City of Glendale, Arizona
Municipal Forest Resource Analysis

E. Gregory McPherson, James R. Simpson, Paula J. Peper, Scott E. Maco, Qingfu Xiao

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Executive Summary

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Municipal Forest Resource Analysis

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Street trees in Glendale are managed by the city's Right of Way/Streets (ROW/S) Department, while park trees are maintained by the Parks and Recreation Department. Over the years Glendale has invested millions in its municipal forest. The primary question that this study asks is *whether the accrued benefits from Glendale's street and park trees justify the annual expenditures?*

This analysis combines results of an updated 1998 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 recommendations (sustainability, pruning, planting)

Resource Structure

- Based on the updated inventory there were 21,480 trees in Glendale, 13,184 street trees and 8,297 park trees. There is about one public tree for every resident.
- There are relatively few opportunities to increase the resource. Only 2% (429) of all street tree-planting sites were unplanted.
- Citywide, the resource represented 104 different tree species, a sizable number. The tree population is diverse, however, Chinese elm comprises 11% of the total, and exceeds the 10% guideline for a single species.
- Having the greatest numbers and leaf area, Chinese elm and Arizona ash were the most important species in Glendale, comprising 18 % of total tree numbers and 13% of total leaf area.
- The tree population is predominantly characterized by young and small trees, that should eventually produce many benefits. These trees represent a focused effort in recent years to increase tree numbers.
- Because of the intensive management that Glendale's trees receive they are quite healthy. Ninety-one percent were in fair, good, or excellent condition and only 2% were dead or dying.
- Only 3% of the inventoried population required maintenance, with staking/training of small trees the most frequent activity needed.
- There were very few conflicts between tree crowns and powerlines or tree roots and sidewalks.

Resource Function and Value

- Because of Glendale's hot summer conditions, air conditioning savings from trees were higher than those found in more temperate locations. Electricity and natural gas saved annually from both shading and

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climate effects totaled 925 MWh and 531 Mbtu, respectively, for a total retail savings of $116,728 ($5.43/tree).

- The ability of Glendale's municipal trees to intercept rain—thereby avoiding stormwater runoff—was estimated at 1 million gallons annually, providing a substantial environmental benefit to the community. The total annual value of this benefit was $37,298 ($1.74/tree).

- Annual net air pollutant uptake by tree foliage (pollutant deposition and particulate interception, plus avoided power plant emissions, minus BVOC emissions) was 2,503 lb. The total annual value of this benefit for all trees was $32,572, or about $1.52/tree. Blue palo verde ($3.46/tree), Arizona ash ($2.14/tree), and Chilean mesquite ($2.07/tree) provide the greatest air quality benefits.

- Citywide, municipal trees sequestered 340 tons of the greenhouse gas carbon dioxide. The same trees offset an additional 462 tons through reductions in energy plant emissions. Total savings were valued at $12,039 ($0.56/tree) annually.

- The estimated total annual benefit associated with property value increases and other less tangible benefits was $467,213 or $21.75/tree on average. Coolibah gum ($56/tree) and Aleppo pine ($54/tree) averaged the greatest benefits, while the palms averaged the least benefits due to their relatively slow growth.

- Overall, annual benefits were determined largely by tree size, where large-stature trees typically produced greater benefits. For example, in parks average annual benefits were most for Eucalyptus ($68/tree), Aleppo pine ($53/tree), and Mulberry ($53/tree). Benefits were least for the Mexican fan palm ($4/tree), Live oak ($6/tree, most are young), and California palm ($8/tree).

- The municipal tree resource of Glendale is a valuable asset, providing approximately $665,850 ($31/tree) in total annual benefits to the community. The city currently spends approximately $276,436 annually, or $13/tree on their care. Net annual benefits totaled $389,415, or $18/tree and $1.77/capita.

- Over the years Glendale has invested millions in its municipal forest. That investment is bearing fruit. Citizens are now receiving a relatively large return on that investment – $2.41 in benefits for every $1 spent on tree care. Because of the preponderance of young trees, the municipal forest is poised to generate an even greater return. Continued management is critical to insuring that the community increases its return on investment into the future.

Resource Management Needs

- Use the street tree inventory as a tool for assessing long-term adaptability of new species, particularly medium- and large-stature species, through regular re-evaluations of tree condition and relative performance. This will assist in determining which species to include in a long-term planting program.

- Develop a long-term plan to achieve resource sustainability. This requires increasing diversity of the street tree population by balancing new plantings of proven, long-lived species with successful, newer introductions. This plan should address:

  - Tree removal and replacement for senescent populations.

  - Planting available large-tree sites first, followed by those allowing medium and small trees.

  - Focus planting efforts along streets and in zones where stocking levels are lowest to improve the distribution of benefits provided to all neighborhoods.

  - Emphasize annual pruning of young trees for structure and form to reduce mature tree care costs.

- Phase-out palms, which are costly to maintain relative to the small benefits they produce.

- Tree health was good and pruning and removal needs were minimal. Efficiency might be bolstered by developing species-specific pruning cycles that target inspection/pruning work on those species and age classes that require the most intensive care.

Glendale’s municipal forest is a dynamic resource. Managers of this resource and the community alike can delight in knowing that their street and park trees do improve the quality of life in Glendale, but they are also faced with a fragile resource in need of constant care to maximize and sustain these benefits through the foreseeable future. The challenge will be to maximize net benefits over the long-term, thereby perpetuating a resource that is both functional and sustainable.

Chapter One—Introduction

City of Glendale, Arizona Municipal Forest Resource Analysis

The City of Glendale believes that the public's investment in stewardship of Glendale's urban forest produces benefits that outweigh the costs to the community. Glendale, incorporated in 1910, is an active economic, cultural and political center for the state. The population has grown rapidly during the past twenty years to 220,000. Current community goals include maintaining and enhancing quality of life while continuing to pursue economic progress.

Research indicates that healthy city trees can mitigate impacts of development on air quality, climate, energy for heating and cooling buildings, and stormwater runoff. Healthy street trees increase real estate values, provide neighborhoods with a sense of place, and foster psychological well-being. Street trees are associated with other intangibles such as increased community attractiveness and recreational opportunities that make Glendale a more enjoyable place to work and play. Glendale's urban forest creates a setting that helps attract tourism and retain businesses and residents.

Glendale's Right of Way/Street Division manages approximately 13,183 street trees in six tree management zones located throughout the city. Street trees are identified as those growing in the City right-of-way area behind the curb. Parks and Recreation manage 8,297 park trees. The total municipal forest consists of 21,479 trees for the purpose of this report.

In an era of dwindling public funds and rising expenditures, residents and elected officials often scrutinize expenditures that are considered "non-essential" such as planting and management of the municipal forest. Hence, the primary question that this study asks is *whether the accrued benefits from Glendale's municipal forest justify the annual expenditures?*

In answering this question, information is provided to:

1. Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for this city's urban forest.
2. Provide critical baseline information for the evaluation of program cost-efficiency and alternative management structures.
3. Highlight the relevance and relationship of Glendale's municipal tree resource to local quality of life issues such as environmental health, economic development, and psychological health.
4. Provide quantifiable data to assist in developing alternative funding sources through utility purveyors, air quality districts, federal or state agencies, legislative initiatives, or local assessment fees.

This report consists of seven chapters and five appendices:

Chapter One—Introduction: Describes purpose of the study.

Chapter Two—Describes the current structure of the street tree resource.

Chapter Three—Details management expenditures for publicly and privately managed trees.

Chapter Four—Benefits of Glendale Municipal Trees: Quantifies estimated value of tangible benefits and calculates net benefits and a benefit-cost ratio for each population segment.

Chapter Five—Management Implications: Evaluates relevancy of this analysis to current programs and posits management challenges.

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

Chapter Seven—References: Lists publications cited in the study and the contributions made by various participants not cited as authors.

Chapter Two—Glendale's Municipal Tree Resource

City of Glendale, Arizona
Municipal Forest Resource Analysis

History and Current Management

Initially established as the terminus of the 44-mile long Arizona Canal in 1885, Glendale grew from a utopian colony to a diverse and progressive community. A flood of immigrants in the early 20th century helped spur agricultural development. In 1941, the construction of Luke Air Force Base and Thunderbird Field brought thousands of airman, along with jobs and residents, to the area. During the past 50 years the city grew rapidly, its size increasing from six to 59 square miles. Glendale today is the region's major industrial and commercial center, and home to two major league sports teams.

Glendale has an active tree management program that promotes tree planting and stewardship throughout the community. It has received Tree City USA recognition annually since 1996. In 2003 Right of Way/Streets (ROW/S) employed 9 full time staff to manage and maintain municipal street trees and Parks and Recreation (PR) employed 25 staff to maintain parks. Together, the Departments are responsible for the management and maintenance of all trees, turf, and other landscape vegetation on all public properties.

Tree maintenance on street right-of-ways is conducted on a six-month rotation by ROW/S and contract crews. About 75-100 trees are planted annually, primarily to replace removed trees. Additionally, ROW/S provides education programs and other information for citizens, conducts tree inspections on residential lots, and provides planning and planting advice for new tree installations. ROW/S also provides citizens with information on Glendale trees, tree care, ordinances, and current issues affecting the urban forest.

PR maintains trees on park lands, inspecting/pruning young trees on a six-month cycle, and large trees on an annual cycle. They plant over 100 trees annually to replace trees that are removed. Vandalism is one of the greatest threats to park trees, and damaged trees are quickly treated or replaced.

Glendale's park and street tree inventory was completed in 1998 and serves as the basis for this assessment. Because the inventory was not regularly updated, the street tree inventory was increased by approximately 4,200 trees to account for new plantings in excess of removals since 1998 (Rodriguez and Wilkinson 2004). Lacking data from planting records, species of new outplants were assumed to be proportional to their numbers in the smallest two size classes. These new plantings were located in a hypothetical zone 7.

On average, about 100 trees were removed from city streets and 100 from city parks annually. A similar number of street and park trees were planted in 2003, most as replacements. Glendale has 6 major tree management zones. The zones are:

- Zone 1 = Barrel
- Zone 2 = Cactus
- Zone 3 = Cholla
- Zone 4 = Ocotillo
- Zone 5 = Sahuaro
- Zone 6 = Yucca

Tree Numbers and Stocking

For the purpose of this report, there were 13,184 street trees and 8,297 park trees in Glendale, for a total of 21,480 public trees (Table 1). Zone 3 contained the most trees and Zone 2 contained the least. Assuming Glendale's human population was 220,000 (City-data.com 2004), there was about one public tree for every ten residents. Calculations of trees per capita are important in determining how well forested a city is. The more residents and greater housing density a city possesses, the more need for trees to provide benefits. Glendale's ratio of street trees per capita was 0.01, considerably lower than the mean ratio of 0.37 reported for 22 U.S. street tree populations (McPherson and Rowntree 1989).

There were only 429 available planting sites (APS); thus, 98% of all street tree planting sites were planted. Stocking levels ranged from 96% to 99%

Table 1. Street and park tree numbers by zone (trees listed in Zone 7 are newly planted street trees whose Zone locations were unknown). APS is available planting sites.

					Streets + Parks		
Zone	# of Street Trees	# of Park Trees	Total Trees	% of Total Trees	# of APS	Total # of Sites	Stocking %
1	1,123	2,086	3,209	14.9	57	3,266	98.3
2	765	609	1,374	6.4	15	1,389	98.9
3	2,346	2,045	4,391	20.4	179	4,570	96.1
4	1,493	879	2,372	11.0	58	2,430	97.6
5	1,851	1,920	3,771	17.6	52	3,823	98.6
6	1,415	758	2,173	10.1	68	2,241	97.0
7	4,190	-	4,190	19.5	-	4,190	100.0
Citywide Total	13,183	8,297	21,480	100.0	429	21,909	98.0

among zones. Hence, nearly all of the inventoried street tree sites were filled with trees. Empty planting sites for parks were not reported in the inventory. Low numbers of trees per capita but relatively high stocking levels may be due to the fact that street tree planting is limited to major streets and boulevards. City code requires one tree and three shrubs every 30 feet of street. Lower per capita tree numbers are characteristic of desert cities, where extreme aridity limits canopy cover.

Medium-stature (30-50-ft tall at maturity) deciduous and broadleaf evergreen trees composed 47% of Glendale's public tree population (Table 2). Small-stature trees (29%, <30-ft tall) were more abundant than large-stature trees (24%, >50-ft tall). Large-stature conifers were most prevalent in parks. Conifers accounted for 12% of the trees, and 10% were palms.

Table 2. Citywide public tree numbers by mature size class and tree type.

Tree Type	Large	Med	Small	Total
Broadleaf Decid.	3.6	29.0	6.1	38.7
Broadleaf Evergrn	5.7	17.5	15.6	38.8
Conifer	12.4	-	0.0	12.4
Palm	2.3	0.3	7.4	10.1
Totals	24.0	46.9	29.1	100.0

Species Composition and Richness

The predominant tree species (Table 3) were Chinese elm (*Ulmus parvifolia*) and Arizona ash (*Fraxinus velutina*), representing 19% of all trees (11% and 8%, respectively). Chinese elm exceeded the customary guideline that no single species should exceed 10% of the population. Although this species is well-adapted to the area, it should not be planted as frequently in the future to reduce risk of catastrophic loss from insect pests, disease, or drought.

Species composition in parks has shifted from broadleaf deciduous trees like ash and mulberry planted in flood- or sprinkler-irrigated turf to mesquite and other arid-adapted species planted in decomposed granite and drip-irrigated. Also, a ban on flowering mulberry and olives due to their pollen that exacerbates allergies has limited their numbers.

There were a total of 104 different tree species in the tree inventory database. This is roughly double the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey of street tree populations in 22 US cities. The unusual richness of tree species in Glendale stems from the benign climate, where with adequate water a wide variety of subtropical and temperate species thrive.

In most zones, Chinese elm or Arizona ash were the most prevalent species (Table 4). Mexican fan palm (*Washingtonia robusta*) and California palm (*Washingtonia filifera*) were common species in Zone 2. Mondel pine (*Pinus eldarica*) were common is Zones 3, 5 and 7.

Importance Value

Importance values are particularly meaningful to managers because they express the degree a city depends on particular urban trees insofar as their benefits are concerned. This evaluation takes into account not only total numbers, but their size and age, here indicated by leaf area.

