	20	52	107	64	47	66	16	13	4	389	1.8
BDL other	169	215	378	109	54	51	19	39	41	1,075	5.0
Total	831	2,018	3,789	1,216	515	521	307	331	238	9,766	45.4
Broadleaf deciduous medium (BDM)											
Raywood ash	134	151	58	5	2	1	1	0	0	352	1.6
Goldenrain tree	42	103	94	14	1	0	0	0	0	254	1.2
Chinese pistache	88	65	69	16	1	0	0	0	0	239	1.1
BDM other	747	753	471	119	57	22	10	7	4	2,190	10.2
Total	1,011	1,072	692	154	61	23	11	7	4	3,035	14.1
Broadleaf deciduous small (BDS)											
Desert willow	776	474	115	2	0	0	0	0	0	1,367	6.4
Russian olive	54	357	307	139	18	14	1	1	1	892	4.1
New Mexico olive	667	66	14	0	0	0	0	0	0	747	3.5
Callery pear	113	310	281	25	0	0	0	0	0	729	3.4
Apple	158	220	141	32	2	0	0	0	0	553	2.6
Purple leaf plum	170	123	175	13	2	0	0	0	0	483	2.2
Eastern redbud	82	73	59	3	1	2	0	0	0	220	1.0
BDS other	139	129	53	10	4	0	0	0	0	335	1.6
Total	2,159	1,752	1,145	224	27	16	1	1	1	5,326	24.8
Conifer evergreen large (CEL)											
Scotch pine	15	71	305	197	19	5	1	0	0	613	2.8
Ponderosa pine	10	12	121	153	31	13	1	0	0	341	1.6
CEL other	45	17	43	51	13	4	0	0	0	173	0.8
Total	70	100	469	401	63	22	2	0	0	1,127	5.2
Conifer evergreen medium (CEM)											
Austrian pine	131	360	420	237	28	8	0	0	0	1,184	5.5
Juniper	218	123	166	69	24	21	6	5	0	632	2.9
CEM other	1	1	4	11	3	0	1	1	0	22	0.1
Total	350	484	590	317	55	29	7	6	0	1,838	8.5
Conifer evergreen small (CES)											
Pinyon pine	164	146	100	11	1	0	0	0	0	422	2.0
CES other	0	0	2	2	0	0	0	0	0	4	0.0
Total	164	146	102	13	1	0	0	0	0	426	2.0
Citywide Total	4,586	5,572	6,787	2,325	722	611	328	345	243	21,519	100.0

while the absence of leaves in winter allows the sun's warming rays to reach buildings.

Species Richness, Composition And Diversity

The tree population in Albuquerque includes a mix of 73 different species—signficantly 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 is especially impressive considering the difficult climate of the area.

The predominant municipal tree species are honeylocust (*Gleditsia triacanthos*, 10%), Modesto ash (*Fraxinus velutina* 'Modesto,' 7.4%), Siberian elm (*Ulmus pumila*, 6.7%), London planetree (*Platanus* x *acerifolia*, 6.4%) and desert willow (*Chilopsis linearis*, 6.4%) (*Table 1*; see also *Appendix A*). The Parks and Recreation Department has done a good job of diversifying their species choice, conforming to the general idea that no single species should represent more than 10% of the population and no genus more than 20% (Clark et al. 1997). Having one very dominant species is of concern because of the impact that drought, disease, pests, or other stressors can have on the urban forest. Providing a wide variety of species reduces the loss of canopy during catastrophic events.

Although the species diversity at the city level is good, at the district level, there are some areas of concern (*Table 2;* see *Figure 4* for districts). In council district 1, for example, 18.4% of the trees are honeylocust; in district 7, Siberian elm accounts for 15% of the population and London planetree another 11%.

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 spe-

Table 2*—Most abundant tree species listed by management zone with percentage of totals in parenthesis.*

District	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)
1	Honeylocust (18.4)	Scotch pine (8.7)	Austrian pine (8.3)	Desert willow (6.1)	New Mexico olive (4.5)
2	Green ash (8.4)	Desert willow (7.9)	Honeylocust (7.9)	Modesto ash (7.6)	Siberian elm (6.3)
3	Siberian elm (9.9)	Honeylocust (9)	Modesto ash (8.5)	London planetree (7.9)	Russian olive (6.7)
4	Desert willow (12.3)	Honeylocust (9.2)	Austrian pine (9.2)	Russian olive (2.7)	Purple leaf plum (2.7)
5	Desert willow (14.5)	Honeylocust (9.9)	Modesto ash (6.8)	London planetree (6.3)	New Mexico olive (5.8)
6	Honeylocust (13.3)	Green ash (9.5)	Siberian elm (9.1)	London planetree (7.7)	Callery pear (7.0)
7	Siberian elm (15.2)	London planetree (10.8)	Modesto ash (8.9)	Honeylocust (8.6)	Austrian pine (5.2)
8	Russian olive (9.9)	Scotch pine (7)	Austrian pine (6.3)	Modesto ash (5.7)	Honeylocust (5.6)
9	Modesto ash (15.3)	Honeylocust (8.4)	Desert willow (6.2)	Green ash (5.5)	London planetree (5.2)
Not in city	Honeylocust (22.1)	London planetree (15.2)	Scotch pine (12.7)	Desert willow (8.3)	Valley cottonwood (7.8)
Citywide total	Honeylocust (9.9)	Modesto ash (7.4)	Siberian elm (6.7)	London planetree (6.4)	Desert willow (6.4)

cies is an important consideration. Planting short-lived or poorly adapted trees can result in short rotations and increased long-term management costs.

The 23 most abundant municipal tree species listed in *Table 3* constitute 82% of the total population, 88% of the total leaf area, and 87% of total canopy cover, for an IV of 86. As *Table 3* illustrates, Albuquerque is relying on the functional capacity of Siberian elms to a great extent. Though the species accounts for less than 7% of all public trees, because of the trees' large size, the amount of leaf area and canopy cover they provide is great, increasing their importance value to 27 when all components are considered. This makes them 3.4 times more significant than the next species. In contrast, small trees tend to have lower importance values than their population numbers would suggest. The desert willow, for example, makes up the same percentage of the population as the Siberian elm, but its IV is ten times lower, only 2.5. The four ash species, Modesto, Raywood, green and white, together represent an IV of 13.6. Almost of these trees are still small and will continue to grow in importance as they age.

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).

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

Species	No. of trees	% of total trees	Leaf area (ft^2)	% of total leaf area	Canopy cover (ft^2)	% of total canopy cover	IV
Honeylocust	2,141	9.9	1,053,943	4.2	934,008	9.6	7.9
Modesto ash	1,596	7.4	1,643,200	6.5	791,071	8.1	7.3
Siberian elm	1,436	6.7	11,852,447	46.7	2,617,526	26.9	26.8
London planetree	1,386	6.4	2,271,379	8.9	850,582	8.8	8.0
Desert willow	1,367	6.4	28,635	0.1	111,461	1.2	2.5
Austrian pine	1,184	5.5	325,912	1.3	271,595	2.8	3.2
Green ash	923	4.3	820,682	3.2	451,733	4.7	4.1
Russian olive	892	4.1	413,127	1.6	340,558	3.5	3.1
New Mexico olive	747	3.5	8,007	-	20,856	0.2	1.2
Callery pear	729	3.4	71,715	0.3	116,792	1.2	1.6
Juniper	632	2.9	217,317	0.9	136,571	1.4	1.7
Scotch pine	613	2.8	164,797	0.7	204,814	2.1	1.9
Apple	553	2.6	53,696	0.2	95,475	1.0	1.3
Purple leaf plum	483	2.2	22,444	0.1	61,477	0.6	1.0
Pinyon pine	422	2.0	14,641	0.1	33,496	0.3	0.8
White ash	410	1.9	253,326	1.0	158,701	1.6	1.5
Valley cottonwood	410	1.9	1,226,800	4.8	577,547	5.9	4.2
Mountain cottonwood	389	1.8	1,447,785	5.7	406,735	4.2	3.9
Raywood ash	352	1.6	39,394	0.2	37,975	0.4	0.7
Ponderosa pine	341	1.6	252,674	1.0	143,111	1.5	1.4
Goldenrain tree	254	1.2	29,290	0.1	52,915	0.5	0.6
Chinese pistache	239	1.1	35,079	0.1	38,825	0.4	0.6
Eastern redbud	220	1.0	16,557	0.1	32,704	0.3	0.5
Other trees	3,800	17.7	3,138,875	12.4	1,234,948	12.7	14.2
Total	21,519	99.9	25,401,722	100.0	9,721,478	100.0	100.0

The overall age structure, represented here in terms of diameter at breast height (DBH), for municipal trees in Albuquerque appears fairly similar to the ideal (*Figure 5*). The proportion of young trees (0–6 inch DBH) is quite high (47%) and will grow even higher as the tree planting initiative continues. The middle size classes (18–30 inch DBH) are less well represented, which may partly be a reflection of fewer trees having been planted, but is also due to the high mortality of trees in the area. The city's urban foresters estimate the tree mortality of new plantings in Albuquerque at around 8% per year for the first five years and 1.5–2% per year after that (Russell and Hart 2006). Many trees simply do not live long enough to grow large.

It is interesting to note that there is a relatively high percentage of very old trees (2.7%). These large trees are almost entirely Siberian elms, which were heavily planted early in the last century. Most of the other large trees are local valley cottonwoods (data not shown), well adapted to the climate and conditions.

Figure 6 shows age distribution by city council district. The desired pattern of a high proportion of new trees and numbers that decline with age holds true at the district level as well. Some small differences can be noted: Districts 6 and 7 have a markedly high proportion of trees in the oldest class.

Tree Condition

Tree condition indicates both how well trees are managed and how well they perform given site-specific conditions. Overall, the condition of trees in Albuquerque is good, with 93% in good or fair shape (*Figure 7*). Condition varies greatly from species to species, however. Only 15.3% of Siberian elms are in good condition; this is mainly a reflection of their age—most were planted more than 50 years ago. Care should be taken when analyzing tree condition to ensure that relevant factors such as age are taken into consideration. For instance, honeylocust and Modesto ash appear to be doing quite well. By comparing *Figure 7* with *Figure 5*, however, it is clear that the honeylocust and Modesto ash are all relatively young and therefore have not yet stood the test of time. Conclusions about their suitability to the region should be postponed until the trees have matured.

Poor performers include most of the small flowering species including apple, purple leaf plum and the Eastern redbud. Native species such as the New Mexico olive and the desert willow tend to do quite well.

Tree Canopy

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force

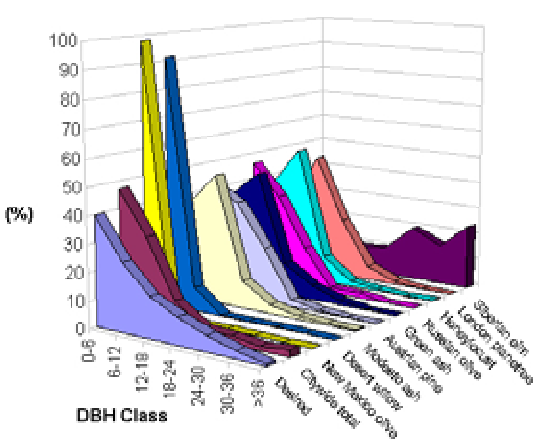

Figure 5—Relative age distribution for Albuquerque's most abundant street and park tree species citywide shown with an ideal distribution.

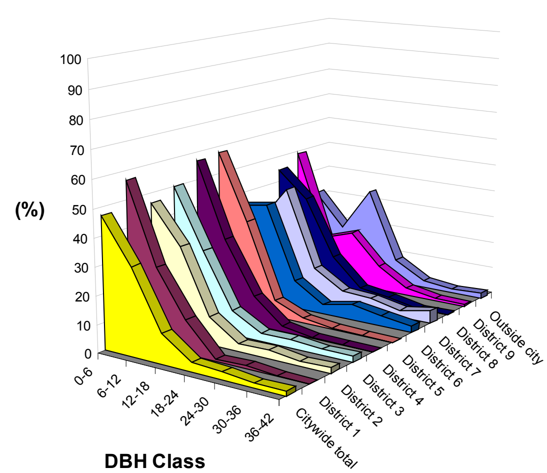

Figure 6—Relative age distribution of all street and park trees by city council district.