As a mean of two relative values, importance values (IVs), in theory, can range between 0 and 100; where an IV of 100 suggests total reliance on one species and an IV of 0 suggests no reliance. The 23 species listed in Table 3 constituted 80% of the total IV.

Table 3. Species abundance (listed in order by percent of total trees) and importance values calculated as the mean of tree numbers and leaf area proportions for the top 1% of all trees.

Species	# of trees	% of Total Trees	Leaf Area (ft2)	% of Total Leaf Area	IV
Chinese elm	2,361	11.0	1,063,609	8.2	9.6
Arizona ash	1,615	7.5	586,423	4.5	6.0
Mondel pine	1,459	6.8	453,714	3.5	5.1
Carob	1,267	5.9	211,739	1.6	3.8
Willow acacia	1,218	5.7	1,135,896	8.8	7.2
Mexican fan palm	1,111	5.2	640,094	4.9	5.1
Citrus spp.	1,060	4.9	338,414	2.6	3.8
Live oak	1,006	4.7	363,571	2.8	3.7
Olive	770	3.6	404,140	3.1	3.4
Aleppo pine	688	3.2	205,479	1.6	2.4
Blue palo verde	662	3.1	600,053	4.6	3.9
Date palm	599	2.8	916,299	7.1	4.9
Coolibah gum	527	2.5	341,854	2.6	2.5
California palm	512	2.4	367,659	2.8	2.6
Evergreen ash	499	2.3	183,952	1.4	1.9
African sumac	487	2.3	234,226	1.8	2.0
Sweet acacia	484	2.3	178,890	1.4	1.8
Chinese pistache	464	2.2	131,974	1.0	1.6
Eucalyptus spp.	400	1.9	171,433	1.3	1.6
White mulberry	302	1.4	41,698	0.3	0.9
Feather tree	268	1.2	622,535	4.8	3.0
Bottle tree	238	1.1	537,559	4.2	2.6
Jeruselum thorn	233	1.1	90,102	0.7	0.9
Total for top 1% all trees	18,230	84.9	10,144,420	78.4	80.4

Table 4. Top five species listed in order by percent (in parentheses) of total zone tree numbers.

Zone	Total	1st	2nd	3rd	4th	5th
1	3,209	Citrus Species (19.7)	Arizona Ash (12.9)	Willow Acacia (6.4)	California Palm (5.6)	Live Oak (5.5)
2	1,374	Mexican Fan Palm (20.2)	Arizona Ash (10.9)	Chinese Elm (7.9)	California Palm (7.9)	Aleppo Pine (7.1)
3	4,391	Mondel Pine (11.2)	Chilean Mesquite (11)	Willow Acacia (8)	Coolibah Gum (6.5)	Blue Palo Verde (6.1)
4	2,372	Chinese Elm (19.8)	Arizona Ash (10.1)	Mexican Fan Palm (5.5)	Indian Laurel Fig (4.7)	Italian Cypress (4.6)
5	3,771	Chinese Elm (12.5)	Mondel Pine (9.5)	Willow Acacia (7)	Mexican Fan Palm (6.1)	Olive (4.9)
6	2,173	Olive (8.9)	Chilean Mesquite (7.8)	Live Oak (7.8)	Chinese Elm (6.5)	Arizona Ash (5.4)
7	4,190	Chinese Elm (21.5)	Live Oak (12)	Willow Acacia (11)	Mondel Pine (9.8)	Olive (9)
Total	21,480	Chinese Elm (10.8)	Mondel Pine (7.4)	Willow Acacia (6.7)	Live Oak (5.8)	Arizona Ash (5.6)

They accounted for 85% of the municipal tree population in Glendale and 78% of the leaf area. Therefore, these species represent the bulk of the population. Species with the highest IVs were Chinese elm (9.6), Willow acacia (7.2) (*Acacia salicina*), and Arizona ash (6.0). Relative numbers and leaf areas for these species were consistent. However, carob for example, comprised 5.9% of the population, but only 1.6% of total leaf area. As a result, their IV is 3.8, indicating that benefits produced may be less than suggested by their numbers alone.

The relatively even distribution of importance values among species indicates that Glendale is not heavily reliant on only a few species for the majority of the environmental benefits associated with municipal trees. This is desirable for long-term stability of the population, and benefits the trees produce.

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 assure continuity in overall tree canopy cover. An "ideal" distribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

Age curves for different tree species help explain their relative importance and suggest how tree management needs may change as the populations continue to age. Figure 1 compares the "ideal" age distribution with Glendale's age structure for all species citywide, as well as the 10 predominant species. What stands out is how few older, large-diameter trees were present. With the exception of Mexican fan palm, Citrus (*Citrus spp*.), Olive (*Olea europaea*), and Arizona ash, the Glendale street and park tree populations consisted of relatively young and small trees. The age structure of public trees in Glendale differed from the "ideal" distribution by containing an overabundance of young and small-stature trees. This suggests that the continued health and welfare of the population is linked to the future survival and ultimate size of these species. Also, it suggests that if these small trees mature into larger trees, benefits could increase significantly from those presented in this report. One future challenge will be increasing the taxonomic and age diversity among large-stature trees.

Tree Condition

Tree condition indicates both how well trees are managed and their relative performance given site-specific conditions. Based on our sample of 819 trees, 63% were in good to excellent condition with an additional 28% in fair condition (Figure 2 and Table 5). Six percent of the trees were in poor condition, and 2% were dead or dying.

Typically, the relative performance index (RPI) of each species provides an indication of their suitability to local growing conditions, as well as their performance. It is calculated for each species by dividing its proportion of all trees rated as good or excellent by the percentage of all trees rated as good or excellent. For example, the RPI for Live oak (*Quercus virginiana*) was 1.41 because 88.9% were good or excellent compared to 62.9% of all trees citywide rated good or excellent (88.9/62.9 = 1.41). Species with RPIs greater than 1.0 have proportionately more individuals classified as good or excellent (Table 5). Species with RPIs greater than 1.0 are likely to be better adapted to Glendale's climate and site conditions, requiring fewer management inputs than species with values less than 1.0.

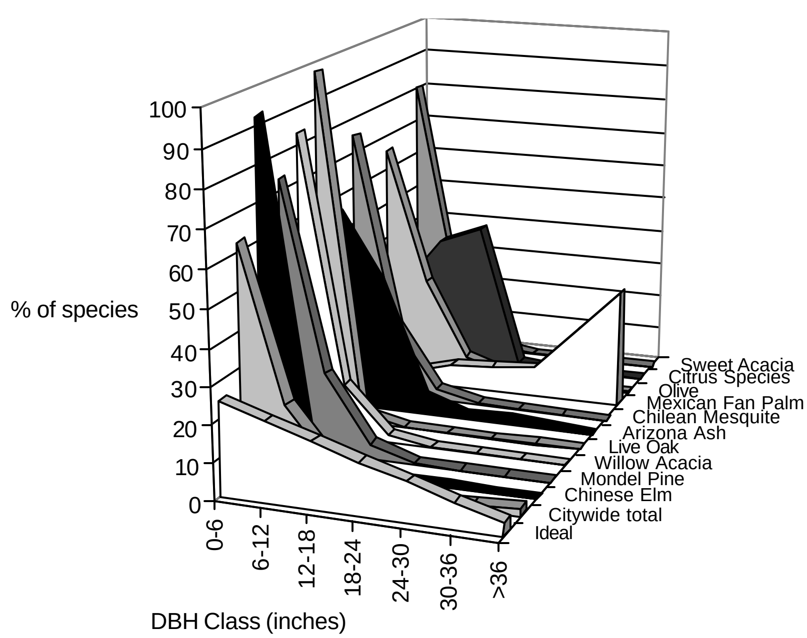

Figure 1. The distribution of common species by size reflects age diversity. Compared to the ideal distribution, Glendale has a preponderance of small, young trees.

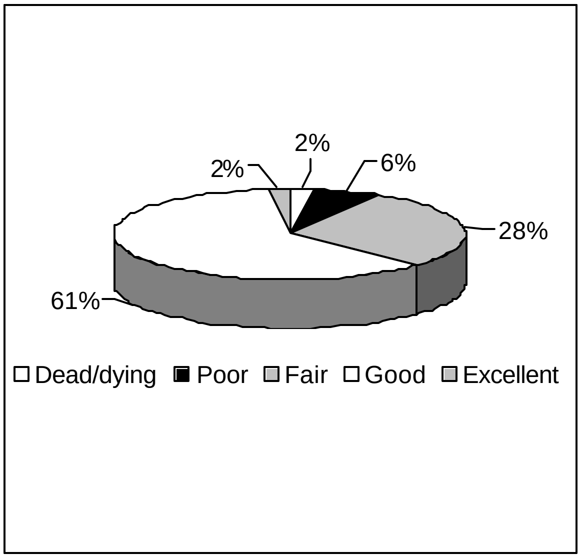

Figure 2. Citywide distribution of street and park trees by condition class.

Table 5. Condition (%) and relative performance index (RPI) of Glendale's municipal tree population.

	% of Trees in Each Condition Class				
Common Name	Dead/dying	Poor	Fair	Good/Excellent	RPI
Live Oak	-	-	11.1	88.9	1.41
California palm	-	-	18.3	81.7	1.30
Bottle tree	-	8.8	11.8	79.4	1.26
Chinese elm	-	-	22.9	77.1	1.23
Mexican Fan Palm	-	1.6	22.2	76.2	1.21
Date Palm	-	-	25.0	75.0	1.19
Blue Palo Verde	3.2	-	29.0	67.7	1.08
Coolibah Gum	-	-	34.3	65.7	1.05
Aleppo Pine	-	5.9	29.4	64.7	1.03
African Sumac	-	9.7	25.8	64.5	1.03
Chilean Mesquite	-	3.3	33.3	63.3	1.01
Mondel Pine	6.1	9.1	24.2	60.6	0.96
Sweet Acacia	-	6.7	33.3	60.0	0.95
Evergeen ash	-	26.7	13.3	60.0	0.95
Willow Acacia	8.1	5.4	29.7	56.8	0.90
Olive	5.6	8.3	36.1	50.0	0.80
Chinese pistache	3.1	3.1	46.9	46.9	0.75
Jeruselum thorn	-	9.1	45.5	45.5	0.72
Arizona Ash	10.0	20.0	25.0	45.0	0.72
Mulberry	10.3	10.3	43.6	35.9	0.57
Desert willow	-	12.1	57.6	30.3	0.48

Species rated as having the best performance, overall, were Live oak, California palm, Bottle tree (*Brachychiton populneum*), Chinese elm, Mexican fan palm, Date palm (*Phoenix dactylifera*), and Blue palo verde (*Cercidium floridum*). For the most part, these species were widely adapted to growing conditions throughout the city. However, most of the Live oak and Chinese elm were relatively young, making it difficult to assess their long-term performance. Both Arizona and Evergreen ash had large numbers of trees in the poor, dead, or dying classes. Similarly, Desert willow (*Chilopsis linearis*), Mulberry (*Morus alba*), Jeruselum thorn (*Parkinsonia aculeat*), Chinese pistache (*Pistacia* *chinensis*), and Olive had a high percentage of poor performers compared to other species.

Location

The majority (60%) of the 8,993 street trees in Glendale were located along boulevards, 33% were in planting strips ranging from 4 to 12-ft wide. Only 4% were in cutouts and 3% in medians. Inventory data indicated that 52% of these trees were adjacent to single family residential land uses and others were on commercial/industrial (43%), multi-family residential (3%), and other land uses (2%, institutional, vacant, or agricultural use).

Maintenance Needs

Understanding age structure and tree condition can assist in determining proper pruning cycle length.

The city's recent pruning cycle may be reflected in the actual pruning and maintenance needs of the city trees on a species basis. These needs provide clues to whether or not the pruning cycle is adequate, the level of risk and liability associated with the city's tree population, and the magnitude of future tree care budget requirements.

Maintenance tasks recommended for Glendale trees included planting, staking/training, pruning (clean, raise, reduce), removal, and treat pest/disease. Only 3% of all inventoried trees were assigned maintenance tasks (Table 6). Not surprising given theyoung age of most trees, the majority of these (490) required staking or training. Palm trees accounted for most of the trees requiring staking/training. Sixty trees required pest/disease treatment, and 55 needed crown raising for better visibility and safety. Pecan (*Carya illinoensis*), Arizona ash, Mulberry, and Eucalyptus (*Eucalyptus spp*.) were species most in need of pruning. Only 17 trees, primarily Pecan and Mulberry, needed to be removed. These data suggest that Glendale's intensive inspection and pruning cycle has resulted in a very well-tended urban forest, with minimal needs beyond the scheduled care trees receive.

Conflicts

No sidewalk heaves by tree roots were reported and only 88 tree crowns were too close to powerlines. Mexican fan palm, a tall growing tree, was the species most frequently conflicting with powerlines. The largest number of conflicts (40%) were in Zone 4. Conflicts were less in Zones 1 (22%), 2 (16%), and 6 (14%).

Table 6. The number of trees requiring recommended maintenance by task for each DBH size class.

Task	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total population
Plant	429									429	2.0
Stake/Train	27	18	84	52	36	43	44	36	80	420	2.0
Prune - Clean	-	-	-	2	-	-	1	-	-	3	0.0
Prune - Raise	1	-	10	20	13	9	2	-	-	55	0.3
Prune - Reduce	-	-	1	1	1	-	-	-	1	4	0.0
Remove	-	-	7	5	4	-	-	-	1	17	0.1
Treat Pest/Disease	9	9	25	16	1	-	-	-	-	60	0.3
Totals	466	27	127	96	55	52	47	36	82	988	4.6

Fiscal Year 2002 Program Expenditures

Costs of Managing Public Trees

Costs were based on a review of expenditures during fiscal year 2002. Total annual spending was $276,436 for street and park tree management (Rodriguez and Wilkinson 2004; Van Meeteren 2004). The amount spent on street tree management alone was $220,626 ($16.74/tree), or 80% of the entire budget (Table 7). Of this amount, 89% was for street tree program expenditures incurred by the Right of Way/Streets (ROW/S) Department, and 11% was for expenditures by other departments for green waste disposal and infrastructure repair. Park tree management expenditures totaled $55,810 ($6.73/tree), and all costs were incurred by the Parks and Recreation (PR) Department.