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 Albuquerque—likely represent less than 20% of the entire urban forest (Moll and Kollin 1993). The municipal tree canopy in Albuquerque is estimated at 223 acres and covers 0.19% of the city, given a city area of 116,000 acres (181 square miles) (Russell and Hart 2006) or 10% of the total park area (2,286 acres; Master Plan 2005).

Replacement Value

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

Replacing Albuquerque's 21,519 municipal trees with trees of similar size, species, and condition if, for example, all were destroyed by a catastrophic storm, would cost approximately $40.6 million (*Table 4*; see also *Appendix B*). Albuquerque's street and park trees are a valuable legacy, and as a central component of the city's green infrastructure can be considered a public asset with a value of $40.6 million. The average replacement value per tree is $1,889. Siberian elms account for more than 25% of the total, with most of this value in the older and larger trees.

Replacement value should be distinguished from the value of annual benefits produced by the urban forest. 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 Albuquerque's municipal tree population is many times greater than the value of annual benefits it produces.

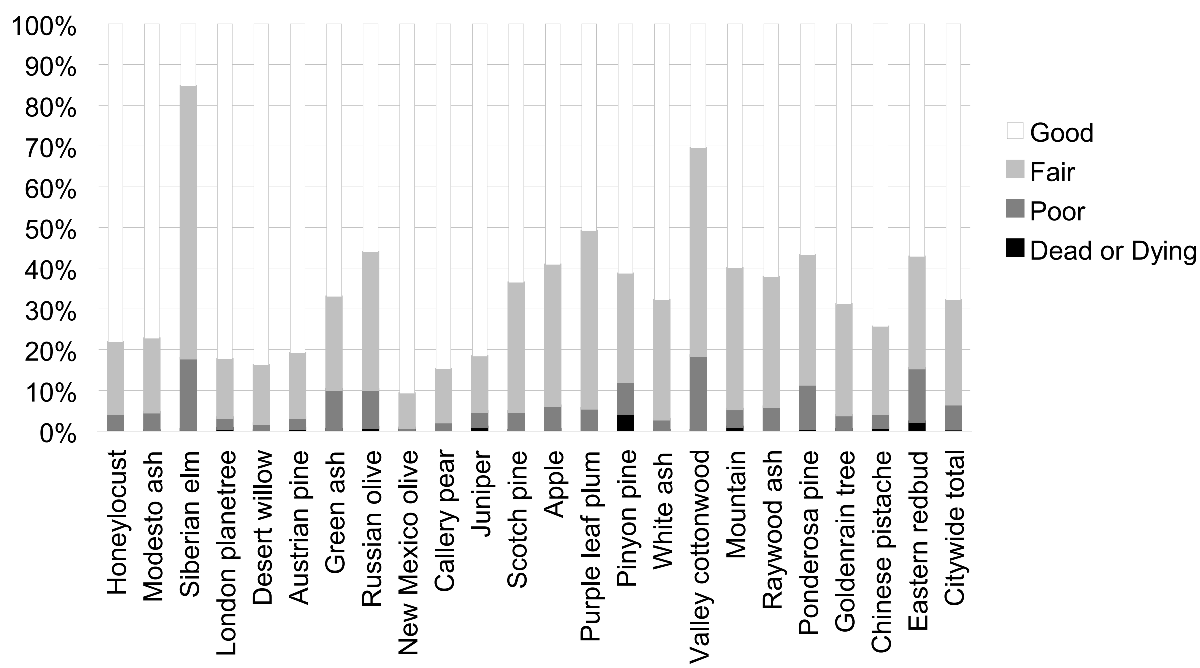

Figure 7—Condition of street and park trees in Albuquerque by species.

***Table 4**—Replacement values, summed by DBH class, for the 32 most valuable species of street and park trees in Albuquerque. See Appendix B for complete listing.*

Species	**0–6**	**6–12**	**12–18**	**18–24**	**24–30**	**30–36**	**36–42**	**>42**	**Total**	**% of total**
Siberian elm	55,717	185,288	325,083	726,318	2,237,553	2,415,019	2,984,548	2,312,142	11,241,668	27.7
Honeylocust	346,803	1,661,631	803,347	288,038	172,070	-	78,006	37,743	3,387,639	6.0
London planetree	169,977	882,208	1,078,546	516,729	168,429	16,985	-	-	2,832,874	5.5
Modesto ash	204,099	982,728	518,618	325,705	197,193	134,844	73,635	-	2,436,822	3.3
Valley cottonwood	7,697	64,532	148,481	140,983	316,449	358,507	688,127	509,444	2,234,221	3.2
Austrian pine	183,313	596,334	904,053	202,411	90,148	-	-	-	1,976,259	2.3
Green ash	149,492	527,434	308,839	246,750	87,334	25,728	-	-	1,345,577	2.1
Mountain cottonwood	23,685	103,440	148,544	204,340	450,902	169,683	166,245	54,349	1,321,188	1.6
Scotch pine	32,514	400,304	662,146	123,328	57,177	17,662	-	-	1,293,131	1.1
Ponderosa pine	4,381	127,040	469,471	190,134	130,184	16,391	-	-	937,601	0.8
Cottonwood	427	5,337	27,634	58,087	155,626	70,645	161,286	363,625	842,666	0.6
Russian olive	117,148	253,266	281,285	71,392	93,718	5,320	6,870	12,445	841,445	0.4
Callery pear	192,032	500,328	112,947	-	-	-	-	-	805,306	0.4
Juniper	68,973	157,987	166,085	102,867	146,621	54,655	56,070	-	753,259	0.3
White ash	71,759	269,811	168,662	69,621	36,841	-	23,478	-	640,173	0.2
American elm	-	-	44,878	74,854	96,032	134,682	212,814	58,983	622,243	0.2
Desert willow	368,127	156,937	7,180	-	-	-	-	-	532,244	0.1
Apple	148,864	225,783	122,758	15,726	-	-	-	-	513,130	0.1
Purple leaf plum	100,758	283,748	46,889	16,149	-	-	-	-	447,543	0.1
Spruce	15,095	51,202	146,255	75,104	29,273	-	-	-	316,929	0.1
Goldenrain tree	66,248	165,098	64,987	9,295	-	-	-	-	305,627	0.0
Japanese pagoda tree	6,860	174,583	78,811	14,293	-	-	-	-	274,548	0.0
Arizona sycamore	6,943	99,370	85,596	21,083	16,169	-	-	41,728	270,888	0.0
Catalpa	4,111	46,718	63,493	67,217	28,131	-	17,954	20,052	247,678	0.0
Raywood ash	106,748	75,827	15,816	12,654	10,282	14,879	-	-	236,204	0.0
Chinese pistache	57,090	86,568	48,831	6,327	-	-	-	-	198,816	0.0
Eastern redbud	53,979	100,891	11,874	6,680	12,779	-	-	-	186,204	0.0
Pinyon pine	61,388	87,618	21,931	2,185	-	-	-	-	173,122	0.0
New Mexico olive	131,760	10,728	-	-	-	-	-	-	142,488	0.0
Oak	82,361	30,743	-	-	-	-	-	-	113,104	0.0
Other trees	170,844	275,856	134,656	92,783	61,384	39,426	68,012	32,792	875,759	0.0
Citywide total	3,580,991	9,162,966	7,384,025	4,012,064	4,774,768	3,581,614	4,657,083	3,496,135	40,649,648	100.0

Figure 8—Although there are 76 trees planted in Albuquerque's Civic Plaza, opportunities remain for many more: to protect visitors from the scorching summer sun, to block the cold winter winds, to intercept rainfall, and to absorb pollutants.

Chapter Three—Costs of Managing Albuquerque's Municipal Trees

The benefits that Albuquerque's trees provide come, of course, at a cost. This chapter presents a breakdown of annual expenditures for fiscal year 2005, with exceptions noted below. Total annual tree-related expenditures for Albuquerque's municipal forestry program are currently approximately $1 million (Russell and Hart 2006), including $600,000 to fund the tree planting initiative. Because these planting costs do not represent an average year, the budget was adjusted for more typical planting numbers (75 trees x $300 = $22,500; Russell and Hart 2006). In this analysis we will consider a "typical" budget to be $428,500 (*Table 5*).

The city spends about $20 per tree on average during the year, approximately equal to the 1997 mean value of $19 per tree reported for 256 California cities after adjusting for inflation (Thompson and Ahern 2000). However, non-program expenditures (e.g., sidewalk repair, litter clean-up) were not included in the California survey. Albuquerque's annual expenditure is approximately equal to that of Charlotte, NC ($21), Bismarck, ND ($18) and is far less than some communities such as Charleston, SC ($35), Santa Monica, CA ($53), and Berkeley, CA ($65) (McPherson et al. 2005b, 2004a, 2006, 2005a, 2005e, respectively).

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

Tree Planting and Establishment

Quality nursery stock, careful planting, and follow-up care are critical to perpetuation of a healthy urban forest. By planting new trees that are relatively large, with DBH of 2 inches, the city of Albuquerque is giving its urban forest a healthy start. In a typical year, the Open Space Division plants about 75 trees, but this year, and for the next several years, they will plant 2,000 trees annually. In an average year, tree planting activities including materials, labor, administration, and equipment costs, account for 5.3% of the program budget or approximately $22,500.

Pruning, Removals, and General Tree Care

Pruning accounts for about one-quarter of the annual expenditures, at $103,500 ($4.81 per tree). New trees receive a training prune once every three years. Small trees are pruned at the same frequency. Medium and large trees are pruned slightly less often, every 5 years.

As might be expected in a region where evaporation exceeds precipitation 11 months of the year, irrigation is necessary for the health and survival of most trees. The city's annual budget for irrigation of all park areas is $2.2 million. Albuquerque's urban forester estimates that the trees account for only a small part of this: about $0.86 per tree or $18,500 (Russell and Hart 2006).

Table 5*—Albuquerque's annual municipal forestry-related expenditures.*

Expenditures	Total ($)	$/Tree	$/Capita	% of total
Purchasing Trees and Planting	22,500	1.05	0.05	5.3
Contract Pruning	103,500	4.81	0.21	24.2
Irrigation	24,000	1.12	0.05	5.6
Removal	35,000	1.63	0.07	8.2
Administration	175,000	8.13	0.36	40.8
Inspection/Service	6,000	0.28	0.01	1.4
Infrastructure Repairs	47,500	2.21	0.10	11.1
Litter Clean-up	15,000	0.70	0.03	3.5
Total Expenditures	428,500	19.91	0.88	100.0

Tree and stump removal accounts for about 8% of tree-related expenses ($35,000). About 250 trees are removed each year. All of the removed wood is taken to the City Soil Amendment Facility for transformation into mulch or compost. The operating costs of the program are funded by selling some of the products.

Administration

About $6,000 is spent annually on inspection and answering calls from the public. An additional $175,000 is spent on administration expenses including supervisory salaries, clerical salaries, equipment, supplies, and training.

Other Tree-Related Expenditures

In a typical year, Albuquerque spends about $15,000 on litter clean-up. Annually, about $45,000 is spent by the city on infrastructure repair related to tree roots. This amount is comparatively low because the majority of Albuquerque's trees are located in parks where they are less likely to conflict with infrastructure compared to street trees. As well, the remainder of the trees are planted in medians, where less damage can be expected than if located adjacent to sidewalks and water lines.