Total annual municipal tree care costs represented 0.06% of the city's total 2002 operating budget ($403 million). Assuming a population of 220,000 and 21,480 trees, total expenditures averaged $1.12/capita and $12.87/tree. The average per tree program expenditure of $11.43 (excludes non-program costs for comparison) was lower than the 1997 mean value of $19/tree reported for 256 California cities (Thompson and Ahern 2000). However, it was higher than the mean expenditure of $4.62/tree for Desert Southwest communities reported in a national municipal tree management survey (Tschantz and Sacamano 1994).

Expenditures fell into three categories: tree planting and establishment, tree care, and administration.

Tree Planting and Establishment

The production of quality nursery stock, its subsequent planting, and follow-up care are critical to perpetuation of a healthy community forest in Glendale. ROW/S and PR each plant about 100 trees per year. Most of these trees are planted to replace removed trees. As new parks and residential developments are built, trees are planted by developers as part of the projects. The city becomes responsible for maintaining these trees. Some additional trees are planted in parks and other public lands by community-minded sponsors that partner

Table 7. Glendale annual expenditures for street and park trees in 2002.

Program Expenditures	Street	Park	Total	$/tree	% program
Pruning	77,620	10,792	88,412	4.12	36.0
Planting	17,600	3,500	21,100	0.98	8.6
Removal & Disposal	10,000	2,710	12,710	0.59	5.2
Inspection	2,118	-	2,118	0.10	0.9
Pest & Disease	-	333	333	0.02	0.1
Administration & Other	70,000	12,950	82,950	3.86	33.8
Irrigation	5,468	22,525	27,993	1.30	11.4
Litter Clean-Up	6,820	3,000	9,820	0.46	4.0
Total Program Expenditures	189,626	55,810	245,436	11.43	100.0

Other Expenditures	Street	Park	Total	$/tree	% total
Liability & Legal	-	-	-	-	0.0
Green Waste & Other	28,000	-	28,000	1.30	10.1
Infrastructure Repairs/Mitigation	3,000	-	3,000	0.14	1.1
Total Other	31,000	-	31,000	1.44	11.2
Total Expenditures	220,626	55,810	276,436	12.87	

with the city to provide funds to assist in purchasing and planting trees. No information was available to determine the amount spent for tree planting by homeowners and through grants from partners. The total annual cost of planting trees was $21,100, about $100/tree.

Approximately 12,000 young trees were inspected and pruned twice annually for structure and form. Young street trees received about 25 gal of water per week by drip irrigation throughout the first several years after planting at a total annual cost of less than $1/tree per. Park trees were watered longer at an average annual cost of $2.73/tree. Total annual watering costs were $27,993. Tree planting and irrigation costs accounted for about 20% of total program expenditures. Because 63% of Glendale's municipal urban forest consisted of trees less than 6-inches DBH, substantial resources were allocated to young tree management.

Tree Care

Approximately 28% of Glendale's public trees were maturing (6-18 inch DBH) and only 9% were mature (over 18-inches DBH), primarily Palms, Eucalyptus, Pine, and Mulberry. About 25% ($69,000) of the 2002 total budget was spent keeping these trees healthy and safe. Inspection, pruning, tree removal, green waste clean-up and infrastructure repair accounted for most of this amount. Approximately $25,000 was spent for programmed pruning. Trees were inspected and pruned as needed annually. Pruning was the largest tree management cost in the city, accounting for 36% ($4.12/tree) of the total per tree expenditures ($16.74/tree). ROW/S and PR each removed about 100 street trees pe year (based on the past 5 years) at a total cost of $12,710 (includes stump removal), or $63.55/tree.

Storms cause trees to topple, branches to fall, and other tree debris to scatter. Cleaning up this litter costs $9,820 annually ($0.46/tree). Without regular pruning and healthy trees, this number could be larger. Pest infestations seldom pose a serious threat to the health and survival of trees in Glendale. The 2002 pest and disease control expenditures totaled $333.

Administration

Approximately 34% of all program expenditures were for administration, totaling $82,950 ($3.86/tree). This item accounted for salaries and benefits of supervisory staff that performed planning and management functions, as well as contract development and supervision.

Other Tree-Related Expenditures External to the Program

Tree-related expenses accrued to the city that were not captured in the ROW/S and PR budgets. These expenditures included sidewalk and curb repair and a wood waste program.

Sidewalk and Curb Repair

Shallow roots that heave sidewalks, crack curbs, and damage driveways are an important aspect of mature tree care. Once problems occur, the city attempts to resolve the problem without removing the tree. Compared to other cities, Glendale spends relatively little on infrastructure repair ($3,000, $0.14/tree). Sidewalk repairs were few because most street trees were planted in wide areas along major streets.

Wood-Waste Disposal

Upon pruning and removal of trees, the city hauled material to the landfill. Landfilling green waste was a substantial cost, $28,000 or $1.30/tree. Budget cuts caused the wood waste recycling center to close, and landfill tipping fees were about $20/ton.

Chapter Four—Benefits of Glendale Municipal Trees

City of Glendale, Arizona
Municipal Forest Resource Analysis

Introduction

Estimates of benefits and costs are initial approximations—as some benefits and costs are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). Also, limited knowledge about the physical processes at work and their interactions make 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 and benefits and costs depend on the specific conditions at the site (e.g., tree species, growing conditions, maintenance practices). Therefore, this method of quantification was not intended to account for every benefit or be accurate to the penny. Rather, this approach gives a general accounting of the benefits produced by municipal trees in Glendale; an accounting with an accepted degree of uncertainty that can nonetheless, provide a platform on which decisions can be made (Maco and McPherson 2003). Methods used to quantify and price these benefits are described in Appendix A.

Energy Savings

Trees modify climate and conserve building-energy use in three principal ways:

1. Shading—reduces the amount of radiant energy absorbed and stored by built surfaces.

2. Transpiration—converts moisture to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.

3. Wind speed reduction—reduces the infiltration 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 greenspace within individual building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace (Chandler 1965). At the larger scale of urban 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 cool air and pollutants along streets and out of urban canyons. Appendix A provides additional information on specific areas of contribution trees make toward energy savings.

Electricity and Natural Gas Results

Electricity and natural gas saved annually in Glendale from both shading and climate effects totaled 925 MWh and 531 Mbtu, respectively, for a total retail savings of $116,728 (Table 8 and 9) or a citywide average of $5.43/tree. Chinese elm, Arizona ash, and Citrus were the primary contributors.

In general, larger trees produced larger benefits. Differences in benefits between life forms (evergreen, deciduous) were dramatic, with large deciduous street trees producing nearly four times the benefit of large conifers (Table 10). Energy benefits associated with conifers and broadleaf evergreens adjacent to homes were lower than deciduous tree benefits because of the detrimental effect of their winter shade on heating costs.

Atmospheric Carbon Dioxide Reductions

Urban forests can reduce atmospheric CO_2 in two ways:

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

2. Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

On the other hand, CO_2 is released by vehicles, chain saws, chippers, and other equipment during

Table 8. Net annual energy savings produced by Glendale street trees.

Species	Electricity (MWh)	Natural Gas (Mbtu)	Total ($)	% of total trees	% of Total $	Avg. $/tree
Chinese Elm	75.7	59.1	9,703	13.8	16.9	5.35
Willow Acacia	28.6	20.0	3,644	9.9	6.3	2.81
Live Oak	17.3	14.4	2,225	8.8	3.9	1.93
Mondel Pine	21.5	14.5	2,739	8.3	4.8	2.51
Olive	20.6	18.6	2,667	6.3	4.6	3.19
Mexican Fan Palm	2.7	1.8	348	6.3	0.6	0.42
Chilean Mesquite	36.4	27.4	4,651	5.0	8.1	7.08
Sweet Acacia	18.6	15.5	2,393	4.1	4.2	4.41
Coolibah Gum	23.2	14.9	2,947	3.5	5.1	6.41
Chinese Pistache	7.6	6.4	976	2.5	1.7	3.01
Date Palm	13.7	14.6	1,796	2.4	3.1	5.68
African Sumac	10.7	9.3	1,385	2.3	2.4	4.54
Bottle Tree	5.1	4.1	649	2.3	1.1	2.18
Carob	2.2	1.6	283	2.2	0.5	0.96
Aleppo Pine	14.6	11.7	1,878	1.9	3.3	7.39
Blue Palo Verde	21.3	14.1	2,709	1.8	4.7	11.20
Canary Island Pine	3.5	2.9	451	1.4	0.8	2.52
California Palm	2.5	2.3	326	1.3	0.6	1.92
Sonoran Palo Verde	6.8	5.5	871	1.2	1.5	5.31
Arizona Ash	7.9	6.2	1,014	1.2	1.8	6.22
Desert willow	7.7	6.5	989	1.1	1.7	6.68
Jerusalem Thorn	17.9	9.0	2,243	1.1	3.9	15.68
Other Street Trees	82.3	64.9	10,558	11.4	18.4	7.05
Citywide total	448.7	345.1	57,444	100.0	100.0	4.36

Table 9. Net annual energy savings produced by Glendale park trees.

Species	Electricity (MWh)	Natural Gas (Mbtu)	Total ($)	% of total trees	% of Total $	Avg. $/tree
Arizona Ash	61.8	24.7	7,700	12.7	13.0	7.30
Citrus Species	55.6	27.4	6,969	7.9	11.8	10.69
Chinese Elm	33.5	12.8	4,173	6.6	7.0	7.63
Mondel Pine	18.6	6.7	2,307	6.3	3.9	4.39
Chilean Mesquite	18.1	7.0	2,253	5.5	3.8	4.96
Evergreen Ash	13.2	5.4	1,646	5.4	2.8	3.66
Aleppo Pine	27.5	10.2	3,422	4.2	5.8	9.92
California Palm	4.4	2.0	554	3.5	0.9	1.88
Blue Palo Verde	18.8	6.2	2,331	3.3	3.9	8.63
White Mulberry	35.9	11.8	4,442	2.8	7.5	18.82
Mexican Fan Palm	0.8	0.3	101	2.7	0.2	0.45
African Sumac	15.1	6.7	1,887	2.7	3.2	8.50
Feathertree	6.8	2.7	851	2.5	1.4	4.03
Coolibah Gum	10.0	3.6	1,241	2.4	2.1	6.14
Date Palm	11.7	5.3	1,468	2.2	2.5	8.02
Olive	7.6	3.2	951	2.0	1.6	5.60
Eucalyptus	18.6	6.2	2,301	2.0	3.9	14.12
Willow Acacia	2.7	1.1	342	1.9	0.6	2.14
Chinese Pistache	8.8	3.3	1,097	1.9	1.9	6.86
Sweet Acacia	3.8	1.6	469	1.8	0.8	3.21
Live Oak	1.0	0.4	120	1.4	0.2	1.05
Italian Cypress	6.1	2.4	755	1.3	1.3	6.80
Bottle Tree	4.4	1.6	542	1.2	0.9	5.26
Jerusalem Thorn	10.6	3.1	1,314	1.0	2.2	15.64
Other Park Trees	80.9	29.8	10,049	14.6	17.0	8.27
Citywide total	476.3	185.7	59,284	100.0	100.0	7.15

Table 10. Average annual street tree energy benefit by tree type.

Tree-Type	$/tree
Lg. Deciduous	12.36
Med. Deciduous	6.39
Sm. Deciduous	5.35
Lg. Brdlf Evrgrn	7.68
Med. Brdlf Evrgrn	2.53
Sm. Brdlf Evrgrn	4.31
Lg. Conifer	3.50
Sm. Conifer	0.00
Lg. Palm	5.68
Med. Palm	0.00
Sm. Palm	0.68
Citywide total	4.36

the process of planting and maintaining trees. Eventually, all trees die and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere through decomposition unless recycled.

Citywide, Glendale's municipal forest reduced atmospheric CO_2 by 802.6 tons annually. This benefit was valued at $12,039 or $0.56/tree. Carbon dioxide released through decomposition and tree care activities totaled 71,345 lb and 8,677 lb, respectively, or 5% of the net total benefit. Tree reduction of energy plant CO_2 emissions and sequestration rates were 924,479 lb and 760,744 lb, respectively. Avoided emissions were greater than the amount of sequestration due to relatively high power plant emission rates and electricity savings. Avoided emissions are important in Glendale because fossil fuels (39% coal) are an important energy source (US EPA 2003). Coal has a relatively high CO_2 emission factor. Shading by trees during hot summers reduces the need for air conditioning, resulting in reduced use of coal for cooling energy production.

Chinese elm, Arizona ash, and Willow acacia accounted for the greatest CO_2 benefits (Tables 11 and 12). However, tree species with the highest per tree benefits were Eucalyptus, Mulberry, and Jerusalem thorn.

Air Quality Improvement

Urban trees provide air quality benefits in five main ways:

1. Absorbing gaseous pollutants (ozone, nitrogen oxides) through leaf surfaces.

2. Intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke)

Table 11. Net CO_2 reductions by Glendale street trees.

Species	Sequestered (lb)	Decomposition Release (lb)	Maintenance Release (lb)	Avoided (lb)	Net Total (lb)	Total ($)	% of Total Trees	% of Total ($)	Avg. $/ Tree
Chinese Elm	25,920	1,059	213	75,681	100,329	752	13.8	12.4	0.41
Willow Acacia	50,917	2,803	153	28,600	76,562	574	9.9	9.5	0.44
Live Oak	19,654	743	225	17,288	35,974	270	8.8	4.5	0.23
Mondel Pine	11,409	734	354	21,537	31,859	239	8.3	4.0	0.22
Olive	12,276	856	359	20,620	31,681	238	6.3	3.9	0.28
Mexican Fan Palm	20,380	9,437	769	2,747	12,920	97	6.3	1.6	0.12
Chilean Mesquite	20,092	950	271	36,347	55,219	414	5.0	6.8	0.63
Sweet Acacia	19,817	1,185	64	18,591	37,160	279	4.1	4.6	0.51
Coolibah Gum	39,183	1,992	220	23,220	60,191	451	3.5	7.5	0.98
Chinese Pistache	3,145	131	38	7,577	10,553	79	2.5	1.3	0.24
Date Palm	5,076	4,405	223	13,720	14,168	106	2.4	1.8	0.34
African Sumac	3,707	214	130	10,732	14,096	106	2.3	1.8	0.35
Bottle Tree	6,054	419	35	5,049	10,650	80	2.3	1.3	0.27
Carob	3,048	114	35	2,219	5,118	38	2.2	0.6	0.13
Aleppo Pine	22,817	731	178	14,633	36,541	274	1.9	4.5	1.08
Blue Palo Verde	10,445	579	28	21,320	31,157	234	1.8	3.9	0.97
Canary Island Pine	4,990	86	65	3,508	8,347	63	1.4	1.0	0.35
California Palm	2,368	821	111	2,514	3,951	30	1.3	0.5	0.17
Sonoran Palo Verde	2,704	106	19	6,776	9,355	70	1.2	1.2	0.43
Arizona Ash	6,107	431	73	7,907	13,511	101	1.2	1.7	0.62
Desert willow	3,319	30	17	7,677	10,948	82	1.1	1.4	0.55
Jerusalem Thorn	8,143	705	117	17,859	25,179	189	1.1	3.1	1.32
Other Street Trees	96,058	7,146	717	82,302	170,497	1,279	11.4	21.1	0.85
Citywide total	397,631	35,676	4,414	448,424	805,965	6,045	100.0	100.0	0.46

Table 12. Net CO_2 reductions by Glendale park trees.