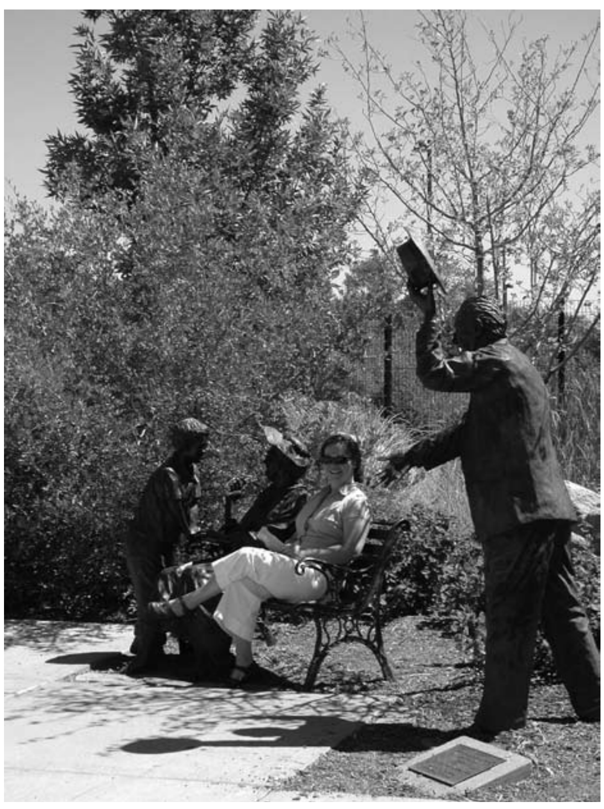

Figure 9—Trees create a pleasant resting spot for a visitor to the Rio Grande Botanical Garden.

Chapter Four—Benefits of Albuquerque'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 Albuquerque's municipal 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 trees in Albuquerque—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 10*):

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

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

Trees reduce air movement into buildings and conductive heat loss from buildings. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Decreasing wind speed reduces heat transfer through conductive materials as well. *Appendix C* provides additional information on specific contributions that trees make toward energy savings.

Figure 10—Trees shade an Old Town shop, moderating the climate and reducing energy use, cleaning the air, and providing a more enticing shopping experience.

Table 6—Net annual energy savings produced by Albuquerque street and park trees.

Species	Electricity (MWh)	Electricity ($)	Natural gas (therms)	Natural gas ($)	Total ($)	% of total trees	% of total $	Avg. $/tree
Honeylocust	127	10,020	5,438	5,982	16,002	9.9	9.4	7.47
Modesto ash	107	8,445	4,330	4,763	13,208	7.4	7.8	8.28
Siberian elm	510	40,241	9,982	10,981	51,221	6.7	30.1	35.67
London planetree	116	9,124	4,525	4,977	14,101	6.4	8.3	10.17
Desert willow	16	1,235	772	849	2,084	6.3	1.2	1.52
Austrian pine	38	3,029	1,663	1,829	4,857	5.5	2.9	4.1
Green ash	61	4,814	2,480	2,728	7,541	4.3	4.4	8.17
Russian olive	47	3,714	2,014	2,216	5,930	4.2	3.5	6.65
New Mexico olive	3	230	142	156	387	3.5	0.2	0.52
Callery pear	16	1,291	766	842	2,133	3.4	1.3	2.93
Juniper	19	1,489	795	874	2,363	2.9	1.4	3.74
Scotch pine	29	2,296	1,236	1,359	3,655	2.8	2.1	5.96
Apple	13	1,042	604	664	1,706	2.6	1.0	3.08
Purple leaf plum	9	682	407	448	1,130	2.2	0.7	2.34
Pinyon pine	5	377	219	241	618	2.0	0.4	1.46
White ash	22	1,707	871	958	2,665	1.9	1.6	6.5
Valley cottonwood	75	5,892	2,524	2,776	8,668	1.9	5.1	21.14
Mountain cottonwood	53	4,188	1,818	2,000	6,188	1.8	3.6	15.91
Raywood ash	5	418	249	274	692	1.6	0.4	1.97
Ponderosa pine	20	1,590	832	915	2,505	1.6	1.5	7.35
Goldenrain tree	7	578	335	368	946	1.2	0.6	3.73
Chinese pistache	5	427	256	281	708	1.1	0.4	2.96
Eastern redbud	5	358	209	230	588	1.0	0.4	2.67
Other street trees	173	13,661	6,242	6,867	20,528	17.7	12.1	8.78
Citywide total	1,482	116,847	48,708	53,579	170,426	100.0	100.0	7.92

Electricity and Natural Gas Results

Electricity and natural gas saved annually in Albuquerque from both shading and climate effects equal 1,482 MWh ($116,847) and 48,708 therms ($53,579), respectively, for a total retail savings of $170,426 (*Table 6*) or a citywide average of $7.92 per tree. Siberian elms provide 30.1% of the energy savings although they account for only 6.7% of total tree numbers, as expected for a tree species with such a high Importance Value (IV). Honeylocust (9.4%) and London planetrees (8.3%) make the next greatest contributions to overall energy savings. On a per tree basis, Siberian elms again are the greatest contributors, reducing energy needs by approximately $36 per tree annually. Valley and mountain cottonwoods provide the next greatest savings on a per tree basis ($21 and $16).

It should be noted again that this analysis describes the urban forest as it exists at the time of the inventory. This explains why the energy benefits of the Siberian elm on a per tree basis ($36.24) are so much greater than, for instance, the London planetree ($10.69). The majority of Albuquerque's Siberian elms are old and large, while the London planetrees have only been planted in recent years. As the London planetrees 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 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, chain saws, chippers, and other equipment during the process of 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 carbon dioxide benefits of trees.

Avoided and Sequestered Carbon Dioxide

Citywide, Albuquerque's municipal forest reduces atmospheric CO_2 by a net of 2,332 tons annually (*Table 7*). This benefit was valued at $15,576 or $0.72 per tree. Avoided CO_2 emissions from power plants due to cooling energy savings totaled 1,725 tons, while CO_2 sequestered by trees was 735 tons. CO_2 released through decomposition and tree care activities totaled 128 tons, or 5.4% of the net total benefit. Avoided emissions are important in Albuquerque because coal, which has a relatively high CO_2 emissions factor, accounts for almost all of the fuel used in power plants that generate electricity there (98%, US EPA 2003). Shading by trees during summer reduces the need for air conditioning, resulting in reduced use of coal for electricity generation.

On a per tree basis, Siberian elm ($3.45), mountain ($0.99) and valley ($1.32) cottonwoods, and London planetrees ($0.93) provide the greatest CO_2 benefits (*Table 7*). Because of their age and great size, Siberian

***Table 7**—CO_2 reductions, releases, and net benefits produced by street and park trees.*

Species	Sequestered (lb)	Decomp. release(lb)	Maint. release (lb)	Avoided (lb)	Net total (lb)	Total ($)	% of trees	% of total $	Avg. $/tree
Honeylocust	203,043	−16,071	−2,258	295,862	480,576	1,605	9.9	10.3	0.75
Modesto ash	114,326	−7,643	−1,749	249,364	354,298	1,183	7.4	7.6	0.74
Siberian elm	430,566	−131,570	−4,690	1,188,178	1,482,483	4,952	6.7	31.8	3.45
London planetree	127,896	−9,583	−1,787	269,408	385,934	1,289	6.4	8.3	0.93
Desert willow	9,109	−408	−567	36,456	44,590	149	6.3	1.0	0.11
Austrian pine	70,087	−3,484	−1,294	89,423	154,732	517	5.5	3.3	0.44
Green ash	47,288	−4,658	−1,071	142,131	183,690	614	4.3	3.9	0.66
Russian olive	88,707	−2,625	−174	109,675	195,583	653	4.2	4.2	0.73
New Mexico olive	3,909	−109	−185	6,803	10,418	35	3.5	0.2	0.05
Callery pear	35,821	−2,275	−142	38,119	71,523	239	3.4	1.5	0.33
Juniper	38,370	−2,634	−634	43,963	79,066	264	2.9	1.7	0.42
Scotch pine	22,851	−2,126	−858	67,795	87,661	293	2.8	1.9	0.48
Apple	8,971	−748	−392	30,754	38,585	129	2.6	0.8	0.23
Purple leaf plum	26,044	−1,542	−94	20,142	44,549	149	2.2	1.0	0.31
Pinyon pine	3,721	−342	−259	11,131	14,252	48	2.0	0.3	0.11
White ash	31,276	−1,541	−80	50,392	80,046	267	1.9	1.7	0.65
Valley cottonwood	370	−11,254	−1,287	173,971	161,801	540	1.9	3.5	1.32
Mountain cottonwood	619	−7,756	−802	123,663	115,724	387	1.8	2.5	0.99
Raywood ash	6,586	−492	−203	12,330	18,221	61	1.6	0.4	0.17
Ponderosa pine	28,393	−1,975	−583	46,953	72,787	243	1.6	1.6	0.71
Goldenrain tree	4,825	−408	−208	17,063	21,272	71	1.2	0.5	0.28
Chinese pistache	1,567	−206	−169	12,600	13,792	46	1.1	0.3	0.19
Eastern redbud	3,182	−233	−143	10,571	13,376	45	1.0	0.3	0.20
Other street trees	163,008	−25,002	−2,978	403,366	538,393	1,797	17.7	11.5	0.79
Citywide total	1,470,536	−234,686	−22,609	3,450,111	4,663,352	15,576	100.0	100.0	0.72

elms also provide the greatest total CO_2 benefits, accounting for nearly 32% of citywide CO_2 reduction.

Air Quality Improvement

Urban trees improve air quality in five main ways (*Figure 11*):

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

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

Figure 11—Trees in a downtown pedestrian area help clean the air by absorbing pollutants, and as they moderate the temperature and reduce energy needs, they also reduce pollutants produced at the power plant.

Deposition and Interception

Each year 5.95 tons ($8,720) of nitrogen dioxide (NO_2), small particulate matter (PM_{10}), ozone (O_3), and sulfur dioxide (SO_2) is intercepted or absorbed by trees (pollution deposition and particulate interception) in Albuquerque (*Table 8*). Albuquerque's trees are most effective at removing O_3 and PM_{10}, with an implied annual value of $7,912. Again, due to their substantial leaf area, Siberian elms contribute the most to pollutant uptake, removing more than 3,000 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 8*). Together, 8.9 tons of pollutants are avoided annually with an implied value of $16,553. In terms of amount, avoided emissions of NO_2 are greatest (8,001 lb, $4,881). In dollar terms, however, avoided SO_2 emissions are higher (6,818 lb, $9,682). Siberian elms have the greatest impact on reducing energy needs: by moderating the climate they account for 5,562 lbs 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 3.7 tons, these emissions offset about one-quarter of air quality improvements and are calculated as a cost to the city of $1,412. London planetrees and cottonwoods are fairly heavy emitters of BVOCs, accounting for more than half of the urban forest's emissions.

Net Air Quality Improvement

Net air pollutants removed, released, and avoided are valued at $23,862 annually. The average benefit per

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

Species	Deposition					Avoided					BVOC emissions		Net total		% of trees	Avg. $/tree
	O_3 (lb)	NO_2 (lb)	PM_{10} (lb)	SO_2 (lb)	Total ($)	NO_2 (lb)	PM_{10} (lb)	VOC (lb)	SO_2 (lb)	Total ($)	(lb)	($)	(lb)	($)		
Honeylocust	702	105	224	3	752	699	130	128	585	1,429	−161	−31	2,414	2,150	10.0	1.00
Modesto ash	625	96	212	3	685	587	109	108	493	1,202	0	0	2,232	1,888	7.4	1.18
Siberian elm	2,103	311	697	9	2,279	2,686	512	507	2,348	5,652	0	0	9,172	7,931	6.7	5.52
London planetree	655	102	217	3	713	632	118	116	532	1,298	−1,900	−361	475	1,650	6.4	1.19
Desert willow	84	13	27	0	90	87	16	16	72	177	−9	−2	305	265	6.4	0.19
Austrian pine	290	57	115	2	346	211	39	39	177	432	−125	−24	805	754	5.5	0.64
Green ash	357	55	121	1	391	334	62	61	281	685	0	0	1,273	1,077	4.3	1.17
Russian olive	269	41	91	1	295	259	48	47	217	530	−11	−2	963	822	4.2	0.92
New Mexico olive	16	2	5	0	17	16	3	3	13	33	−16	−3	43	47	3.5	0.06
Callery pear	96	15	33	0	106	91	17	17	75	185	0	0	343	290	3.4	0.40
Juniper	146	29	58	1	174	104	19	19	87	212	−83	−16	379	370	2.9	0.59
Scotch pine	219	43	87	2	261	160	30	29	134	327	−180	−34	523	554	2.9	0.90
Apple	73	11	24	0	80	73	13	13	61	149	−110	−21	160	208	2.6	0.38
Purple leaf plum	49	7	16	0	54	48	9	9	40	98	0	0	179	151	2.2	0.31
Pinyon pine	36	7	14	0	43	26	5	5	22	54	−10	−2	106	95	2.0	0.22
White ash	122	19	41	1	133	118	22	22	100	243	0	0	444	376	1.9	0.92
Valley cottonwood	477	72	162	2	522	404	76	75	344	835	−1,394	−265	217	1,093	1.9	2.66
Mountain cottonwood	336	51	114	1	368	288	54	53	244	594	−1,645	−313	−504	649	1.8	1.67
Raywood ash	30	5	10	0	33	29	5	5	24	60	0	0	109	93	1.6	0.26
Ponderosa pine	153	30	61	1	182	111	21	20	93	227	−94	−18	395	391	1.6	1.15
Goldenrain tree	41	6	14	0	44	41	7	7	34	83	−60	−11	90	115	1.2	0.45
Chinese pistache	26	4	8	0	28	30	6	5	25	61	−12	−2	93	87	1.1	0.36
Eastern redbud	25	4	8	0	27	25	5	5	21	51	−34	−6	59	72	1.0	0.33
Other street trees	1,000	156	340	4	1,098	941	176	173	796	1,940	−1,586	−301	2,000	2,736	17.7	1.16
Citywide total	7,929	1,240	2,698	36	8,720	8,001	1,500	1,482	6,818	16,553	−7,431	−1,412	22,273	23,862	100.0	1.11

tree is $1.11 (1.03 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, such as the Siberian elm, produce the greatest benefits ($7,931 total; $5.52 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.

Albuquerque's municipal trees intercept 11.1 million gal of stormwater annually, or 518 gal per tree on average (*Table 9*). The total value of this benefit to the city is $55,833, or $2.59 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

Table 9*—Annual stormwater reduction benefits of Albuquerque's public trees by species.*

Species	Rainfall interception (gal)	Total ($)	% of trees	% of total $	Avg. $/tree
Honeylocust	777,078	3,886	9.9	7.0	1.81
Modesto ash	778,434	3,892	7.4	7.0	2.44
Siberian elm	3,720,080	18,602	6.7	33.3	12.95
London planetree	1,067,714	5,339	6.4	9.6	3.85
Desert willow	61,978	310	6.3	0.6	0.23
Austrian pine	351,053	1,755	5.5	3.1	1.48
Green ash	431,105	2,156	4.3	3.9	2.34
Russian olive	297,201	1,486	4.2	2.7	1.67
New Mexico olive	16,199	81	3.5	0.2	0.11
Callery pear	97,258	486	3.4	0.9	0.67
Juniper	194,093	971	2.9	1.7	1.54
Scotch pine	231,367	1,157	2.8	2.1	1.89
Apple	77,537	388	2.6	0.7	0.70
Purple leaf plum	46,612	233	2.2	0.4	0.48
Pinyon pine	31,417	157	2.0	0.3	0.37
White ash	147,093	736	1.9	1.3	1.79
Valley cottonwood	643,140	3,216	1.9	5.8	7.84
Mountain cottonwood	502,184	2,511	1.8	4.5	6.46
Raywood ash	31,466	157	1.6	0.3	0.45
Ponderosa pine	207,067	1,035	1.6	1.9	3.04
Goldenrain tree	42,903	215	1.2	0.4	0.84
Chinese pistache	31,581	158	1.1	0.3	0.66
Eastern redbud	26,212	131	1.0	0.2	0.60
Other street trees	1,355,128	6,777	17.7	12.1	3.21
Citywide total	11,165,899	55,833	100.0	100.0	2.59

the amount of precipitation trees can intercept and hold to reduce runoff. Trees that perform well include Siberian elm ($12.95 per tree), valley cottonwood ($7.84 per tree), and mountain cottonwood ($6.46 per tree). Interception by Siberian elms alone accounts for one-third of the total dollar benefit from street and park trees. Poor performers are species with relatively small leaf and stem surface areas, such as New Mexico olive and desert willow.

Aesthetic, Property Value, Social, Economic and Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place, and well-being are 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. To estimate the value of these "other" intangible benefits, research that compares differences in sales prices of houses was used to estimate the contribution associated with trees. The difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with trees. This approach has the virtue of capturing what buyers perceive as both the benefits and costs of trees in the sales price. One limitation of using this approach is the difficulty associated with extrapolating results from front-yard trees on residential properties to 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 is $295,282, or $14 per tree on average (*Table 10*). Tree

Table 10*—Annual aesthetic and other benefits of Albuquerque's street and park trees.*

Species	Total ($)	% of trees	% of total $	Avg. $/tree
Honeylocust	21,399	9.9	7.3	9.99
Modesto ash	35,688	7.4	12.1	22.36
Siberian elm	57,300	6.7	19.4	39.90
London planetree	45,047	6.4	15.3	32.50
Desert willow	841	6.3	0.3	0.62
Austrian pine	9,554	5.5	3.2	8.07
Green ash	12,489	4.3	4.2	13.53
Russian olive	16,711	4.2	5.7	18.73
New Mexico olive	534	3.5	0.2	0.72
Callery pear	1,834	3.4	0.6	2.52
Juniper	4,588	2.9	1.6	7.26
Scotch pine	2,559	2.8	0.9	4.17
Apple	948	2.6	0.3	1.71
Purple leaf plum	559	2.2	0.2	1.16
Pinyon pine	254	2.0	0.1	0.60
White ash	7,862	1.9	2.7	19.18
Valley cottonwood	7,074	1.9	2.4	17.25
Mountain cottonwood	19,252	1.8	6.5	49.49
Raywood ash	1,441	1.6	0.5	4.09
Ponderosa pine	6,165	1.6	2.1	18.08
Goldenrain tree	512	1.2	0.2	2.02
Chinese pistache	360	1.1	0.1	1.50
Eastern redbud	346	1.0	0.1	1.57
Other street trees	41,968	17.7	14.2	19.41
Citywide total	295,282	100.0	100.0	13.72

species that produce the highest average annual benefits include mountain cottonwood ($50 per tree), Siberian elm ($40 per tree), and London planetree ($33), while small trees such as the pinyon pine ($1 per tree), desert willow ($1 per tree) and New Mexico olive ($1 per tree) produce the least benefits.

Figure 12—Trees add value to commercial and residential property.

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

Total annual benefits produced by Albuquerque's municipal trees are estimated at $560,979 ($26 per tree, $1.16 per capita) (*Table 11*). Over the same period, tree-related expenditures are estimated to be $428,580 ($20 per tree, $0.88 per capita). Net annual benefits (benefits minus costs) are $132,399, or $6 per tree and $0.27 per capita. The Albuquerque municipal forest currently returns $1.31 to the community for every $1 spent on management. Albuquerque's benefit–cost ratio of 1.31 is similar those reported for Berkeley, CA (1.37), and Charleston, SC (1.34), exceeds that for San Francisco (1.00), but is below those reported for Minneapolis, MN (1.57), Fort Collins, CO (2.18), Glendale, AZ (2.41), and Charlotte, NC (3.25) (McPherson et al. 2003, 2004b, 2005a–f).

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

Benefits	Total ($)	$/tree	$/capita
Energy	170,426	7.92	0.35
CO_2	15,576	0.72	0.03
Air quality	23,862	1.11	0.05
Stormwater	55,833	2.59	0.12
Aesthetic/other	295,282	13.72	0.61
Total benefits	560,979	26.07	1.16
Costs			
Planting	22,500	1.05	0.05
Contract pruning	103,500	4.81	0.21
Irrigation	24,080	1.12	0.05
Removal	35,000	1.63	0.07
Administration	175,000	8.13	0.36
Inspection/service	6,000	0.28	0.01
Infrastructure repairs	47,500	2.21	0.10
Litter clean-up	15,000	0.70	0.03
Total costs	428,580	19.92	0.88
Net benefits	132,399	6.15	0.27
Benefit-cost ratio		1.31	

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

Species	Energy	CO_2	Air quality	Stormwater	Aesthetic/other	$/tree	Total $	% of total $
Honeylocust	7.47	0.75	1.00	1.81	9.99	21.04	45,041	8.0
Modesto ash	8.28	0.74	1.18	2.44	22.36	35.00	55,860	10.0
Siberian elm	35.67	3.45	5.52	12.95	39.90	97.50	140,006	25.0
London planetree	10.17	0.93	1.19	3.85	32.50	48.65	67,426	12.0
Desert willow	1.52	0.11	0.19	0.23	0.62	2.67	3,648	0.7
Austrian pine	4.10	0.44	0.64	1.48	8.07	14.73	17,437	3.1
Green ash	8.17	0.66	1.17	2.34	13.53	25.87	23,876	4.3
Russian olive	6.65	0.73	0.92	1.67	18.73	28.70	25,603	4.6
New Mexico olive	0.52	0.05	0.06	0.11	0.72	1.45	1,084	0.2
Callery pear	2.93	0.33	0.40	0.67	2.52	6.83	4,983	0.9
Juniper	3.74	0.42	0.59	1.54	7.26	13.54	8,556	1.5
Scotch pine	5.96	0.48	0.90	1.89	4.17	13.41	8,217	1.5
Apple	3.08	0.23	0.38	0.70	1.71	6.11	3,378	0.6
Purple leaf plum	2.34	0.31	0.31	0.48	1.16	4.60	2,222	0.4
Pinyon pine	1.46	0.11	0.22	0.37	0.60	2.78	1,171	0.2
White ash	6.50	0.65	0.92	1.79	19.18	29.04	11,906	2.1
Valley cottonwood	21.14	1.32	2.66	7.84	17.25	50.22	20,591	3.7
Mountain cottonwood	15.91	0.99	1.67	6.46	49.49	74.51	28,986	5.2
Raywood ash	1.97	0.17	0.26	0.45	4.09	6.94	2,443	0.4
Ponderosa pine	7.35	0.71	1.15	3.04	18.08	30.32	10,339	1.8
Goldenrain tree	3.73	0.28	0.45	0.84	2.02	7.32	1,860	0.3
Chinese pistache	2.96	0.19	0.36	0.66	1.50	5.68	1,358	0.2
Eastern redbud	2.67	0.20	0.33	0.60	1.57	5.37	1,182	0.2
Other street trees	8.78	0.79	1.16	3.21	19.41	33.36	54,005	13.1

Albuquerque's municipal trees have beneficial effects on the environment. Nearly half (47%) of the annual benefits provided to residents of the city are environmental services. Energy savings represents 64% of environmental benefits, with stormwater runoff reduction accounting for another 21%. Air quality improvement (9%) and carbon dioxide reduction (6%) provide the remaining environmental benefits. Annual increases in property value are very valuable, accounting for 53% of total annual benefits in Albuquerque.

Table 12 shows the distribution of total annual benefits in dollars for the predominant municipal tree species in Albuquerque. Siberian elms are most valuable to the city overall (25% of total benefits, $98 per tree). On a per tree basis, mountain cottonwood ($75 per tree) and London planetree ($49 per tree) also produce significant benefits. It should be noted once again that this analysis provides benefits for a snap shot in time.

As the London planetrees and other newly planted, large-stature trees grow they will provide increasingly greater benefits. Small-stature species, such as the New Mexico olive ($1 per tree), the pinyon pine ($3 per tree), and the desert willow ($3 per tree) will provide correspondingly lower benefits.

This is not to argue that large trees are always the best option. Numerous considerations drive species choice, including planting site, potential conflicts with infrastructure, maintenance concerns, water use, and design considerations. In some cases, small trees are the best or only option. Nonetheless, the results of this analysis emphasize that large trees should be planted wherever possible to increase the benefits to the citizens of Albuquerque.

Figure 13 illustrates the average annual benefits per tree by council district and reflects differences in tree types and ages. The trees of district 7 provide $50 in benefits on average each year, which can attributed to the predominant species (see *Table 2*), all of which are large-stature trees, and the maturity of the trees (see *Figure 6*). The trees of district 4, in contrast, provide only $20 in benefits on average, due to the predominance of small species (three of the five most common species are small-stature, *Figure 6*), and very few trees in the largest size class (only 0.1% are larger than 36-inch dbh).