Species	Sequestered (lb)	Decomposition Release (lb)	Maintenance Release (lb)	Avoided (lb)	Net Total (lb)	Total ($)	% of Total Trees	% of Total ($)	Avg. $/ Tree
Arizona Ash	47,482	3,295	553	61,788	105,421	791	12.7	13.2	0.75
Citrus Species	21,629	1,941	545	55,533	74,677	560	7.9	9.3	0.86
Chinese Elm	11,884	566	64	33,523	44,777	336	6.6	5.6	0.61
Mondel Pine	9,369	881	238	18,566	26,817	201	6.3	3.4	0.38
Chilean Mesquite	9,759	519	144	18,094	27,191	204	5.5	3.4	0.45
Evergreen Ash	8,435	503	146	13,193	20,978	157	5.4	2.6	0.35
Aleppo Pine	31,145	1,975	281	27,525	56,414	423	4.2	7.1	1.23
California Palm	4,103	1,377	187	4,428	6,968	52	3.5	0.9	0.18
Blue Palo Verde	9,380	584	32	18,802	27,565	207	3.3	3.5	0.77
White Mulberry	19,434	2,879	242	35,838	52,151	391	2.8	6.5	1.66
Mexican Fan Palm	5,126	3,156	259	805	2,516	19	2.7	0.3	0.08
African Sumac	5,684	473	156	15,088	20,143	151	2.7	2.5	0.68
Feathertree	3,673	151	58	6,828	10,292	77	2.5	1.3	0.37
Coolibah Gum	17,146	998	98	9,985	26,035	195	2.4	3.3	0.97
Date Palm	2,641	3,054	127	11,731	11,191	84	2.2	1.4	0.46
Olive	4,256	598	114	7,621	11,164	84	2.0	1.4	0.49
Eucalyptus	30,087	2,887	141	18,554	45,614	342	2.0	5.7	2.10
Willow Acacia	4,944	228	19	2,747	7,444	56	1.9	0.9	0.35
Chinese Pistache	3,301	239	19	8,819	11,862	89	1.9	1.5	0.56
Sweet Acacia	3,501	150	17	3,751	7,085	53	1.8	0.9	0.36
Live Oak	792	20	15	957	1,713	13	1.4	0.2	0.11
Italian Cypress	12,977	259	81	6,064	18,701	140	1.3	2.3	1.26
Bottle Tree	3,539	503	12	4,359	7,382	55	1.2	0.9	0.54
Jerusalem Thorn	4,742	414	68	10,627	14,887	112	1.0	1.9	1.33
Other Park Trees	88,085	8,017	649	80,829	160,248	1,202	14.6	20.0	0.99
Citywide total	363,114	35,669	4,263	476,054	799,236	5,994	100.0	100.0	0.72

3. Reducing emissions from power generation by limiting building energy consumption
4. Releasing oxygen through photosynthesis
5. Transpiring water and shading surfaces, which lower local air temperatures, thereby reducing ozone levels.

In the absence of the cooling effects of trees, higher air temperatures contribute to ozone formation. Most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can contribute to ozone formation. The ozone forming potential of different tree species varies considerably (Benjamin and Winer 1998). A computer simulation study for the Los Angeles basin found that increased tree planting of low BVOC emitting tree species would reduce ozone concentrations and exposure to ozone, while planting of medium- and high-emitters would increase overall ozone concentrations (Taha 1996).

Deposition and Interception Result

Pollutant uptake by tree foliage (pollution deposition and particulate interception) in Glendale was 2,814 lb for all trees and pollutants. Trees were most effective removing ozone (O_3) and particulate matter (PM_{10}). Citrus, Arizona ash, and Mulberry had the highest uptake rates (Tables 13 and 14).

Avoided Pollutants and BVOC Emissions Result

Annual avoided pollutant emissions at power plants totaled 3,627 lb, with sizable reductions for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). Avoided emission benefits exceeded direct uptake due to the large amount of electricity savings and associated reduction in release of pollutants from power plants. Although Glendale's public trees provided substantial reductions of power plant emissions due to energy savings, they released 3,938 lb of more highly priced BVOCs, thereby reducing net air quality benefits. High emitters (> 10 ug/g/hr) in Glendale were limited to species belonging to the Oak (*Quercus*) and Date palm (*Phoenix*) genera, but trees of these types were relatively abundant.

Net Air Quality Improvement

Glendale's municipal forest produced annual air quality benefits valued at $32,572 ($1.52/tree) by removing 2,503 lb of pollutants from the atmosphere. Trees producing the greatest per tree benefit included Citrus ($5.41), Palo verde ($3.46), and Arizona ash

Table 13. Air quality benefits for all street trees.

	Deposition (lb)				Avoided (lb)				BVOC Emissions	Net		% of Total	% of Total	Avg. $
Species	O3	NO2	PM10	SO_2	NO_2	PM_{10}	VOC	SO_2	(lbs)	Total (lb)	Total ($)	Trees	$	/tree
Chinese Elm	32.0	12.4	40.9	2.6	134.9	6.9	1.2	115.1	0.0	346.0	2,856.6	13.8	25.4	1.57
Willow Acacia	23.5	12.8	28.0	2.6	51.1	2.6	0.5	43.7	-63.0	101.8	1,010.0	9.9	9.0	0.78
Live Oak	4.3	2.4	8.7	0.5	30.7	1.6	0.3	26.2	-417.6	-343.1	-1,039.8	8.7	-9.2	-0.90
Mondel Pine	15.2	8.3	18.5	1.7	38.6	2.0	0.3	33.1	-36.0	81.7	774.4	8.3	6.9	0.71
Olive	18.9	10.3	22.2	2.1	36.7	1.9	0.3	31.3	-16.9	106.6	864.9	6.3	7.7	1.03
Mexican Fan Palm	35.8	19.5	33.5	3.9	4.9	0.3	0.0	4.2	-259.7	-157.6	-467.8	6.3	-4.2	-0.56
Chilean Mesquite	31.6	15.2	35.1	3.1	64.7	3.3	0.6	55.3	-59.6	149.4	1,358.3	5.0	12.1	2.07
Sweet Acacia	25.5	12.2	24.9	2.5	33.0	1.7	0.3	28.2	-72.0	56.3	637.8	4.1	5.7	1.18
Coolibah Gum	20.4	11.1	23.7	2.2	41.6	2.1	0.4	35.7	-254.9	-117.8	23.8	3.5	0.2	0.05
Chinese Pistache	4.7	1.8	5.1	0.4	13.5	0.7	0.1	11.5	-75.5	-37.6	0.3	2.5	0.0	0.00
Date Palm	28.3	15.4	28.0	3.1	24.5	1.3	0.2	20.8	-268.2	-146.6	-247.7	2.4	-2.2	-0.78
African Sumac	9.6	5.2	11.5	1.1	19.1	1.0	0.2	16.3	0.0	63.8	483.0	2.3	4.3	1.58
Bottle Tree	2.7	1.5	3.5	0.3	9.1	0.5	0.1	7.7	-26.5	-1.1	97.6	2.3	0.9	0.33
Carob	0.4	0.2	0.9	0.0	4.0	0.2	0.0	3.4	-12.5	-3.2	29.9	2.2	0.3	0.10
Aleppo Pine	5.7	3.1	9.0	0.6	26.2	1.3	0.2	22.4	-38.8	29.9	409.8	1.9	3.6	1.61
Blue Palo Verde	28.6	13.7	28.4	2.8	37.9	1.9	0.3	32.4	-55.3	90.8	836.5	1.8	7.4	3.46
Canary Island Pine	0.5	0.3	1.4	0.1	6.2	0.3	0.1	5.3	-8.9	5.2	87.3	1.4	0.8	0.49
California Palm	2.9	1.6	2.7	0.3	4.5	0.2	0.0	3.8	-51.2	-35.2	-86.8	1.3	-0.8	-0.51
Sonoran Palo Verde	4.0	1.9	5.1	0.4	12.0	0.6	0.1	10.3	-16.7	17.9	208.1	1.2	1.8	1.27
Arizona Ash	7.8	3.0	7.3	0.6	14.2	0.7	0.1	12.1	0.0	45.9	348.3	1.2	3.1	2.14
Desert willow	7.9	2.2	6.1	0.5	13.7	0.7	0.1	11.7	-50.3	-7.4	126.1	1.1	1.1	0.85
Jerusalem Thorn	27.7	13.3	26.5	2.8	31.7	1.6	0.3	27.2	-191.4	-60.3	165.3	1.1	1.5	1.16
Other Street Trees	113.4	57.8	114.9	11.6	147.2	7.5	1.3	125.8	-346.0	233.5	2,787.2	11.4	24.7	1.86
Citywide total	451.5	225.4	485.7	45.9	800.0	40.8	7.2	683.5	-2,321.1	419.0	11,263.2	100.0	100.0	0.85

Table 14. Air quality benefits for all park trees.

	Deposition (lb)				Avoided (lb)				BVOC Emissions	Net		% of Total	% of Total	Avg. $
Species	O3	NO2	PM10	SO_2	NO_2	PM_{10}	VOC	SO_2	(lbs)	Total (lb)	Total ($)	Trees	$	/tree
Arizona Ash	59.5	23.0	56.1	4.8	142.3	7.3	1.3	121.1	0.0	415.4	3,260.7	12.7	15.3	3.09
Citrus Species	89.8	49.0	91.8	9.9	128.4	6.6	1.2	108.8	0.0	485.4	3,527.0	7.9	16.6	5.41
Chinese Elm	19.8	7.6	21.9	1.6	77.2	3.9	0.7	65.7	0.0	198.4	1,632.2	6.6	7.7	2.98
Mondel Pine	21.7	11.8	23.0	2.4	42.7	2.2	0.4	36.4	-29.2	111.3	949.1	6.3	4.5	1.81
Chilean Mesquite	17.0	8.2	18.3	1.7	41.7	2.1	0.4	35.5	-31.2	93.6	849.8	5.5	4.0	1.87
Evergreen Ash	9.1	4.0	10.1	0.8	30.5	1.6	0.3	25.9	0.0	82.3	665.1	5.4	3.1	1.48
Aleppo Pine	20.7	11.3	25.6	2.3	63.3	3.2	0.6	53.9	-77.1	103.8	1,130.5	4.2	5.3	3.28
California Palm	4.7	2.6	4.4	0.5	10.2	0.5	0.1	8.7	-85.6	-53.8	-97.6	3.5	-0.5	-0.33
Blue Palo Verde	30.1	14.4	28.5	3.0	43.2	2.2	0.4	36.8	-51.6	107.0	955.1	3.3	4.5	3.54
White Mulberry	55.9	15.2	37.9	3.4	82.3	4.2	0.7	70.2	-92.2	177.6	1,655.8	2.8	7.8	7.02
Mexican Fan Palm	12.7	6.9	11.9	1.4	1.9	0.1	0.0	1.6	-90.0	-53.5	-155.0	2.7	-0.7	-0.69
African Sumac	21.3	11.6	22.5	2.3	34.8	1.8	0.3	29.6	0.0	124.2	918.5	2.7	4.3	4.14
Feathertree	4.9	2.4	5.8	0.5	15.7	0.8	0.1	13.4	-11.2	32.4	304.9	2.5	1.4	1.45
Coolibah Gum	10.5	5.7	11.7	1.2	23.0	1.2	0.2	19.6	-117.1	-44.1	91.9	2.4	0.4	0.46
Date Palm	38.7	21.1	36.3	4.3	27.1	1.4	0.3	23.0	-186.8	-34.8	255.1	2.2	1.2	1.39
Olive	11.2	6.1	11.6	1.2	17.6	0.9	0.2	14.9	-6.0	57.8	445.2	2.0	2.1	2.62
Eucalyptus	33.3	18.1	33.4	3.7	42.6	2.2	0.4	36.4	-213.5	-43.4	365.9	2.0	1.7	2.24
Willow Acacia	1.5	0.8	2.1	0.2	6.3	0.3	0.1	5.4	-5.7	11.0	113.7	1.9	0.5	0.71
Chinese Pistache	12.5	4.8	10.6	1.0	20.3	1.0	0.2	17.3	-88.9	-21.1	152.7	1.9	0.7	0.95
Sweet Acacia	3.4	1.6	3.7	0.3	8.7	0.4	0.1	7.3	-13.2	12.4	148.0	1.8	0.7	1.01
Live Oak	0.1	0.0	0.3	0.0	2.2	0.1	0.0	1.9	-22.7	-18.0	-48.8	1.4	-0.2	-0.43
Italian Cypress	1.8	1.0	3.2	0.2	14.0	0.7	0.1	11.9	-16.2	16.7	216.1	1.3	1.0	1.95
Bottle Tree	5.8	3.2	6.0	0.6	10.0	0.5	0.1	8.5	-21.7	13.1	172.8	1.2	0.8	1.68
Jerusalem Thorn	16.4	7.9	15.6	1.6	24.4	1.2	0.2	20.8	-111.6	-23.4	202.8	1.0	1.0	2.41
Other Park Trees	126.5	62.3	122.5	12.5	185.9	9.5	1.7	158.4	-345.8	333.6	3,597.9	14.6	16.9	2.96
Citywide total	628.8	300.8	614.9	61.3	1,096.2	56.0	10.1	932.9	-1,617.3	2,083.8	21,309.3	100.0	100.0	2.57

($3.09). Low deposition rates coupled with higher BVOC emissions resulted in net costs for Live oaks and Palms. Over 25% of the total net air quality benefit for street trees was attributable to Chinese elm, which accounted for only 14% of all street trees.

Stormwater Runoff Reductions

Urban stormwater runoff is an increasing concern as a significant pathway for contaminants entering local streams, lakes and reservoirs. To protect threatened fish and wildlife, stormwater management requirements are becoming increasingly broad, stringent, and costly; cost-effective means of mitigation are needed. Healthy urban trees can reduce the amount of runoff and pollutant loading in receiving waters in four primary ways:

1. Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.

2. Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduces overland flow.

3. Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.

4. Transpiration through tree leaves reduces soil moisture, increasing the soil's capacity to store rainfall.

The ability of Glendale's street trees to intercept rain and reduce annual runoff was estimated at 1,038,750 gallons with an implied value of $37,298. On average, each tree reduced annual stormwater runoff by 48 gallons and the value of this benefit was $1.74. Although fewer in number, park trees provided more benefit than street trees because of their larger size and greater number of evergreen trees that effectively intercepted winter rainfall (Tables 15 and 16). Eucalyptus ($7.16/tree), Aleppo pine (*Pinus halepensis*) ($5.75/tree), Citrus ($4.10/tree) and Jerusalem thorn ($3.98/tree) had the highest rainfall interception rates.

Aesthetic And Other Benefits

Trees provide a host of aesthetic, social, economic, and health benefits that should be described and monetized in this benefit-cost analysis.

Environmental benefits not accounted for previously include noise abatement, wildlife habitat, and UV radiation attenuation and skin cancer reduction. Although these types of environmental benefits are more difficult to quantify than those previously described, they can be important. Another important benefit from street tree shade is money saved for repaving because shaded streets do not deteriorate as quickly as unshaded streets (Muchnick 2003). The social and psychological benefits provided by Glendale's street and park trees improve human well-being. Trees provide important settings for recreation in and near Glendale. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality. Healthy trees increase the sales prices of property.

In this study, the estimated annual benefit associated with property value increase due to trees increasing property sales prices is used to indicate the value of aesthetics and other benefits. In Glendale, where a mature street tree was estimated to add $1,269 to the

Table 15. Annual stormwater reduction benefits of Glendale street trees by species.

Species	Rainfall Intercept. (gal)	Total $	% of total trees	% of Total $	Avg. $/tree
Chinese Elm	41,783	1,500	13.8	8.2	0.83
Willow Acacia	40,274	1,446	9.9	7.9	1.11
Live Oak	20,251	727	8.8	4.0	0.63
Mondel Pine	32,506	1,167	8.3	6.4	1.07
Olive	27,620	992	6.3	5.4	1.19
Mexican Fan Palm	20,738	745	6.3	4.1	0.89
Chilean Mesquite	34,048	1,223	5.0	6.7	1.86
Sweet Acacia	13,212	474	4.1	2.6	0.88
Coolibah Gum	37,190	1,335	3.5	7.3	2.90
Chinese Pistache	4,749	171	2.5	0.9	0.53
Date Palm	7,699	276	2.4	1.5	0.87
African Sumac	15,782	567	2.3	3.1	1.86
Bottle Tree	8,154	293	2.3	1.6	0.99
Carob	3,831	138	2.2	0.8	0.47
Aleppo Pine	28,186	1,012	1.9	5.6	3.98
Blue Palo Verde	13,888	499	1.8	2.7	2.06
Canary Island Pine	6,831	245	1.4	1.4	1.37
California Palm	699	25	1.3	0.1	0.15
Sonoran Palo Verde	4,011	144	1.2	0.8	0.88
Arizona Ash	5,966	214	1.2	1.2	1.31
Desert willow	3,073	110	1.1	0.6	0.75
Jerusalem Thorn	15,844	569	1.1	3.1	3.98
Other Street Trees	120,474	4,326	11.4	23.8	2.89
Citywide total	506,808	18,198	100.0	100.0	1.38

Table 16. Annual stormwater reduction benefits of Glendale park trees by species.

Species	Rainfall Intercept. (gal)	Total $	% of total trees	% of Total $	Avg. $/tree
Arizona Ash	46,748	1,679	12.7	8.8	1.59
Citrus Species	74,503	2,675	7.9	14.0	4.10
Chinese Elm	18,891	678	6.6	3.5	1.24
Mondel Pine	27,675	994	6.3	5.2	1.89
Chilean Mesquite	16,980	610	5.5	3.2	1.34
Evergreen Ash	13,338	479	5.4	2.5	1.06
Aleppo Pine	55,246	1,984	4.2	10.4	5.75
California Palm	1,158	42	3.5	0.2	0.14
Blue Palo Verde	13,302	478	3.3	2.5	1.77
White Mulberry	18,126	651	2.8	3.4	2.76
Mexican Fan Palm	7,196	258	2.7	1.4	1.15
African Sumac	20,759	745	2.7	3.9	3.36
Feathertree	6,248	224	2.5	1.2	1.06
Coolibah Gum	16,868	606	2.4	3.2	3.00
Date Palm	5,517	198	2.2	1.0	1.08
Olive	9,929	357	2.0	1.9	2.10
Eucalyptus	32,523	1,168	2.0	6.1	7.16
Willow Acacia	3,766	135	1.9	0.7	0.85
Chinese Pistache	5,583	200	1.9	1.0	1.25
Sweet Acacia	2,339	84	1.8	0.4	0.58
Live Oak	1,081	39	1.4	0.2	0.34
Italian Cypress	11,824	425	1.3	2.2	3.82
Bottle Tree	6,876	247	1.2	1.3	2.40
Jerusalem Thorn	9,504	341	1.0	1.8	4.06
Other Park Trees	105,962	3,805	14.6	19.9	3.13
Total Park Trees	531,942	19,100	100.0	100.0	2.30

sales price of a typical home, the annual benefit totaled $467,213, or $21.75/tree on average. This amount was about half that for trees in Fort Collins, CO, not surprising because median home sales prices greatly influence the average annual dollar savings. The price in Fort Collins ($212,000) was substantially greater than the price in Glendale ($144,250).

Because of their numbers and size, Chinese elm, Willow acacia, and Arizona ash produced the greatest aesthetic and other benefits (Tables 17 and 18). Tree species with the largest average annual benefit per tree were the Coolibah gum (*Eucalyptus microtheca*) ($55.71/tree), Aleppo pine ($54.58/tree), Jerusalem thorn ($43.72/tree), and Mesquite (*Prosopis chilensis*) (40.08/tree). These species produced the highest average annual benefit because they added the largest amount of leaf area over the course of a year.

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

Total annual benefits produced by Glendale's street and park trees were estimated to have a value of $665,850 or about $31/tree and $3/resident (Table 19). Costs totaled $276,436, or $13/tree and $1/resident. Net benefits were $389,415, or $18/tree and $2/resident. Glendale's street and park trees returned $2.41 to the community for every $1 spent on their management

Glendale's street and park trees have beneficial effects on the environment. Approximately 30% of the annual benefits were attributed to environmental values. Energy savings, primarily for air conditioning, was 59% of this value ($5/tree). Benefits associated with stormwater runoff reduction (19%) and air quality improvement (16%) were next in importance, followed by carbon dioxide reductions (6% of environmental benefits).

Table 17. Total annual increases in property value from Glendale street trees by species.

Species	Total ($)	% of total trees	% of Total $	Avg. $/tree
Chinese Elm	54,254	13.8	17.0	29.91
Willow Acacia	33,708	9.9	10.6	25.95
Live Oak	13,358	8.8	4.2	11.59
Mondel Pine	15,413	8.3	4.8	14.14
Olive	12,824	6.3	4.0	15.34
Mexican Fan Palm	4,549	6.3	1.4	5.45
Chilean Mesquite	26,332	5.0	8.2	40.08
Sweet Acacia	7,589	4.1	2.4	14.00
Coolibah Gum	25,627	3.5	8.0	55.71
Chinese Pistache	5,952	2.5	1.9	18.37
Date Palm	1,242	2.4	0.4	3.93
African Sumac	6,355	2.3	2.0	20.84
Bottle Tree	4,273	2.3	1.3	14.39
Carob	3,312	2.2	1.0	11.27
Aleppo Pine	13,837	1.9	4.3	54.48
Blue Palo Verde	9,164	1.8	2.9	37.87
Canary Island Pine	5,552	1.4	1.7	31.02
California Palm	1,789	1.3	0.6	10.52
Sonoran Palo Verde	3,694	1.2	1.2	22.52
Arizona Ash	4,843	1.2	1.5	29.71
Desert willow	2,418	1.1	0.8	16.34
Jerusalem Thorn	6,252	1.1	2.0	43.72
Other Street Trees	57,266	11.4	17.9	38.23
Citywide total	319,605	100.0	100.0	24.24

Table 18. Total annual increases in property value from Glendale park trees by species.

Species	Total ($)	% of total trees	% of Total $	Avg. $/tree
Arizona Ash	19,386	12.7	13.1	18.38
Citrus Species	9,296	7.9	6.3	14.26
Chinese Elm	11,733	6.6	7.9	21.45
Mondel Pine	5,002	6.3	3.4	9.53
Chilean Mesquite	8,795	5.5	6.0	19.37
Evergreen Ash	6,265	5.4	4.2	13.92
Aleppo Pine	11,395	4.2	7.7	33.03
California Palm	1,748	3.5	1.2	5.95
Blue Palo Verde	4,808	3.3	3.3	17.81
White Mulberry	5,344	2.8	3.6	22.64
Mexican Fan Palm	648	2.7	0.4	2.88
African Sumac	2,995	2.7	2.0	13.49
Feathertree	3,792	2.5	2.6	17.97
Coolibah Gum	6,344	2.4	4.3	31.41
Date Palm	291	2.2	0.2	1.59
Olive	1,362	2.0	0.9	8.01
Eucalyptus	6,884	2.0	4.7	42.23
Willow Acacia	2,103	1.9	1.4	13.14
Chinese Pistache	2,296	1.9	1.6	14.35
Sweet Acacia	1,028	1.8	0.7	7.04
Live Oak	510	1.4	0.3	4.47
Italian Cypress	3,686	1.3	2.5	33.20
Bottle Tree	1,043	1.2	0.7	10.13
Jerusalem Thorn	2,066	1.0	1.4	24.60
Other Park Trees	28,788	14.6	19.5	23.69
Citywide total	147,608	100.0	100.0	17.79

Table 19. Benefit-cost summary for Glendale's street and park trees.

	Street			Park			All		
Benefit	Total ($)	$/capita	$/tree	Total ($)	$/capita	$/tree	Total ($)	$/capita	$/tree
Energy	57,444	0.26	4.36	59,284	0.27	7.15	116,728	0.53	5.43
CO2	6,045	0.03	0.46	5,994	0.03	0.72	12,039	0.05	0.56
Air Quality	11,263	0.05	0.85	21,309	0.10	2.57	32,572	0.15	1.52
Stormwater	18,198	0.08	1.38	19,100	0.09	2.30	37,298	0.17	1.74
Environmental Subtotal	92,950	0.42	7.05	105,688	0.48	12.74	198,638	0.90	9.25
Property Increase	319,605	1.45	24.24	147,608	0.67	17.79	467,213	2.12	21.75
Total benefits	412,555	1.88	31.29	253,296	1.15	30.53	665,850	3.03	31.00
Total costs	220,626	1.00	16.74	55,810	0.25	6.73	276,436	1.26	12.87
Net benefits	191,929	0.87	14.56	197,486	0.90	23.80	389,415	1.77	18.13
Benefit-cost ratio	1.87			4.54			2.41		

While species varied in their ability to produce benefits, common characteristics of trees within tree-type classes aid in identifying the most beneficial trees in Glendale (Figure 3). As is typical in most cities, Glendale's larger trees – deciduous and broadleaf evergreens -- produced the greatest benefits on a per tree basis. The anomaly was small-stature broadleaf evergreens. These trees provided a higher average return than medium broadleaf evergreens trees, primarily due to increased property value benefits associated with their increasing leaf area.

Large deciduous street trees ($103/tree) provided the highest level of average benefits in Glendale (Figure 3). In parks, large broadleaf evergreens ($57/tree) provided more benefits than large deciduous ($38/tree) and conifer ($35/tree) trees due to their larger size and faster growth.

Table 20 shows the distribution of total annual benefits in dollars for the predominant street tree species in Glendale. Aleppo pine ($69/tree), Coolibah gum and Jerusalem thorn (both $66/tree), and Palo verde ($56/tree) produced the highest average annual benefits. In parks (Table 21), Eucalyptus ($68/tree), Aleppo pine and Mulberry (both $53/tree) produced the greatest benefits.

Average annual street tree benefits were relatively uniformly distributed among zones, except for Zone 2, where the average benefit ($22/tree) was 30-50% of that found in the other zones (Table 22). This difference can be attributed largely to smaller and younger trees in this zone, including a large number of Palms.

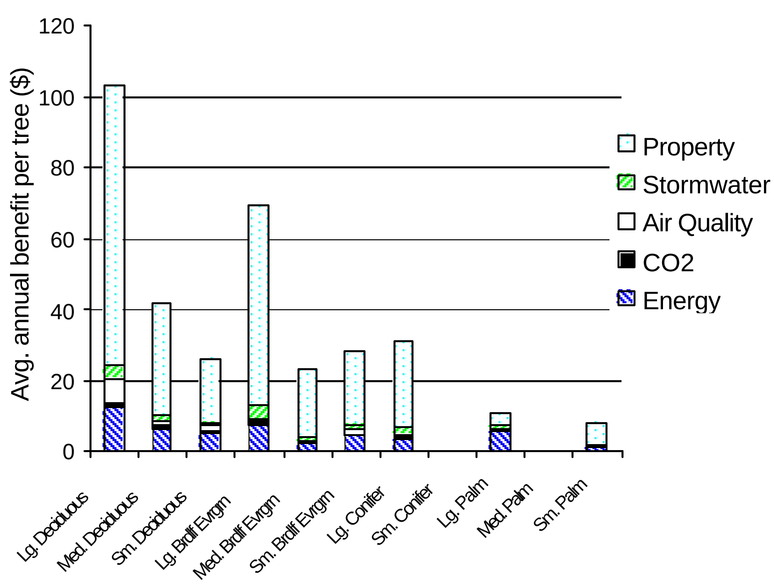

Figure 3. Average annual street tree benefits per tree by tree type.