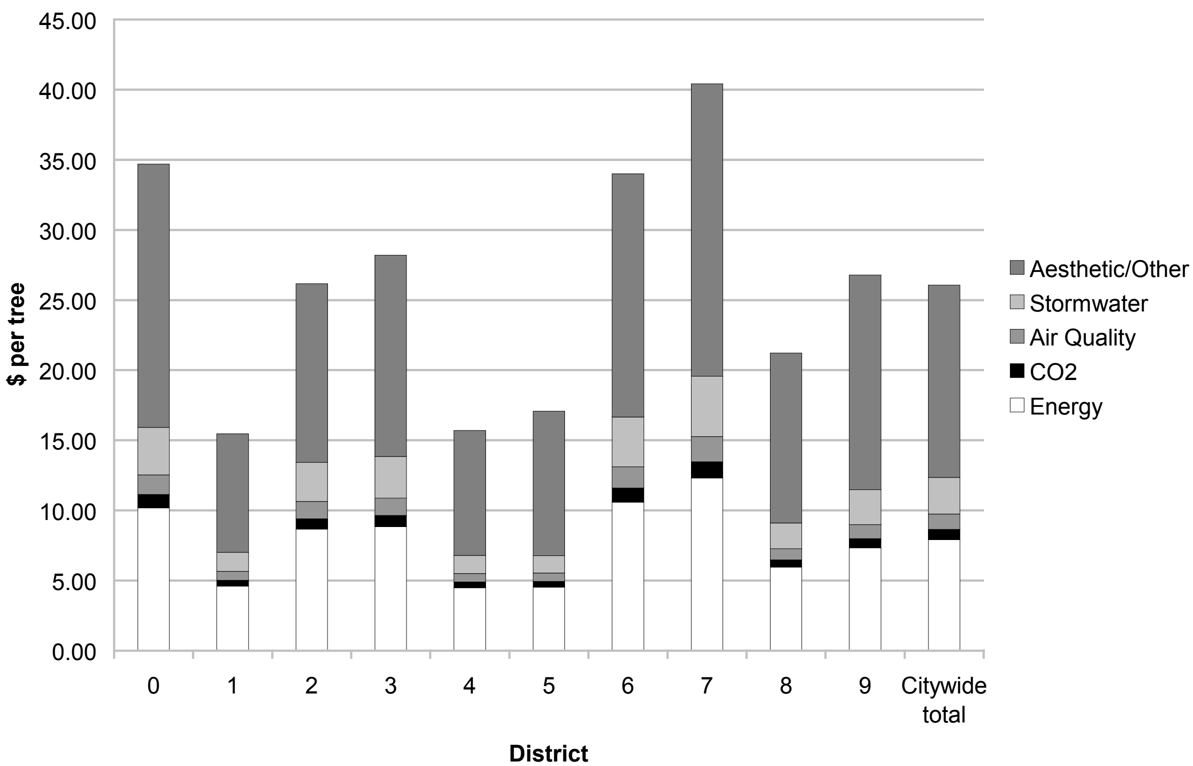

Figure 13—Average annual street and park tree benefits per tree by management zone.

Chapter Five—Management Implications

Albuquerque's urban forest reflects the values, lifestyles, preferences, and aspirations of current and past residents. It is a dynamic legacy whose character will change greatly over the next decades. Although this study provides a "snapshot" in time of the resource, it also serves as an opportunity to speculate about the future. Given the status of Albuquerque's municipal 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 Parks and Recreation Department of Albuquerque is to be commended for its commitment to increasing the diversity of the urban forest. The number of species (73) is excellent, considering the difficult climate of the region, especially the arid conditions that prevail most of the year. As well, the distribution of trees across species, with no one species representing more than 10% of the total, will serve the citizens of Albuquerque well, protecting their urban forest, and consequently the benefits they receive from it, from disease or pest infestations.

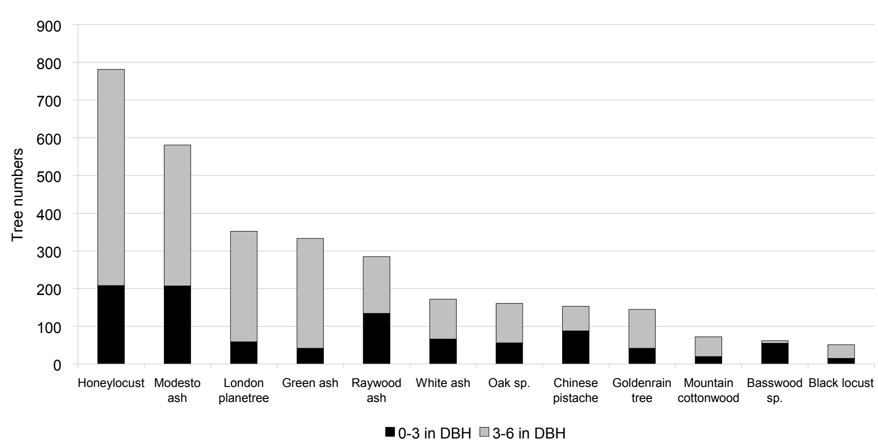

Figure 14—Municipal trees being planted in the highest numbers.

Species choice in recent years may be some cause for concern. *Figure 14* displays large- and medium-growing trees in the smallest DBH size classes, indicating trends in new and replacement trees. Honeylocust predominates and though the species has proven successful as an urban tree, its popularity has increased its susceptibility to some pests and diseases. The ashes as a group predominate among new trees, representing 21% of recent plantings. This may put the future urban forest at risk from the emerald ash borer, a recently introduced pest from Asia that has devastated tree populations in the Midwest.

The National Elm Trial, a study to evaluate and promote the use of elm trees resistant to Dutch elm disease, could offer the urban foresters of Albuquerque suggestions for new hybrid cultivars of elms to replace the aging Siberian elm population (see below). For more information on the Trial and cultivars suited to the region, see http://treehealth.agsci.colostate.edu/research/nationalelmtrial/NationalElmTrial.htm.

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 Albuquerque's canopy cover.

The Parks and Recreation Department is currently planting 2,000 new trees annually and will continue for several years. This exciting initiative offers great opportunities to improve the level of benefits provided to the people of Albuquerque. A number of things can be done to maximize the results.

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.

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 emissions from parked cars by lowering local air temperature (Scott et al. 1999). Evaporative emissions from non-operating vehicles account for 16% of total vehicular emissions; lowering the air temperature by increasing shade cover in Sacramento parking lots to 50% from 8% was estimated to reduce overall emissions by 2% (0.85 tons per day). Although seemingly modest, many existing programs to improve air quality have similar goals.

The importance of size in achieving high levels of benefits should also not be forgotten. Large-growing trees should be planted wherever possible.

Maintenance

Albuquerque's maintenance challenges in the coming years will be to establish and care properly for the many new trees that have been planted and to maintain and eventually remove the old Siberian elms and cottonwoods as they continue to decline. With 2,000 new trees planted each year, a strong young-tree care program is imperative to insure, first, that the trees survive, and second, that they transition into well-structured, healthy mature trees requiring minimal pruning. 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. It will be a significant challenge, but the Open Space Division should work to secure funding to allow them to increase their pruning cycle to every two years. Funding for irrigation, inspection and pruning of young trees should be a priority.

The Siberian elms and valley cottonwoods are reaching the end of their natural life spans and are in decline. They will require increased maintenance as they age and eventually they will have to be removed. The future of the elms, which provide an enormous share of the benefits of the urban forest, should be considered with special care. Additionally, because of their stature and grace they tend to be especially beloved by residents. In several Albuquerque parks, Siberian elms are the only trees (*Figure 15*). For these reasons, a careful plan should be developed to begin planting similarly beneficial and beautiful trees *before* the elms have to be removed. The trees in the worst condition should be replaced first, while treating the others to prolong their lifespan. New replacements should be planted in anticipation of removals. Successful cultivars from the National Elm Trial might be a good option, considering the long-term success of the Siberian species.

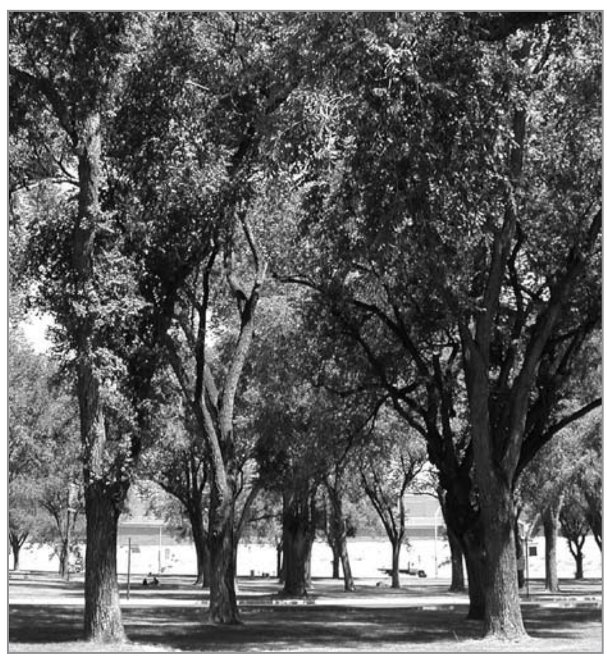

Figure 15—Albuquerque's aging Siberian elms should be gradually replaced with trees of similar stature and beauty.

Chapter Six—Conclusion

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

Albuquerque's 21,519 street and park trees are a valuable asset, providing approximately $560,979 ($26 per tree) in annual gross benefits. Benefits to the community are most pronounced for energy savings and aesthetic and other benefits. Thus, municipal trees play a particularly important role in maintaining the environmental and aesthetic qualities of the city. Albuquerque spends approximately $428,500 maintaining its inventoried trees or $20 per tree.

After costs are taken into account, Albuquerque's municipal tree resource provides approximately $132,399, or $6 per tree ($0.27 per capita) in net annual benefits to the community. Over the years, Albuquerque has invested millions of dollars in its municipal forest. **Citizens are seeing a return on that investment—receiving $1.31 in benefits for every $1 spent on tree care**. The fact that Albuquerque's benefit–cost ratio exceeds 1.0 indicates that the program is not only operationally efficient, but is capitalizing on the functional services its trees can produce. The value of Albuquerque's municipal urban forest will increase as the many trees planted through Mayor Chavez's initiative begin to mature. As the resource grows, continued investment in management is critical to insuring that residents will receive a high return on investment in the future.

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

Management recommendations derived from this analysis are fivefold:

1. Develop a strong young-tree care program that emphasizes reducing mortality. Irrigation, inspection and pruning on a two-year cycle will provide a good foundation for the many new trees being planted.
2. Sustain benefits by investing in intensive maintenance of mature trees to prolong the functional life spans of these heritage trees. Develop a plan to replace the aging Siberian elms with trees of similar stature gradually before they must be removed.
3. Conduct a canopy cover study of the city to identify and prioritize future planting. Streets, parking lots, and schools may provide good opportunities for maximizing air quality, energy savings, and aesthetic benefits.
4. Track the success of the newly planted trees to determine those most adaptable to the difficult conditions. Maintain a diverse mix of tree species to guard against catastrophic losses due to storms, pests or disease while concentrating the species choice on those that have proven most successful.
5. Plant large species where conditions are suitable to maximize benefits.