Table 20. Total annual benefits ($) for predominant street trees in Glendale.

Street Tree Species	Energy	CO2	Air Quality	Stormwater	Property	Total
Chinese Elm	5.35	0.41	1.57	0.83	29.91	38.07
Willow Acacia	2.81	0.44	0.78	1.11	25.95	31.09
Live Oak	1.93	0.23	-0.90	0.63	11.59	13.48
Mondel Pine	2.51	0.22	0.71	1.07	14.14	18.65
Olive	3.19	0.28	1.03	1.19	15.34	21.04
Mexican Fan Palm	0.42	0.12	-0.56	0.89	5.45	6.31
Chilean Mesquite	7.08	0.63	2.07	1.86	40.08	51.72
Sweet Acacia	4.41	0.51	1.18	0.88	14.00	20.98
Coolibah Gum	6.41	0.98	0.05	2.90	55.71	66.05
Chinese Pistache	3.01	0.24	0.00	0.53	18.37	22.15
Date Palm	5.68	0.34	-0.78	0.87	3.93	10.04
African Sumac	4.54	0.35	1.58	1.86	20.84	29.17
Bottle Tree	2.18	0.27	0.33	0.99	14.39	18.15
Carob	0.96	0.13	0.10	0.47	11.27	12.93
Aleppo Pine	7.39	1.08	1.61	3.98	54.48	68.55
Blue Palo Verde	11.20	0.97	3.46	2.06	37.87	55.55
Canary Island Pine	2.52	0.35	0.49	1.37	31.02	35.74
California Palm	1.92	0.17	-0.51	0.15	10.52	12.25
Sonoran Palo Verde	5.31	0.43	1.27	0.88	22.52	30.41
Arizona Ash	6.22	0.62	2.14	1.31	29.71	40.00
Desert willow	6.68	0.55	0.85	0.75	16.34	25.17
Jerusalem Thorn	15.68	1.32	1.16	3.98	43.72	65.86
Other Street Trees	7.05	0.85	1.86	2.89	38.23	50.88

Table 21. Total annual benefits ($) for predominant park trees in Glendale.

Park Tree Species	Energy	CO2	Air Quality	Stormwater	Property	Total
Arizona Ash	7.30	0.75	3.09	1.59	18.38	31.11
Citrus Species	10.69	0.86	5.41	4.10	14.26	35.32
Chinese Elm	7.63	0.61	2.98	1.24	21.45	33.92
Mondel Pine	4.39	0.38	1.81	1.89	9.53	18.01
Chilean Mesquite	4.96	0.45	1.87	1.34	19.37	28.00
Evergreen Ash	3.66	0.35	1.48	1.06	13.92	20.47
Aleppo Pine	9.92	1.23	3.28	5.75	33.03	53.20
California Palm	1.88	0.18	-0.33	0.14	5.95	7.82
Blue Palo Verde	8.63	0.77	3.54	1.77	17.81	32.51
White Mulberry	18.82	1.66	7.02	2.76	22.64	52.90
Mexican Fan Palm	0.45	0.08	-0.69	1.15	2.88	3.87
African Sumac	8.50	0.68	4.14	3.36	13.49	30.17
Feathertree	4.03	0.37	1.45	1.06	17.97	24.88
Coolibah Gum	6.14	0.97	0.46	3.00	31.41	41.97
Date Palm	8.02	0.46	1.39	1.08	1.59	12.54
Olive	5.60	0.49	2.62	2.10	8.01	18.82
Eucalyptus	14.12	2.10	2.24	7.16	42.23	67.85
Willow Acacia	2.14	0.35	0.71	0.85	13.14	17.19
Chinese Pistache	6.86	0.56	0.95	1.25	14.35	23.97
Sweet Acacia	3.21	0.36	1.01	0.58	7.04	12.20
Live Oak	1.05	0.11	-0.43	0.34	4.47	5.55
Italian Cypress	6.80	1.26	1.95	3.82	33.20	47.04
Bottle Tree	5.26	0.54	1.68	2.40	10.13	20.01
Jerusalem Thorn	15.64	1.33	2.41	4.06	24.60	48.04
Other Street Trees	8.27	0.99	2.96	3.13	23.69	39.05

Table 22. Average annual street tree benefits by zone in Glendale.

Zone	Energy	CO2	Air Quality	Stormwater	Property	Total
1	6.53	0.80	1.34	2.28	30.44	41.38
2	3.44	0.36	0.14	1.37	17.06	22.38
3	4.45	0.48	0.81	1.52	27.15	34.41
4	6.55	0.61	1.66	1.79	27.67	38.28
5	5.63	0.64	1.34	1.90	30.69	40.20
6	5.55	0.56	1.14	1.76	25.12	34.12
Citywide total	4.36	0.46	0.85	1.38	24.24	31.29

Zone 2 had the largest average annual per tree benefits, in contrast having the lowest street tree benefits (Table 22). The lowest park tree benefits were found in Zone 3 (Table 23).

Table 23. Average annual park tree benefits by zone in Glendale.

Zone	Energy	CO2	Air Quality	Stormwater	Property	Total
1	8.78	0.83	3.51	2.74	17.66	33.52
2	12.55	1.35	4.53	4.52	26.57	49.51
3	3.11	0.31	0.93	0.92	12.92	18.19
4	9.79	1.04	3.66	3.61	21.01	39.11
5	6.73	0.68	2.18	1.97	18.42	29.98
Citywide total	7.15	0.72	2.57	2.30	17.79	30.53

Chapter Five—Management Implications

City of Glendale, Arizona
Municipal Forest Resource Analysis

Street and park trees are only one component of a functional urban forest because most city trees are on private property and maintained by residents or people they hire. In some areas, the municipal forest is the most important component, providing a distinctive portal to neighborhoods and shopping districts. Because of its prominence, cities must seek to maintain a functional municipal forest that is both healthy and safe. In Glendale, there is no doubt that trees are valued as an integral component of the city (Figure 4).

Glendale's urban forest reflects the values, lifestyles, preferences, and aspirations of current and past residents. It is a dynamic legacy, on one hand dominated by trees planted years ago and, at the same time, constantly changing as many new trees are planted. 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 Glendale's street and park tree populations, what future trends are likely and what management challenges will need to be met to achieve sustainability?

Achieving sustainability will produce long-term net benefits to the community while reducing the associated costs incurred with managing the resource. The structural features of a sustainable urban forest include adequate complexity (species and age diversity), well-adapted healthy trees, appropriate tree numbers, and effective management. By focusing on these components – resource complexity, extent, and management – it is possible to refine municipal tree management goals.

Resource Complexity

Although 100 different species have been planted in parks and streets, Chinese elm (11%), Mondel pine

Figure 4. Glendale today, showing a typical urban forest scene in the historic district, planted to beautify the area, as well as protect residents from the sun and heat

(7.5%), Willow acacia (6.8%), and Live oak (6.8%) are the dominant species, accounting for 32% of all municipal trees. Species diversity was adequate when viewed on a citywide scale, but planting for population stability requires planting a diverse mix of species when a single species, like Chinese elm, is planted beyond a set threshold (e.g., 10% of total population).

Figure 5 displays new and replacement planting trends. These five species composed 50% of the total number of young trees in the tree inventory. Chinese elm accounted for 16% of all trees less than 6-inches DBH, while Mondel pine, Willow acacia, and Live oak each accounted for 9%, and Chilean mesquite represented 6%. With the exception of some Mondel pine and Mesquite, these species have not been planted long enough for trees to grow into mature size classes (greater than 18-inch DBH). Initial indications are that, with the exception of Chilean mesquite, these species are well adapted and will mature gracefully. Mesquite are seldom planted now because they have been prone to blow-over and require frequent inspection and maintenance. All of these new plantings are medium-stature species, a vital consideration in efforts to diversify the forest while increasing the flow of benefits that larger-stature trees produce. Further evaluation of these species is needed.

Large, long-lived deciduous trees such as Mulberry and Arizona ash, Eucalyptus, and Aleppo pine were species that reached functional age and produced substantial benefits (Figure 6). These species had substantial tree numbers in large DBH classes, indicating their proven adaptability. However, except for Arizona ash, few of these larger-stature species have been planted recently. This is due in part to perceived hazard issues when planted along streets and in parks.

Palms accounted for 10% of the population, and one-half of these were Mexican fan palms. Although palms are a unique part of the visual landscape, they produce relatively little benefit (Figure 6). In parks, the average annual benefit from palms ranged from $6/tree for small palms to $12/tree for large palms. In comparison, benefits from small conifers, broadleaf evergreens, and deciduous trees were $13, $29, and $20 per tree, respectively. Palms are more costly to maintain than other tree-types, because they require more frequent pruning to remove fronds and fruit. From a cost-effectiveness perspective, phasing out of the palms is recommended.

Planting large- and medium-stature trees where space allows will be vital for maintaining the stream of benefits the community currently enjoys. A shift towards planting more palms or trees that have not proven to be long-lived could have the potential to reduce the future level of benefits afforded the community. The placement for the smaller trees in Glendale tends to be appropriate – under utility lines and in other restricted locations. Further evaluation of species performance and placement over the long-term

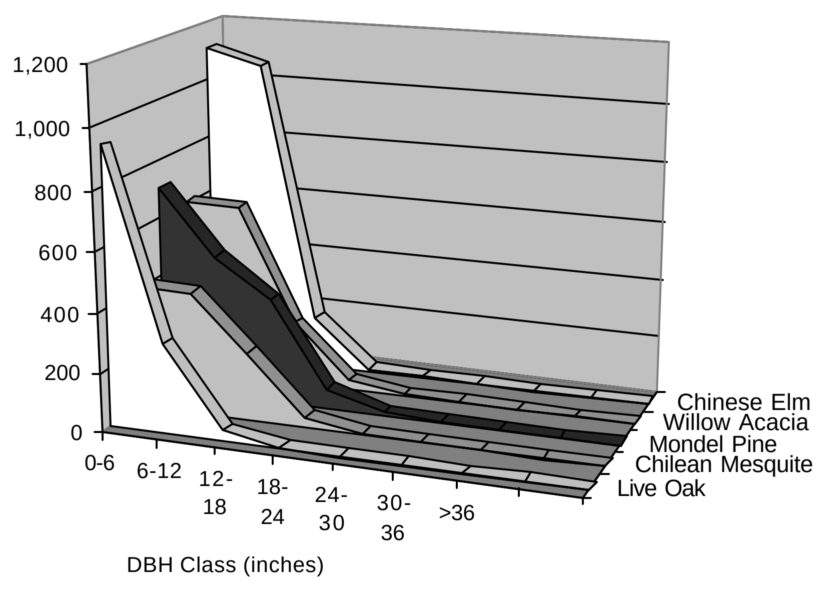

Figure 5. Top street trees planted by numbers and DBH.

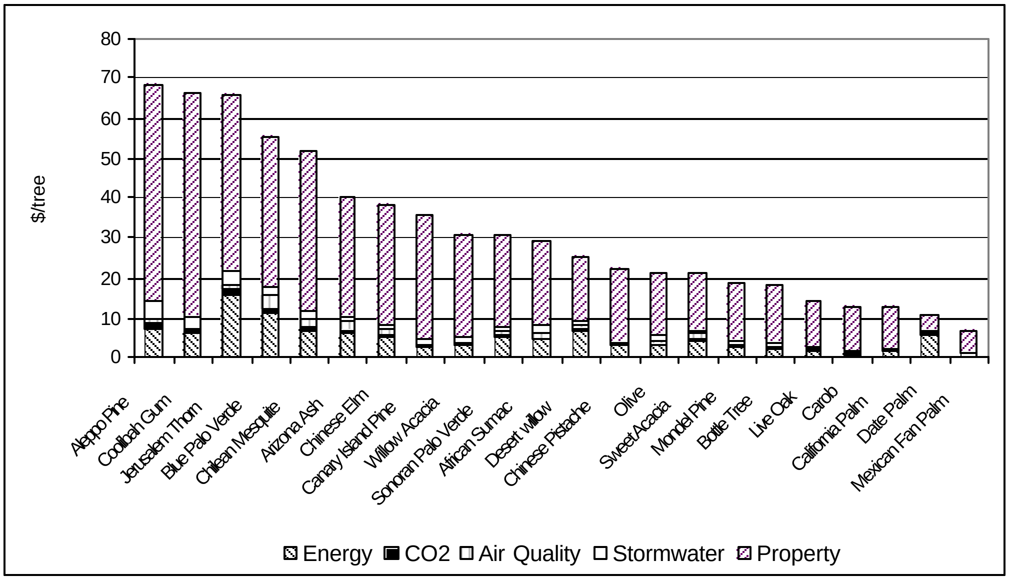

Figure 6. Street trees in Glendale that are producing the largest average annual benefits on a per tree basis.

is recommended with additional emphasis on planting long-lived large stature trees.

Live oak and Chinese elm are among the newer species requiring continued observation to determine their long-term suitability. Other large-growing species that appear to be performing adequately as they grow older include Bottle tree, Coolibah gum, Aleppo pine, and African sumac (*Rhus lancea*). Because the predominance of Chinese elm leaves Glendale open to potentially catastrophic losses from disease and insect infestation, it is important to limit the numbers planted. Simultaneously, the city should continue to increase age diversity by increasing the numbers of other long-lived large-stature trees.

By making a concerted effort to diversify its plantings, the city can help insure the stability of its canopy cover in the future. The city should establish a systematic planting program focused on planting species that have proven to be successful, as well as new species for evaluation. New introductions should not number more than 5-10% of total annual plantings. A continuing examination of species performance will aid in determining which species to include in the planting program.

Resource Extent

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As canopy cover increases, so do the benefits afforded by leaf area. It is important to remember that street trees throughout the US—and those of Glendale—likely represent less than 10% of the entire urban forest (Moll and Kollin 1993). In other words, the benefits Glendale residents realize from all urban vegetation is far greater than the values found through this analysis. But due to their location, street and park trees are typically the most visually important and expensive component to manage. Glendale invests 0.07% of its $403 million annual budget on the street and park tree population. It is unknown what amount residents expend on tree maintenance, but maximizing the return on the total investment is contingent upon maximizing and maintaining the canopy cover of these trees.

Increasing the street tree canopy cover requires a multifaceted approach in Glendale. Plantable spaces must be filled and use of large stature trees must be encouraged wherever feasible. According to the inventory, there were only 429 available tree planting spaces. To encourage increasing the flow of tree-provided benefits over time, sites for large trees should be planted first wherever possible, followed by those for medium and then small trees. As trees like the palms, and older Mulberry and Arizona ash are phased out, they should be replaced with trees that the city has experimented with and found suitable. These include varieties of Oak, Elm, Acacia, Pine, and Eucalyptus. Focusing planting efforts in zones where stocking levels are lowest will improve the distribution of benefits provided to all neighborhoods.

Management

Unfortunately, budget constraints of municipal tree programs often dictate the length of pruning cycles and maintenance regimes rather than the needs of the urban forest. Programmed pruning, under a reasonable timeline, can improve public safety by eliminating conflicts and increase benefits by improving tree health. Any dollar savings realized by the city deferring street tree planting and maintenance to residents is done at a loss in tree value and the cumulative value of the street and park tree population (Miller and Sylvester 1981).

Glendale's programmed pruning is a 1-year cycle or less, with more frequent inspection/pruning of Palms and trees in commercial districts. Inventory results indicated that only 62 of Glendale's trees needed pruning and 17 needed removal. About 400 young trees need pruning or staking adjustments. Hence, relatively few trees need attention because they have been maintained on a regular basis. In fact, the current inspection/pruning schedule may be more intensive than required for certain species. In their study of Milwaukee, WI, Miller and Sylvester (1981) found that extending pruning cycles beyond 4 or 5 years resulted in a loss of tree value that exceeded any savings accrued by deferring maintenance. In order to maintain consistency and maximize urban forest benefits while reducing city liabilities and public safety conflicts, the city of Modesto, CA had also found 4 years to be the ideal pruning cycle for their municipal forest (Gilstrap 1983). Certain species in Glendale may not require annual inspection/pruning once they have reached mature size, such as Oak, Acacia, Bottle tree, and Pines. Utilizing a "species pruning" approach to target these specific species and mature size classes could potentially reduce the total number of trees needing pruning over the short-term.

Chapter Six—Conclusion

City of Glendale, Arizona
Municipal Forest Resource Analysis

Glendale's street and park trees are a valuable asset, providing approximately $389,415 ($18.13/tree; $1.77/capita) in annual net benefits. Benefits alone totaled $665,850 ($31/tree; $3.03/capita). Increased aesthetic and local property values ($467,213; $20.62/tree) and energy savings ($116,728, $5.43/tree) were the most important benefits. Trees provided particularly important functions by reducing the amount of particulate matter and ozone in the air, and reducing stormwater runoff. Annual expenditures to manage and maintain this valuable resource totaled $276,436 ($12.87/tree; $1.26/capita). Pruning ($88,412; $4.12/tree), irrigation ($27,993; $1.30/tree), and administration ($82,950; $3.86/tree) were the largest costs. The resultant benefit-cost ratio (BCR) was $2.41. Thus, the street and park trees returned $2.41 in benefits to the community for every dollar ($1.00) spent.

Glendale's street and park trees are a dynamic resource. Managers of this resource and the community alike can delight in knowing that street trees do improve the quality of life in Glendale, but they are also faced with a fragile resource that needs constant care to maximize and sustain these benefits through the foreseeable future. The challenge will be to maximize net benefits from available growing space over the long-term, providing an urban forest resource that is both functional and sustainable. Chinese elm, Willow acacia, and Arizona ash are currently the most important species within the community, responsible for producing substantial benefits. Glendale's systematic effort to provide intensive care, pest management and maintenance for its street and park trees is exemplary. This high level of care is reflected by the fact that relatively few trees require pruning or removal. The age structure of Glendale's municipal forest is excellent, with many young trees poised to replace the aging Mulberry, Ash, and Eucalyptus. New plantings should strive to increase species diversity and locate large stature trees where feasible to promote an increasing stream of benefits. Regular updating of the tree inventory will enhance its use as a tool for evaluating the performance of new introductions over time. Continual testing of new types of trees, as well as continued planting of those species proven to be well-adapted, is vital to maintaining the flow of benefits into the future.

This analysis has provided the information necessary for resource managers to weigh the citywide needs with the more specific needs of individual tree management zones. Utilizing the structural indices outlined above— species composition, relative performance values, importance values, condition values, age distribution tables, maintenance requirements, etc.—along with benefit data, provide the requisite understanding for short- and long-term resource management.

Management recommendations include the following:

- Use the street tree inventory as a tool for assessing long-term adaptability of new species, particularly large-stature species, through regular re-evaluations of tree condition and relative performance. This will assist in determining which species to include in a long-term planting program.
- Develop a long-term plan to achieve resource sustainability. This requires increasing diversity of the street tree population by balancing new plantings of proven, long-lived species with successful, newer introductions. This plan should address:
    - Tree removal and replacement for senescent populations.
    - Planting available large-tree sites first, followed by those allowing medium and small trees.
    - Focus planting efforts along streets and in zones where stocking levels are lowest to improve the distribution of benefits provided to all neighborhoods.
    - Emphasize annual pruning of young trees for structure and form to reduce mature tree care costs.

- Phase-out palms, which are costly to maintain relative to the small benefits they produce.

- Tree health was good and pruning and removal needs were minimal. Efficiency might be bolstered by developing species-specific pruning cycles. This approach would target inspection/pruning work on those species and age classes that require the most intensive care. For example, young Mesquite could be pruned twice a year, while mature Eucalyptus could be pruned once every 2 years. Also, increased public education on appropriate pruning to demonstrate the resultant beneficial effects on tree health could also assist in improving the functionality, longevity, and the overall benefits produced by street trees.

Chapter Seven—References

City of Glendale, Arizona Municipal Forest Resource Analysis

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Appendix A

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 section describes the inputs and calculations used to derive the aforementioned outputs: growth modeling, identifying and calculating benefits, estimating magnitude of benefits provided, assessing resource unit values, calculating net benefits and benefit-cost ratio, and assessing structure.

Growth Modeling

Glendale's park and street tree inventory was completed in 1998 and served as the basis for this assessment. It contained 17,290 trees, 8,993 along streets and 8,297 in parks. Because the inventory was not regularly updated, the street tree inventory was increased by 4,190 trees to account for new plantings in excess of removals since 1998 (Wilkinson 2004). Lacking data from planting records, species of new outplants were assumed to be proportional to their numbers in the smallest two size classes. These new plantings were located in a hypothetical zone 7. After this adjustment, Glendale's tree population contained 13,183 street trees, and a total of 21,480 trees.

Tree growth models developed from Glendale data were used as the basis for modeling tree growth. Using Glendale's tree inventory, a stratified random sample of 21 tree species were measured to establish relations between tree age, size, leaf area and biomass for comparison with the regional growth curves.

For both the regional and local growth models information spanning the life cycle of predominant tree species was collected. The inventory was stratified into 9 diameter-at-breast height (DBH) classes: 0-7.62 in (0-7.62 cm), 3-6 in (7.62-15.24 cm), 6-12 in (15.24-30.48 cm), 12-18 in (30.48-45.72 cm), 18-24 in (45.72-60.96 cm), 24-30 in (60.96-76.2 cm), 30-36 in (76.2-91.44), 36-42 in (91.44-106.68 cm), and >42 in (106.68 cm). Thirty to 70 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 tape), tree crown and bole height (to nearest 0.5m by hypsometer), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5m by hysometer), tree condition and location, and crown pruning level (percentage of crown removed by pruning). Replacement trees were sampled when trees from the original sample population could not be located. Tree age was determined by street and park tree managers, interviews with residents, and historical planting records. Fieldwork was conducted in September and October 2003.

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 (±20 percent of actual leaf area) in estimating crown volume and leaf area of open-grown trees (Peper and McPherson 2003).

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

Identifying & Calculating Benefits

Annual benefits for Glendale's street trees were estimated for the year 2003. 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. The approach directly connects benefits with tree size variables such DBH and LSA. Many functional benefits of trees are related to leaf-atmosphere processes (e.g., interception, transpiration, photosynthesis), and, therefore, benefits increase as tree canopy cover and leaf surface area increase.

Prices were assigned to each benefit (e.g., heating/cooling energy savings, air pollution absorption, stormwater runoff reduction) through direct estimation and implied valuation as environmental externalities. Implied valuation is used to price 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 was not intended to be accurate to the penny. Rather, this approach provides a general accounting of the benefits produced by urban trees; an accounting with an accepted degree of uncertainty that can, nonetheless, provide a platform on which decisions can be made.

Energy Savings

Buildings and paving, along with low canopy and soil cover, increase the ambient temperatures within a city. Research shows that even in temperate climate zones—such as those of the Pacific Northwest—temperatures in urban centers are steadily increasing by approximately 0.5°F (0.3°C) per decade. Winter benefits of this warming do not compensate for the detrimental effects of magnifying summertime temperatures. Because electric demand of cities increases about 1-2% per 1°F (3-4% per °C) increase in temperature, approximately 3-8% of current electric demand for cooling is used to compensate for this urban heat island effect of the last four decades (Akbari et al. 1992).

Warmer temperatures in cities, compared to surrounding rural areas, have other implications. Increases in CO_2 emissions from fossil fuel power plants, municipal water demand, unhealthy ozone levels, and human discomfort and disease are all symptoms associated with urban heat islands. In Glendale, there are many opportunities to ameliorate the problems associated with hardscape through strategic tree planting and stewardship of existing trees allowing for streetscapes that reduce storm-water runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits through urban renewal developments and new development.

For individual buildings, street trees can increase energy efficiency in the summer and increase or decrease energy efficiency in winter, depending on placement. Solar angles are important when the summer sun is low in the east and west for several hours each day. Tree shade to protect east—and especially west—walls help keep buildings cool. In the winter, solar access on the southern side of buildings can warm interior spaces.

Trees reduce air infiltration and conductive heat loss from buildings. Rates at which outside air infiltrate into a building can increase substantially with wind speed. In cold, windy weather, the entire volume of air in a poorly sealed home may change two to three times per hour. Even in newer or tightly sealed homes, the entire volume of air 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). Reductions in wind speed reduce 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 by increasing the temperature gradient between inside and outside temperatures.

Electricity and Natural Gas Methodology

Calculating annual building energy use per residential unit (Unit Energy Consumption [UEC]) is based on computer simulations that incorporate building, climate and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs from trees (? UECs) 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. Typical meteorological year (TMY2) weather data for Phoenix Sky Harbor Airport were used (Marion and Urban 1995). Shading effects for each tree species measured were simulated at three tree-building distances, eight orientations and nine tree sizes.

Shading coefficients for tree crowns in leaf were based on a photographic method that estimates visual density. These techniques have been shown to give good estimates of light attenuation for trees in leaf (Wilkinson 1991). Visual density was calculated as the ratio of crown area computed with and without included gaps. Crown areas were obtained from digital images isolated from background features using the method of Peper and McPherson (2003). Values for trees not measured, and for all trees not in leaf, were based on published values where available (McPherson 1984, Hammond et al. 1980). Values for remaining species were assigned based on taxonomic considerations (trees of the same genus assigned the same value) or observed similarity in the field to known species. Foliation periods for deciduous trees were obtained from the literature (McPherson 1984, Hammond et al. 1980) and adjusted for Glendale's climate based on consultation with the local tree managers.

Tree distribution by location (e.g. frequency of occurrence at each location determined from distance between trees and buildings (setbacks), and tree orientation with respect to buildings) specific to Glendale was used to calculate average energy savings per tree as a function of distance and direction. 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 that was independent of location. Location-weighted savings per tree were multiplied by number of trees in each species/DBH class and then summed to find total savings for the city. Tree location measurements were based on samples of 819 park and right-of-way trees taken in late summer of 2003.

Land use (single family residential, multifamily residential, commercial/industrial, other) for right-of-way trees was based on the same tree sample. The same tree distribution was used for all land uses.

Three prototype buildings were used in the simulations to represent pre-1950, 1950 and post-1980 construction practices for Glendale (Mountain census region, Ritschard et al. 1992). Building footprints were modeled as square, which was found to be reflective of average impacts for large building populations (Simpson 2002). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37%, and were assumed closed when the air conditioner is operating. Summer and winter thermostat settings were 78° F and 68° F during the day, respectively, and 60° F at night. Unit energy consumptions were adjusted to account for saturation of central air conditioners, room air conditioners, and evaporative coolers (Table A1).

Single-Family Residential Adjustments

Unit energy consumptions for simulated single-family residential buildings were adjusted for type and saturation of heating and cooling equipment, and for various factors that modified the effects of shade and climate modifications on heating and cooling loads, using the expression,

$$?UEC_x = ?ŲEC^{sh}_{SFD} \times F_{sh} + ?ŲEC^{cl}_{SFD} \times F_{cl}$$

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

$$F_{cl} = F_{equipment} \times PCF \qquad \text{(Equation 1)}$$

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

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

$$\text{Total change} = N \times ?ŲEC_x. \qquad \text{(Equation 2)}$$

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

Estimated shade savings for all residential structures were adjusted by factors that accounted for shading of neighboring buildings, and reductions in shading from overlapping trees. Homes adjacent to those with shade trees may benefit from their shade. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an 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 reduction in average cooling and heating energy use per tree 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 to 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 (5-18 m) of buildings; lowered air temperatures and wind speeds from 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

Table A1. Saturation adjustments for cooling.

	Single family detached			Mobile Homes			Single family attached			MF 2-4 units			MF 5+ units			Commercial/ Industrial		Institution/ 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	
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	47%	55%	78%	47%	55%	78%	47%	55%	78%	47%	55%	78%	47%	55%	78%	63%	63%	63%
Evaporative cooler	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	2%	2%
Wall/window unit	23%	25%	11%	23%	25%	11%	23%	25%	11%	23%	25%	11%	23%	25%	11%	13%	13%	13%
None	60%	39%	22%	60%	39%	22%	60%	39%	22%	60%	39%	22%	60%	39%	22%	22%	22%	22%
Adjusted cooling saturation	53%	62%	81%	53%	62%	81%	53%	62%	81%	53%	62%	81%	53%	62%	81%	67%	67%	67%

use, air temperature and wind speed reductions as a function of neighborhood canopy cover were estimated from published values following McPherson and Simpson (1999), then used as input for building energy use simulations described earlier. Peak summer air temperatures were assumed reduced by 0.4 °F for each percentage increase in canopy cover. Wind speed reductions were based on the canopy cover resulting from the addition of the particular tree being simulated to that of the building plus other trees. A lot size of 10,000 ft^2 (929 m^2) was assumed.