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

Appendix A—Tree Distribution

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

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	42+	Total
Broadleaf deciduous large (BDL)										
Gleditsia triacanthos	208	573	1,084	210	42	17	-	5	2	2,141
Fraxinus velutina 'Modesto'	207	374	765	162	53	20	10	5	-	1,596
Ulmus pumila	52	97	156	141	150	286	214	198	142	1,436
Platanus hybrida	59	293	637	306	75	15	1	-	-	1,386
Fraxinus pennsylvanica	42	291	415	110	48	15	2	-	-	923
Fraxinus americana	66	106	178	45	11	3	-	1	-	410
Populus fremontii	8	17	69	69	35	48	45	70	49	410
Populus angustifolia	20	52	107	64	47	66	16	13	4	389
Quercus spp.	56	105	17	-	-	-	-	-	-	178
Sophora japonica	3	13	107	18	2	-	-	-	-	143
Populus spp.	1	1	8	15	15	28	11	20	33	132
Platanus wrightii	5	12	79	26	3	2	-	-	2	129
Robinia pseudoacacia	15	36	43	6	1	1	-	1	-	103
Catalpa spp.	3	7	32	18	10	3	-	1	1	75
Tilia spp.	55	7	3	3	1	-	-	-	-	69
Ulmus americana	0	-	-	13	15	13	8	12	3	64
Ulmus parvifolia	1	12	51	-	-	-	-	-	-	64
Acer saccharinum	2	6	14	6	2	3	-	-	-	33
Acer platanoides	6	5	15	-	1	-	-	-	-	27
Salix matsudana	1	2	3	1	1	-	-	5	2	15
Gymnocladus dioicus	2	7	2	-	-	-	-	-	-	11
Quercus macrocarpa	10	1	-	-	-	-	-	-	-	11
Catalpa speciosa	0	-	3	2	2	1	-	-	-	8
Acer negundo	4	-	-	-	-	-	-	-	-	4
Fraxinus pennsylvanica 'Patmore'	3	-	-	-	-	-	-	-	-	3
Ailanthus altissima	0	-	1	1	-	-	-	-	-	2
Quercus shumardii	2	-	-	-	-	-	-	-	-	2
Fraxinus pennsylvanica 'Marshall'	0	-	-	-	1	-	-	-	-	1
Zelkova serrata	0	1	-	-	-	-	-	-	-	1
Total	831	2,018	3,789	1,216	515	521	307	331	238	9,766
Broadleaf deciduous medium (BDM)										
Other	506	474	347	94	47	19	7	7	3	1,504
Unknown	240	279	123	24	10	-	1	-	-	677
Fraxinus angustifolia	134	151	58	5	2	1	1	-	-	352
Koelreuteria paniculata	42	103	94	14	1	-	-	-	-	254
Pistacia chinensis	88	65	69	16	1	-	-	-	-	239
Morus spp.	0	-	-	1	-	2	1	-	-	4
Maclura pomifera	0	-	-	-	-	1	1	-	1	3
Celtis sinensis	1	-	-	-	-	-	-	-	-	1

Species	0–3	3–6	6–12	12–18	18–24	24–30	30–36	36–42	42+	Total
Fraxinus berlandieriana	0	-	1	-	-	-	-	-	-	1
Total	1,011	1,072	692	154	61	23	11	7	4	3,035
Broadleaf deciduous small (BDS)										
Chilopsis linearis	776	474	115	2	-	-	-	-	-	1,367
Elaeagnus angustifolia	54	357	307	139	18	14	1	1	1	892
Forestiera pubescens	667	66	14	-	-	-	-	-	-	747
Pyrus calleryana	113	310	281	25	-	-	-	-	-	729
Malus spp.	158	220	141	32	2	-	-	-	-	553
Prunus cerasifera	170	123	175	13	2	-	-	-	-	483
Cercis canadensis	82	73	59	3	1	2	-	-	-	220
Prunus spp.	12	57	21	1	1	-	-	-	-	92
Pyrus spp.	4	45	20	6	3	-	-	-	-	78
Crataegus spp.	46	14	1	-	-	-	-	-	-	61
Vitex spp.	47	4	-	-	-	-	-	-	-	51
Chitalpa spp.	29	8	10	-	-	-	-	-	-	47
Albizia julibrissin	0	-	1	3	-	-	-	-	-	4
Cercis reniformis	1	-	-	-	-	-	-	-	-	1
Sorbus spp.	0	1	-	-	-	-	-	-	-	1
Total	2,159	1,752	1,145	224	27	16	1	1	1	5,326
Broadleaf evergreen small (BES)										
Magnolia spp.	1	-	-	-	-	-	-	-	-	1
Total	1	-	-	-	-	-	-	-	-	1
Conifer evergreen large (CEL)										
Pinus sylvestris	15	71	305	197	19	5	1	-	-	613
Pinus ponderosa	10	12	121	153	31	13	1	-	-	341
Picea spp.	32	12	43	51	13	4	-	-	-	155
Pinus strobiformis	6	3	-	-	-	-	-	-	-	9
x *Cupressocyparis leylandii*	5	2	-	-	-	-	-	-	-	7
Cedrus deodara	1	-	-	-	-	-	-	-	-	1
Pinus eldarica	1	-	-	-	-	-	-	-	-	1
Total	70	100	469	401	63	22	2	-	-	1,127
Conifer evergreen medium (CEM)										
Pinus nigra	131	360	420	237	28	8	-	-	-	1,184
Juniperus spp.	218	123	166	69	24	21	6	5	-	632
Cupressus arizonica	1	-	4	11	3	-	1	1	-	21
Pinus flexilis	0	1	-	-	-	-	-	-	-	1
Total	350	484	590	317	55	29	7	6	-	1,838
Conifer evergreen small (CES)										
Pinus edulis	164	146	100	11	1	-	-	-	-	422
Juniperus scopulorum	0	-	2	2	-	-	-	-	-	4
Total	164	146	102	13	1	-	-	-	-	426
Citywide total	4586	5,572	6,787	2,325	722	611	328	345	243	21,519

Appendix B—Replacement Values

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Honeylocust	48,699	298,104	1,661,631	803,347	288,038	172,070	-	78,006	37,743	3,387,639
Modesto ash	42,626	161,473	982,728	518,618	325,705	197,193	134,844	73,635	-	2,436,822
Other	134,670	232,866	434,144	292,588	273,323	180,475	96,685	120,036	52,832	1,817,619
Siberian elm	11,398	44,319	185,288	325,083	726,318	2,237,553	2,415,019	2,984,548	2,312,142	11,241,668
London planetree	15,177	154,800	882,208	1,078,546	516,729	168,429	16,985	-	-	2,832,874
Desert willow	153,312	214,815	156,937	7,180	-	-	-	-	-	532,244
Austrian pine	20,482	162,831	596,334	904,053	202,411	90,148	-	-	-	1,976,259
Green ash	8,268	141,224	527,434	308,839	246,750	87,334	25,728	-	-	1,345,577
Russian olive	5,648	111,500	253,266	281,285	71,392	93,718	5,320	6,870	12,445	841,445
New Mexico olive	110,436	21,324	10,728	-	-	-	-	-	-	142,488
Callery pear	22,067	169,965	500,328	112,947	-	-	-	-	-	805,306
Unknown	66,122	138,142	139,479	73,740	57,687	-	10,503	-	-	485,673
Juniper	29,463	39,510	157,987	166,085	102,867	146,621	54,655	56,070	-	753,259
Scotch pine	2,139	30,375	400,304	662,146	123,328	57,177	17,662	-	-	1,293,131
Apple	33,907	114,957	225,783	122,758	15,726	-	-	-	-	513,130
Purple leaf plum	33,710	67,048	283,748	46,889	16,149	-	-	-	-	447,543
Pinyon pine	19,463	41,925	87,618	21,931	2,185	-	-	-	-	173,122
White ash	17,655	54,104	269,811	168,662	69,621	36,841	-	23,478	-	640,173
Valley cottonwood	1,697	6,000	64,532	148,481	140,983	316,449	358,507	688,127	509,444	2,234,221
Mountain cottonwood	4,270	19,415	103,440	148,544	204,340	450,902	169,683	166,245	54,349	1,321,188
Raywood ash	33,086	73,662	75,827	15,816	12,654	10,282	14,879	-	-	236,204
Ponderosa pine	930	3,451	127,040	469,471	190,134	130,184	16,391	-	-	937,601
Goldenrain tree	8,718	57,530	165,098	64,987	9,295	-	-	-	-	305,627
Chinese pistache	23,926	33,164	86,568	48,831	6,327	-	-	-	-	198,816
Eastern redbud	14,802	39,177	100,891	11,874	6,680	12,779	-	-	-	186,204
Oak	17,005	65,356	30,743	-	-	-	-	-	-	113,104
Spruce	9,138	5,957	51,202	146,255	75,104	29,273	-	-	-	316,929
Japanese pagoda tree	760	6,100	174,583	78,811	14,293	-	-	-	-	274,548
Cottonwood	238	189	5,337	27,634	58,087	155,626	70,645	161,286	363,625	842,666
Arizona sycamore	1,343	5,600	99,370	85,596	21,083	16,169	-	-	41,728	270,888
Black locust	3,567	16,740	45,473	13,325	2,754	4,476	-	13,850	-	100,185
Cherry	2,366	32,593	33,750	4,926	6,682	-	-	-	-	80,318
Pear	786	19,733	31,288	27,390	22,307	-	-	-	-	101,504
Catalpa	643	3,468	46,718	63,493	67,217	28,131	-	17,954	20,052	247,678
Basswood	15,600	3,680	4,430	9,869	5,488	-	-	-	-	39,068
American elm	-	-	-	44,878	74,854	96,032	134,682	212,814	58,983	622,243
Chinese elm	122	6,358	76,027	-	-	-	-	-	-	82,507
Hawthorn	11,355	8,881	1,487	-	-	-	-	-	-	21,724
Chastetree	11,109	2,512	-	-	-	-	-	-	-	13,621
Chitalpa	6,414	4,470	18,794	-	-	-	-	-	-	29,678
Silver maple	362	2,466	17,222	15,827	8,392	25,758	-	-	-	70,028
Norway maple	1,223	3,480	29,032	-	6,551	-	-	-	-	40,286
Arizona cypress	123	-	5,211	35,787	20,876	-	18,420	17,192	-	97,610
Corkscrew willow	231	687	1,545	1,658	1,916	-	-	36,970	17,329	60,336
Kentucky coffeetree	420	3,866	3,521	-	-	-	-	-	-	7,807
Bur oak	2,707	669	-	-	-	-	-	-	-	3,376

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
SW white pine	820	1,623	-	-	-	-	-	-	-	2,442
Western catalpa	-	-	3,615	7,301	11,490	9,377	-	-	-	31,784
Leyland cypress	688	738	-	-	-	-	-	-	-	1,426
Boxelder	1,112	-	-	-	-	-	-	-	-	1,112
Mimosa	-	-	818	8,950	-	-	-	-	-	9,768
Rocky mntn. juniper	-	-	1,161	4,466	-	-	-	-	-	5,627
Mulberry	-	-	-	2,372	-	14,515	10,503	-	-	27,391
Patmore ash	817	-	-	-	-	-	-	-	-	817
Osage orange	-	-	-	-	-	7,258	10,503	-	15,463	33,224
Tree of heaven	-	-	1,111	2,785	-	-	-	-	-	3,896
Shumard oak	419	-	-	-	-	-	-	-	-	419
Deodar cedar	190	-	-	-	-	-	-	-	-	190
Southwestern redbud	171	-	-	-	-	-	-	-	-	171
Chinese hackberry	282	-	-	-	-	-	-	-	-	282
Arizona ash	-	-	1,371	-	-	-	-	-	-	1,371
Marshall ash	-	-	-	-	6,327	-	-	-	-	6,327
Magnolia	173	-	-	-	-	-	-	-	-	173
Afghan pine	105	-	-	-	-	-	-	-	-	105
Limber pine	-	541	-	-	-	-	-	-	-	541
Mountain ash	-	402	-	-	-	-	-	-	-	402
Japanese zelkova	-	243	-	-	-	-	-	-	-	243
Total	952,958	2,628,033	9,162,966	7,384,025	4,012,464	4,774,768	3,581,614	4,657,083	3,496,135	40,649,648

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 the aforementioned outputs.

Growth Modeling

A stratified random sample of 833 park trees, drawn from Albuquerque's municipal tree database, was inventoried to establish relations between tree age, size, leaf area and biomass; subsequently, estimates for determining the magnitude of annual benefits in relation to predicted tree size were derived. The sample was composed of the 20 most abundant species; from these data, growth of all trees was inferred. The species were as follows:

- Desert willow (*Chilopsis linearis*)
- Russian olive (*Elaeagnus angustifolia*)
- White ash (*Fraxinus americana*)
- Raywood ash (*Fraxinus angustifolia*)
- Green ash (*Fraxinus pennsylvanica*)
- Velvet ash (*Fraxinus velutina*)
- Honeylocust (*Gleditsia triacanthos*)
- Goldenrain tree (*Koelreuteria paniculata*)
- Crabapple (*Malus species*)
- Chinese pistache (*Pistacia chinensis*)
- Pinyon pine (*Pinus edulis*)
- Austrian pine (*Pinus nigra*)
- Ponderosa pine (*Pinus ponderosa*)
- Scotch pine (*Pinus sylvestris*)
- London planetree (*Platanus hybrida*)
- Mountain cottonwood (*Populus angustifolia*)
- Valley cottonwood (*Populus fremontii*)
- Cherry plum (*Prunus cerasifera*)
- Callery pear (*Pyrus calleryana*)
- 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 seventy randomly selected trees of each species were selected to survey, along with an equal number of alternative trees. Tree measurements included DBH (to nearest 0.1 cm by sonar measuring device), tree crown and crown base (to nearest 0.5 m by altimeter), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5 m by sonar measuring device), tree condition and location. Replacement trees were sampled when trees from the original sample population could not be located. Tree age was determined by municipal tree managers. Fieldwork was conducted in June 2005.

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. 2001).

Replacement Value

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

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

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

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

$$\text{Replacement value} = \text{Basic value} \times \text{Condition\%} \times \text{Location\%}$$

$$\text{Basic value} = \text{Replacement cost} + (\text{Basic price} \times [TA_A - TA_{R}] \times \text{Species\%})$$

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's longevity, maintenance requirements, and adaptability to the local growing environment (CTLA 1992)

In this study, data from the "ISA, Rocky Mountain Chapter Regional Plant Information" were used to calculate replacement value (ISA Rocky Mountain Chapter 2004). Species rating percentages were the midpoint for the ranges reported. 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 3.14 in^2 for a 2-in caliper tree representing the largest deciduous ornamental commonly available, 4.91 in^2 for a 2.5-in caliper shade tree, and 5.73 in^2 for a 2.7-in caliper conifer; TA_A is calculated using the midpoint for each DBH class. The basic price ranged from \$35 to \$77/in^2 TA, based on the wholesale cost of 2- to 2.5-in caliper deciduous tree. Replacement costs equaled the cost for a 2- to 2.5-in deciduous 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 Albuquerque's municipal trees were estimated for the fiscal year 2005. 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 Albuquerque, there are opportunities to ameliorate the problems associated with hardscape through strategic tree planting and stewardship of existing trees thereby creating street and park landscapes that reduce stormwater runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits.

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

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

Calculating Electricity and Natural Gas Benefits

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate, and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per-tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950–1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same floor area, and other construction characteristics. Shading effects for each of the 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 Albuquerque's climate based on consultation with forestry supervisors and a local nursery representative (Russell and Hart 2006; Angstrom 2006).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to Albuquerque (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 Albuquerque (Ritschard et al. 1992). Building footprints were modeled as square, which was found to reflect 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 Albuquerque were used (National Solar Radiation Data Base 2006). Dollar values for energy savings were based on electricity and natural gas prices of \$0.078844/kWh and \$1.10/therm, respectively (Public Service Company of New Mexico 2006; PNW 2005).

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 approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5–3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% was used here, equivalent to approximately three existing trees per residence.

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

Cooling and heating effects were reduced based on the type and saturation of air conditioning (*Table C2*) or heating (*Table C3*) 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 (Fequipment). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (*Table C2*). Heating loads were con-

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	19	50	80	19	50	80	19	50	80	19	50	80	19	50	80	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	35	27	7	35	27	7	35	27	7	35	27	7	35	27	7	9	9	9
None	46	23	13	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5
Adjusted cooling saturation	28	57	82	28	57	77	28	57	82	28	57	82	28	57	82	88	88	88

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	5.6	8.9	22.9	5.6	8.9	22.9	5.6	8.9	22.9	5.6	8.9	22.9	5.6	8.9	22.9	4.9	4.9	4.9
Heat pump	2.5	4.0	10.4	2.5	4.0	10.4	2.5	4.0	10.4	2.5	4.0	10.4	2.5	4.0	10.4	5.4	5.4	5.4
Adjusted electric heat saturations	1.2	1.9	4.6	1.2	1.9	4.6	1.2	1.9	4.6	1.2	1.9	4.6	1.2	1.9	4.6	1.7	1.7	1.7
Natural gas and other heating saturations																		
Natural gas	48.6	54.3	53.3	48.6	54.3	53.3	48.6	54.3	53.3	48.6	54.3	53.3	48.6	54.3	53.3	89.7	89.7	89.7
Oil	18.9	20.0	0.0	18.9	20.0	0.0	18.9	20.0	0.0	18.9	20.0	0.0	18.9	20.0	0.0	0.0	0.0	0.0
Other	24.3	12.9	13.3	24.3	12.9	13.3	24.3	12.9	13.3	24.3	12.9	13.3	24.3	12.9	13.3	0	0	0
NG heat saturations	92	87	67	92	87	67	92	87	67	92	87	68	92	87	67	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	12.9	44.0	43.1	12.9	44.0	43.1	12.9	44.0	43.1	12.9	44.0	43.1	12.9	44.0	43.1	100	100	100
Tree distribution by vintage and building type	11.3	38.3	37.6	0.5	1.7	1.7	1.1	3.9	3.8	3.8	12.9	12.6	9.1	31.1	30.5	63.0	37.0	100
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	3.05	21.28	29.98	1.14	0.97	1.37	0.27	1.91	2.69	0.76	5.30	7.46	1.01	7.08	9.97	19.4	5.7	0.0
Cooling factor: climate	3.12	21.77	30.67	0.14	0.95	1.34	0.26	1.80	2.53	0.47	3.29	4.64	1.16	8.13	11.45	17.4	34.1	0.0
Combined vintage, equipment saturation for heating																		
Heating factor, natural gas: shade	10.11	32.65	24.47	0.46	1.49	1.12	0.91	2.93	2.20	2.52	8.13	6.09	3.36	10.86	8.14	19.7	5.8	0.0
Heating factor, electric: shade	0.13	0.72	1.69	0.01	0.03	0.08	0.01	0.06	0.15	0.03	0.18	0.42	0.04	0.24	0.56	0.38	0.11	0.00
Heating factor, natural gas: climate	10.35	33.40	25.04	0.26	0.83	0.62	1.01	3.25	2.44	1.49	4.80	3.60	4.09	13.21	9.90	68.0	8.8	0.0
Heating factor, electric: climate	0.13	0.74	1.73	0.00	0.02	0.04	0.01	0.07	0.17	0.02	0.11	0.25	0.05	0.29	0.68	1.30	2.55	0.0

verted to fuel use based on efficiencies in Table C2. The "other" and "fuel oil" heating equipment types were assumed to be natural gas for the purpose of this analysis. Building vintage distributions were combined with adjusted saturations to compute combined vintage/saturation factors for natural gas and electric heating (*Table C3*).

Multi-Family Residence Analysis

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

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

Commercial and Other Buildings

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

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

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

Atmospheric Carbon Dioxide Reduction

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

Carbon dioxide released through decomposition of dead woody biomass varies with characteristics of the wood itself, the fate of the wood (e.g., amount left standing, chipped, or burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. Calculations were conservative because they assumed that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year. Total annual decomposition is based on the number of trees in each species and age class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. Tree mortality for Albuquerque was 8.0% per year for the first five years after planting for street trees and 1.9% every year thereafter (Russell and Hart 2006). Finally, CO_2 released during tree maintenance was estimated to be 1.36 lb CO_2 per inch DBH based on annual fuel consumption of gasoline (~2,000 gal) and diesel fuel (~2,000 gal) (Russell and Hart 2006).

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 Albuquerque. The fuel mix for electrical generation included mainly coal (98.0%) and natural gas (1.8%) (U.S. EPA 2003).

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 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 CO2, again using utility specific emission factors for electricity and heating fuels (US EPA 2003). 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 US EPA (2005 , Table C4), and population estimates from the US Census Bureau (2003).

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

	Emission factor		Implied
	Electricity (lb/MWh)[a]	Natural gas (lb/MBtu)[b]	value[c] ($/lb)
CO_2	940	118	0.00334
NO_2	1.246	0.1020	0.61
SO_2	0.577	0.0006	1.42
PM_{10}	0.240	0.0075	1.14
VOCs	0.061	0.0054	0.19

[a]USEPA 1998, eGRID 2002, except Ottinger et al. 1990 for VOCs
[b]USEPA 1998
[c]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 (2005) and population estimates from the U.S. Census Bureau (2003)

Calculating Deposition and Interception

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of the deposition velocity $V_d = 1/(R_a+R_b+R_c)$, 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 Albuquerque were obtained from insert source and reference. The year 2001 was chosen because data were available and it closely approximated long-term, regional climate records.

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

Calculating BVOC Emissions

Emissions of biogenic volatile organic carbon (sometimes called biogenic hydrocarbons or BVOCs) associated with increased ozone formation were estimated for the tree canopy using methods described by McPherson et al. (1998). In this approach, the hourly emissions of carbon in the form of isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or simply temperature (monoterpene). Annual dry foliar biomass was derived from field data collected in Albuquerque, NM, during June 2005. 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 2001 described in the pollutant uptake section were used as model inputs. Hourly emissions were summed to get annual totals (*Table B4*).

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

Reducing Stormwater Runoff

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

Calculating Stormwater Runoff Reductions

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

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), 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 1998 at the Albuquerque International Airport climate monitoring station (National Oceanic and Atmospheric Administration/National Weather Service, site number: 0234, latitude: 35° 02’ N, longitude: 106° 37’ W, elevation: 5,310 feet) in Bernalillo County, New Mexico, were used in this simulation. The year 1998 was chosen because it most closely approximated the 30-year average rainfall of 9.47 in (240.5 mm). Annual precipitation at Albuquerque during 1998 was 9.83 in (249.7 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).

Albuquerque, NM, spends approximately $11.5 million annually on operations, maintenance, and improvements to its stormwater management system (Hogan 2006). To calculate annual runoff we assigned curve numbers for each land use (USDA SCS 1986). Land use percentages were obtained from the city GIS database. We calculated runoff depth for each land use and found the citywide total to be 0.99 inches (25.1 mm). Given Albuquerque's area of 132.2 sq miles (342.4 km^2), the total annual runoff was 2.3 billion gallons (8,691,007 m^3). The annual stormwater control cost ($11.5 million / 2.3 billion gal) was estimated to be $0.005 per gallon of runoff.

Property Value and Other Benefits

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

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

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

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

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

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

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

Calculating Changes in Property Values and Other Benefits

In an Athens, GA, study (Anderson and Cordell 1988), a large front-yard tree was found to be associated with a 0.88% increase in average home resale values. In our study, the annual increase in leaf surface area of a typical mature large tree (30-year-old white ash, average leaf surface area 3,557 ft2) was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the city of Albuquerque, each large tree would be worth $1,276 based on the 3rd quarter, 2005, meidan single-family-home resale price in Albuquerque ($144,660) (National Association of Realtors 2005). 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 (0.56) 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 Albuquerque by land use. The overall reduction factor for street trees (0.73; 25% of population) was based on reductions of single-home residential (100%), multi-home residential (70%), small commercial (66%), industrial/institutional/large commercial (40%), vacant/other (40%) (Gonzales 2004, McPherson et al. 2001). Trees in parks (75% of population) were assigned a reduction factor of 0.50.

Given these assumptions, a typical large street tree was estimated to increase property values by $0.26/ft^2$ of LSA and a typical park tree by $0.18/ft^2$. For example, it was estimated that a single, street-side white ash added about 240 ft^2 of LSA per year when growing in the DBH range of 12–18 in. Therefore, during this period of growth, white ash trees along streets effectively added $72.21, annually, to the value of an adjacent home, condominium, or business property (240 ft^2x $0.26/$ft^2$ = $62.40). A similar white ash tree growing in a park added $43.20 to the value of an adjacent property.

Estimating Magnitude of Benefits

Resource units describe the absolute value of the benefits of Albuquerque'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 Albuquerque required four steps: (1) categorizing street trees by species and DBH based on the city's street-tree inventory, (2) matching other significant species with those that were modeled, (3) grouping remaining "other" trees by type, and (4) applying resource units to each tree.

Categorizing Trees by DBH Class

The first step in accomplishing this task involved categorizing the total number of street trees by relative age (as a function of DBH class). The inventory was used to group trees into the 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 white ash citywide in the 30–36 in DBH class. The interpolated electricity and natural gas resource unit values for the class midpoint (33 in) were 435.9 kWh and 790.1 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: 130,770 kWh of electricity saved and 237,030 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 >40 ft, 25–40 ft, and <25 ft in mature height, respectively. A typical tree was chosen to represent each of the above 15 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = White ash (*Fraxinus americana*)
BDM Other = Raywood ash (*Fraxinus angustifolia*)
BDS Other = Golden rain tree (*Koelreuteria paniculata*)
BEL Other = Blue gum eucalyptus (*Eucalyptus globulus*)
BEM Other = Coolibah tree (*Eucalyptus microtheca*)
BES Other = American holly (*Ilex opaca*)
CEL Other = Ponderosa pine (*Pinus ponderosa*)
CEM Other = Austrian pine (*Pinus nigra*)
CES Other = Pinyon pine (*Pinus edulis*)
PEL Other = Canary Island date palm (*Phoenix canariensis*)
PEM Other = Date palm (*Phoenix dactilyfera*)
PES Other = Mexican fan palm (*Washingtonia robusta*)

When local data were not measured for certain categories (e.g., CES, PEL), growth data from similar-sized species in a different region were used.

Calculating Net Benefits And Benefit–Cost Ratio

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

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

Net Benefits and Costs Methodology

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

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

Equation 3

where

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

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

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

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

p = price of aesthetics = annual increase in property value

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

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

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. Environmental Protection Agency.; 26 p.

Alden, H.A. 1995. **Hardwoods of North America.** USDA Forest Service, FPL General Technical Report No. 83. Madison, WI. 136 p.

Alden, H.A. 1997. **Softwoods of North America.** USDA Forest Service, FPL General Technical Report No. 102. Madison, WI. 151 p.

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

Angstrom, B. 2006. Personal communication. Osuna Nursery, Albuquerque, NM.

Benjamin, M.T. and A.M. Winer. 1998. **Estimating the ozone-forming potential of urban trees and shrubs.** Atmos. Environ., 32:53-68.

Chandler, T.J. 1965. **The Climate of London.** London, Hutchinson.

Clark, J.R., N.P. Matheny, G. Cross and V. Wake. 1997. **A model of urban forest sustainability**. J. Arboric. 23(1):17-30.

CO2e.com. 2005. **Market Size and Pricing**. Accessed via the World Wide Web <http://www.co2e.com/stratagies/AdditionalInfo.asp?PageID=273#1613> on September 8, 2005.

CTLA (Council of Landscape & Tree Appraisers). 1992. **Guide for Plant Appraisal (8th ed.)**. International Society of Arboriculture, Champaign, IL. 103p.

Costello, L. and Jones, K. 2003. **Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies.** Western Chapter International Society of Arboriculture, Cohasset, CA.

Cullen, S. 2000. **Tree appraisal: What is the trunk formula method (9th edn.)?** Arboric. Consult. 30(5):3.

Cullen, S. 2002. **Tree appraisal: Can depreciation factors be rated greater than 100%?** J. Arbor. 28(3):153-158.

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

Forschler, B.T. 2002. The Formosan Subterranean Termite. Accessed via the World Wide Web http://www.gaipm.org/factsheets/formosan.html on April 26, 2002.

Hammond J., J. Zanetto and C. Adams. 1980. **Planning Solar Neighborhoods.** California Energy Commission.

Heisler, G.M. 1986. **Energy savings with trees.** J. Arboric. 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.

Hogan, D. 2006. Personal communication. Manager, Hydrology Division, City of Albuquerque, 24 March 2006.

Hull, R.B. 1992. **How the public values urban forests.** J. Arboric. 18(2):98-101.

ISA Rocky Mountain Chapter. 2004. **Regional Plant Information**. ISA Rocky Mountain Chapter, Denver CO.

Kaplan, R. 1992. **Urban Forestry and the Workplace.** In P.H. Gobster (Ed). Managing Urban and High-Use Recreation Settings. USDA Forest Service, General Technical Report NC-163. Chicago, IL: North Central Forest Experimentation Center.

Kaplan, R. and S. Kaplan. 1989. T**he Experience of Nature: A Psychological Perspective.** Cambridge University Press, Cambridge, UK.

Lewis, C.A. 1996. **Green Nature/Human Nature: The Meaning of Plants in Our Lives**. University of Illinois Press, Chicago, IL.

Maco, S.E. and E.G. McPherson. 2002. **Assessing canopy cover over streets and sidewalks in street tree populations**. J. Arboric. 28(6):270-276.

Maco, S.E. and E.G. McPherson. 2003. **A practical approach to assessing structure, function, and value of street tree populations in small communities.** J. Arboric. 29(2):84-97.

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

McPherson, E. G. 1984. **Planting design for solar control, chapter 8**. In: Energy Conserving Site Design, Am. Soc. Landscape Archit., Washington, D.C. p.141-164.

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. and S. Mathis (Eds.) 1999. **Proceedings of the Best of the West Summit.** Western Chapter, International Society of Arboriculture: Sacramento, CA: 93 p.

McPherson, E.G. and J. Muchnick. 2005. **Effects of street tree shade on asphalt concrete pavement performance**. J. Arbor. 31(6):303–310.

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

McPherson, E.G. and J.R. Simpson. 1999. **Guidelines for Calculating Carbon Dioxide Reductions Through Urban Forestry Programs**. USDA Forest Service, PSW General Technical Report No. 171, Albany, CA.

McPherson, E.G. and J.R. Simpson. 2002. **A comparison of municipal forest benefits and costs in Modesto and Santa Monica, California, USA**. Urban For. Urban Green. 1(2002):61-74.

McPherson, E.G. and Q. Xiao. 2004. **A Storm Runoff Model for the Trust for Public Land's "What is a Park Worth?" Project.** Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station 12 pp.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Xiao, Q. 1999b. **Benefit-cost analysis of Modesto's municipal urban forest**. J. Arboric. 25(5):235–248.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Xiao, Q. 2001. **Tree Guidelines for Inland Empire Communities**. Western Center for Urban Forest Research and Education, USDA Forest Service: Davis, CA.

McPherson, E.G., J.R. Simpson, Q. Xiao, P.J. Peper, S.E. Maco. 2003. **Benefit–Cost Analysis of Fort Collins' Municipal Forest.** Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Gardner, S.L.; Vargas, K.E.; Ho, J.; Maco, S.; Xiao, Q. 2004a. **City of Bismarck, North Dakota, Street Tree 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. 2004b. **City of Cheyenne, Wyoming, Municipal Tree Resource Analysis**. Internal Tech. Rep. Davis, CA: U.S. Department of Agriculture, Forest Service.

McPherson, E.G., J.R. Simpson, P.J. Peper, S.E. Maco, Q. Xiao. 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.; Gardner, S.L.; Vargas, K.E.; Ho, J.; Maco, S.; Xiao, Q. 2005b. **City of Charlotte, North Carolina, 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.; 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.

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Maco, S.; Gardner, S.L.; Cozad, S.K.; Xiao, Q. 2005d. **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.; Gardner, S.L.; Vargas, K.E.; Ho, J.; Xiao, Q. 2005e. **City of Berkeley, California, 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.; 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.

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

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

National Association of Realtors. 2005. Accessed via the World Wide Web <http http://www.realtor.org/Research.nsf/files/REL05Q3T.pdf/> February 2005.

National Solar Radiation Data Base (1961–1990). 2006. Downloadable from the World Wide Web at <http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/>. Last accessed 15 June 2006.

Ottinger, R.L.; Wooley, D.R.; Robinson, N.A.; Hodas, D.R.; Babb, S.E. 1990. E**nvironmental Costs of Electricity.** Pace University Center for Environmental Legal Studies, Oceana Publications, Inc. New York.

Parsons, R., L.G. Tassinary, R.S. Ulrich, M.R. Hebl and M. Grossman-Alexander. 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 Rev. Pub. Policy 19(3):362–384.

Peper, P.J. and E.G. McPherson. 2003. **Evaluation of four methods for estimating leaf area of isolated trees**. Urban Forestry and Urban Greening 2:19-30.

Peper, P.J., E.G. McPherson and S.M. Mori. 2003. E**quations for predicting diameter, height, crown width, and leaf area of San Joaquin Valley street trees**. Journal of Arboriculture (27(6):306-317.

Pillsbury, N.H.; Reimer, J.L.; Thompson R.P. 1998. **Tree Volume Equations for Fifteen Urban Species in California. Tech. Rpt. 7**. Urban Forest Ecosystems Institute, California Polytechnic State University; San Luis Obispo, CA. 56 p.

Platt, R.H., R.A Rowntree and P.C. Muick, eds. 1994. **The Ecological City**. Boston, MA, Univ. of Massachusetts. 292 p.

PNW. 2005. Rising October Natural Gas Price Underscores Importance of Weatherizing Now. News release, accessed via the World Wide Web <http://www.pnm.com/news/2005/0929_gas.htm> on 15 June 2006.

Public Service Company of New Mexico. 2006. **Public service company of New Mexico Electric Services, 14th revised rate No. 1a.** Accessed via the World Wide Web at < http://www.pnm.com/regulatory> on 15 June 2006.

Renewable Resource Data Center. 2005. **National Solar Radiation Data Base Typical Year Data**. Accessed via the World Wide Web <http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/> November 2004.

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

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

Russell, M and J. Hart. 2006. Personal communication. Foresters, Open Space Division, Parks & Recreation Department, City of Albuquerque, NM.

Ryan, K-L, and M. Wood. 2006. **50 Smart Places to Live.** Accessed via the World Wide Web at http://www.kiplinger.com/personalfinance/features/archives/2006/05/intro.html on 1 June 2006.

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

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

Scott, K.I., J.R. Simpson, and E.G. McPherson. 1999. **Effects of tree cover on parking lot microclimate and vehicle emissions**. J. Arbor. 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. and E.E. Kuo. 1996. **Do trees strengthen urban communities, reduce domestic violence?** Arborist News. 5(2):33-34.

Ter-Mikaelian, M.T. and M.D. Korzukhin. 1997. **Biomass equations for sixty-five North American tree species**. For Ecol and Management 97: 1-24.

Thompson, R.P. and J.J. Ahern. 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. and A. Manthe. 1999. **Skin cancer prevention: another good reason to plant trees**. In McPherson, E.G. and Mathis, S. Proceedings of the Best of the West Summit. University of California, Davis, CA.

Tritton, L.M. and J.W. Hornbeck. 1982. **Biomass Equations for Major Tree Species of the Northeast**. USDA Forest Service, NE General Technical Report No. 69. Broomall, PA. 46 p.

Urban Forest Master Plan for Parks and Recreation Facilities. 2005. Prepared by Sites Southwest, Albuquerque, NM.

U.S. Census Bureau. 2003. 2**003 Population Estimates, Census 2000, 1990**. Accessed via the World Wide Web <http://www.census.gov/population/cen2000/phc-t29/tab06.pdf> on August 18, 2005.

U.S. Department of Agriculture, Soil Conservation Service. 1986. **Urban Hydrology for Small Watersheds**. Technical Release No. 55, 2nd edition. Washington, D.C.

U.S. Environmental Protection Agency. 1998. **Ap-42 Compilation of Air Pollutant Emission Factors (5th Edition). Volume I.** Research Triangle Park, NC.

U.S. Environmental Protection Agency. 2003. **E-GRID** (E-GRID2002 Edition).

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

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

Watson, G. 2002. **Comparing formula methods of tree appraisal.** J.Arbor. 28(1):11-18.

WC-ISA. 2004. **Species Classification and Group Assignment.** Western Chapter, International Society of Arboriculture. Cohasset, CA.

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., E.G. McPherson, J.R. Simpson and S.L Ustin. 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. W**inter rainfall interception by two mature open grown trees in Davis, California**. Hydrological Processes 14(4):763-784.

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Center for Urban Forest Research
Pacific Southwest Research Station, USDA Forest Service
1 Shields Avenue, Suite 1103 • Davis, CA 95616-8587
(530) 752-7636 • Fax (530) 752-6634 • http://cufr.ucdavis.edu/