Dollar value of electrical and natural gas energy savings were based on electricity and natural gas prices $0.1208 per kWh (Arizona Public Service 2003) and $0.9409 per therm (Southwest Gas 2003), respectively. Cooling and heating effects were reduced based on the type and saturation of air conditioning (Table A1) or heating (Table A2) equipment by vintage. Equipment factors of 33% and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning and heating loads (Table A3). The "other" and "fuel oil" heating equipment types were assumed 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.

Multi-Family Residential Analysis

Unit energy consumptions (UECs) from shade for multi-family residences (MFRs) were calculated from single-family residential UECs adjusted by adjusted potential shade factors (APSFs) to account for reduced shade resulting from common walls and multi-story construction. Average potential shade factors were estimated from potential shade factors (PSFs), defined 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=1 indicates that all exterior walls and roof are exposed and could be shaded by a tree, while PSF=0 indicates that no shading is possible (i.e., the common wall between duplex units). Potential shade factors were estimated separately for walls and roofs for both single and multi-story structures. Average potential shade factors were 0.74 for land use MFR 2-4 units and 0.41 for MFR 5+ units.

Unit energy consumptions were also adjusted for climate effects to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes with respect to single-family detached residences. 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

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

Potential climate 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 and others (1992) who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

Change in UECs due to shade 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 to 3,500 ft^2 [65-325 m^2]) is often larger than the building surface areas being shaded. Consequently, more area is shaded with increased surface area. However, for larger buildings, a point is reached at which no additional area is shaded as surface area increases. Therefore, ??UECs will tend to diminish as CFA increases. Since information on the

Table A2. Saturation adjustments for heating

Electric heating

Equipment efficiencies	Siingle family detached			Mobile Homes			Siingle family attached			MF 2-4 units			MF 5+ units			Commercial/Industrial		Institutional/
	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	Transportation
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	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	6.7%	9.9%	24.6%	4.9%	4.9%	4.9%
Heat pump	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	11.5%	16.9%	42.1%	5.4%	5.4%	5.4%
Adj elec heat saturations	3.3%	5.0%	12.0%	3.3%	5.0%	12.0%	3.3%	5.0%	12.0%	3.3%	5.0%	12.0%	3.3%	5.0%	12.0%	1.7%	1.7%	1.7%
Natural Gas and other heating																		
Natural gas	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	72.7%	62.0%	28.6%	89.7%	89.7%	89.7%
Oil	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Other	9%	11%	5%	9%	11%	5%	9%	11%	5%	9%	11%	5%	9%	11%	5%	0.0%	0.0%	0.0%
NG Heat saturations:	82%	73%	33%	82%	73%	33%	82%	73%	33%	82%	73%	33%	82%	73%	33%	90%	90%	90%

Table A3. Building vintage distribution and combined vintage/saturation factors for heating and air conditioning.

	Siingle family detached			Mobile Homes			Siigle family attached			MF 2-4 units			MF 5+ units			Commercial/Industrial		Institutional/
	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	Transportation
Vintage distribution by building type	2%	41%	57%	2%	41%	57%	2%	41%	57%	2%	41%	57%	2%	41%	57%	100%	100%	100%
Tree distribution by vintage and building type	0.95%	21.6%	30.5%	0.10%	2.25%	3.17%	0.08%	1.86%	2.62%	0.02%	0.35%	0.49%	0.09%	1.94%	2.73%	19.7%	11.6%	0.0%
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	0.26%	14.6%	23.0%	0.03%	1.51%	2.39%	0.02%	1.10%	1.74%	0.00%	0.17%	0.28%	0.01%	0.54%	0.85%	6.1%	1.8%	0.0%
Cooling factor: climate	0.27%	14.9%	23.6%	0.03%	1.48%	2.34%	0.02%	1.04%	1.64%	0.00%	0.11%	0.17%	0.01%	0.62%	0.97%	5.5%	10.7%	0.0%
Combined vintage, equipment saturation factors for heating																		
Heating factor, nat. gas: shade	0.76%	15.5%	9.92%	0.08%	1.61%	1.03%	0.06%	1.17%	0.75%	0.01%	0.18%	0.12%	0.03%	0.57%	0.36%	6.2%	1.8%	0.0%
Heating factor, electric: shade	0.03%	1.05%	3.58%	0.00%	0.11%	0.37%	0.00%	0.08%	0.27%	0.00%	0.01%	0.04%	0.00%	0.04%	0.13%	0.12%	0.03%	0.00%
Heating factor, nat. gas: climate	0.78%	15.8	10.2%	0.04%	0.90%	0.58%	0.06%	1.30%	0.83%	0.01%	0.11%	0.07%	0.03%	0.69%	0.44%	21.3%	41.7%	0.0%
Heating factor, electric: climate	0.03%	1.08%	3.66%	0.00%	0.06%	0.21%	0.00%	0.09%	0.30%	0.00%	0.01%	0.03%	0.00%	0.05%	0.16%	0.41%	0.80%	0.00%

precise relationships between change in UEC, CFA, and tree size are not known, it was conservatively assumed that ?UECs don't change in Equation 1 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 tree growth equations for DBH and height described earlier in this Appendix (see Tree Growth Modeling) 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, 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 assume 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 Glendale was 3.0% annually for the first five years after out-planting and 0.8% every year thereafter, based on mortality rates, provided by ROW/S and PR (Rodriguez and Wilkinson 2004; Van Meeteren 2004). Finally, CO_2 released from tree maintenance was estimated to be 0.16 kg CO_2/cm DBH based on tree maintenance activities which release 6.3 kg CO_2/tree based on carbon dioxide equivalent annual release of 37,320 liters (9,859 gal) of gasoline and diesel fuel use (Rodriguez and Wilkinson 2004; Van Meeteren 2004).

Avoided CO_2 Emissions Methodology

Reductions in building energy use result in reduced 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 fuel oil in Glendale. The overall fuel mix for electrical generation provided from Arizona Public Service Company was primarily nuclear (55%) and coal (39%) (U.S. EPA 2003). CO_2 emissions factors for electricity lb/MWh) and natural gas (lb/MBtu) weighted by the appropriate fuel mixes are given in Table A4. Implied value of avoided CO_2 was \$0.0075/lb based on average high and low estimates for emerging carbon trading markets (CO2e.com 2004) (Table A4).

Table A4. Emissions factors and implied values for CO_2 and criteria air pollutants. See text for sources of data

	Emission Factor		Implied
	Electricity	Natural gas	value
	(lb/MWh)[a]	(lb/MBtu)[b]	(\$/lb)[c]
CO_2	999	118	0.0075
NO_2	2.364	0.1020	4.00
SO_2	2.046	0.0006	15.70
PM_{10}	0.120	0.0075	6.00
VOC's	0.020	0.0054	4.00

[a]USEPA, eGRID 2003, except Ottinger et al. 1990 for VOC's, ozone
[b]U. S. Environmental Protection Agency 1998.
[c]CO2 from CO2e.com (2004). Value for SO_2 based on the methods of Wang and Santini (1995) using emissions concentrations from US EPA (2003) and population estimates from the US Census Bureau (2003). All other pollutants from Crumbaker (2004).

Improving Air Quality

Avoided Emissions Methodology

Reductions in building energy use also result in reduced emissions of criteria air pollutants 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 offset values (Table A4) were calculated in the same way as for CO_2, again using utility-specific emission factors for electricity and heating fuels. Values for SO_2 were based on control-cost-based emissions using the methods of Wang and Santini (1995) for the Phoenix area; values for all other criteria pollutants are from the Maricopa Environmental Services Department (Crumbaker 2004). NO_2 prices were used for ozone since ozone control measures typically aim at reducing NO_x, and population estimates from the U.S. Census Bureau (2003). Hourly meteorological data (air temperature, wind speed, solar radiation and precipitation) from the Phoenix Greenway station provided by the

Arizona Meteorological Network were used (AZMET 2004).

Deposition and Interception Methodology

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of a deposition velocity $V_d = 1/(R_a+R_b+R_c)$, a pollutant concentration (C), a canopy projection (CP) area, and a 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 for a year using formulations described by Scott et al. (1998). Hourly concentrations for NO_2, SO_2, O_3, and PM_{10} for Glendale and environs for 2001 were obtained from the Maricopa County Environmental Service Department (Davis 2004). Hourly data from 2001 were selected as representative for modeling deposition based on a review of mean PM_{10} and ozone concentrations for years 1994-2003. Data for stations closest in proximity and climate to Glendale were used – ozone from Glendale, NO_2 from West Phoenix, and PM_{10} and SO_2 from Central Phoenix.

Values of emissions removed and weather data were obtained as described in the Avoided Emissions Methodology section (Table A4). The implied value of NO_2 was again used for ozone. Deposition was determined for deciduous species only when trees were in-leaf. A 50% re-suspension rate was applied to PM_{10} deposition.

BVOC Emissions Methodology

Emission 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 as isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or temperature (monoterpene). Hourly emissions were summed to get annual totals. This is a conservative approach, since we do not account for the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from biogenic as well as anthropogenic sources. determined as described in the Avoided Emissions Methodology section (Table A-4).

Reducing Stormwater Runoff

Stormwater Methodology

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 1998). The interception model accounts for water intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Once the canopy surface's storage capacity is exceeded, water starts to drip from the leaf surface and flows down the stem surface to the ground. Some of the stored surface water will evaporate. Tree canopy parameters include species, leaf and stem surface area, shade coefficient (visual density of the crown), tree height, and foliation data. Tree height data were used to estimate wind speed at different heights above the ground and resulting rates of evaporation.

The volume of water stored in the tree crown was calculated from crown projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and water depth on the canopy surface, while species-specific shade coefficients and tree surface saturation values influence the amount of projected throughfall. Hourly meteorological data for 2001 from the Arizona Meteorological Network's Phoenix Greenway station (latitude: 33° 37' 17" N; longitude: 112° 06' 30" W) were selected to best represent a typical meteorological year and, consequently, used for this simulation (AZMET 2004). Annual precipitation during 2001 was 6.4 inches (162.2 mm). A more complete description of the interception model can be found in Xiao et al. (1998).

To estimate the value of rainfall intercepted by urban trees, stormwater management control costs were based on Glendale's cost for detention/retention basins. These basins are in parks and developers of adjacent land pay the city for use of the retention facilities. The Tarrington Place Park retention facility is 0.67 acres (0.27 ha) and 3-ft deep (0.9 m). The basin holds 2 acre feet (2,468 m^3) of runoff and the developer paid $43,550 for use of the facility (Cardin 2004). With operating and maintenance costs of $80/month for 20 years, the total project costs were $62,750. Assuming that the basin filled once annually for 20 years, the control cost was $0.0048/gal ($1.27/m^3).

Aesthetics & 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 that people plant trees is for beautification. Trees add color, texture, line, and form to the landscape. In this way, trees soften 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 found that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers indicated that they shop 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 domestic 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 tree resources suggests that people are willing to pay 3-7% more for properties with ample tree resources versus few or no trees. One of the most comprehensive studies of 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). A much greater value of 9% ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988). Depending on average home sales prices, the value of this benefit can contribute significantly to cities' 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 recreate 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 show 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've had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, and have a better outlook 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).

Although urban forests contain less biological diversity than rural woodlands, 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 U.S. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience (McPherson and Mathis 1999). Local nonprofit tree groups, along with municipal volunteer programs, often provide educational material, work with area schools, and hands-on training in the care of trees.

Property Value and Other Benefits Methodology

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place and well-being are products that are difficult to price. However, the value of some of these benefits may be captured in the property values for the land on which trees stand. To estimate the value of these "other" benefits, results of research that compares differences in sales prices of houses are used to statistically quantify the difference associated with trees. The amount of difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with the trees. This approach has the virtue of capturing what buyers perceive to be as both the benefits and costs of trees in the sales price. Some limitations to using this approach in Glendale include the difficulty associated with 1) determining the value of individual street trees adjacent to private properties and 2) the need to extrapolate results from front yard trees on residential properties to street and park trees in various locations (e.g., commercial vs. residential).

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. Along with identifying the leaf surface area (LSA) of a typical mature tree (30-year old Evergreen ash) in Glendale (2,691 ft^2) and using the average annual change in LSA per unit area for trees within each DBH class as a resource unit, this increase 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 Glendale, each large tree would be worth $1,269 based on the median 2003 standard home sales price in Glendale ($144,250) (Home Sales News 2004). However, not all trees are as effective as front yard residential 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 a single-family home. Therefore, a street tree reduction factor of 0.88 was applied to prorate trees' value based on the assumption that trees adjacent to differing land-use—single home residential, multi-home residential, commercial/industrial, vacant, park and institutional—were valued at 100%, 75%, 66%, and 50%, respectively, of the full $1,269 (McPherson et al. 2001). For this analysis, the reduction factor reflects Glendale land-use distributions and assumes an even tree distribution. A reduction factor of 0.50 was assumed for park trees.

Given these assumptions, a typical large street tree was estimated to increase property values by $0.47/$ft^2$ of LSA. For example, a 30-year old Evergreen ash that added 260 ft^2 of LSA annually, effectively added $123, annually, to the value of an adjacent home, condominium, or business property (260 ft^2 x $0.47/$ft^2$ = $123).

Estimating Magnitude of Benefits

Defined as *resource units*, the absolute value of the benefits of Glendale's street and park trees—electricity (kWh/tree) and natural gas savings (kBtu/tree), atmospheric CO_2 reductions (lbs/tree), air quality improvement (NO_2, PM_{10} and VOCs [lbs/tree]), stormwater runoff reductions (precipitation interception [ft^3/tree]) and property value increases (Δ LSA [ft^2/tree])—were assigned prices through methods described above for model trees.

Estimating the magnitude of benefits (resource units) produced by all street trees in Glendale required four procedures: 1) categorizing street trees by species and DBH based on the city's street tree inventory, 2) matching significant species with the growth models (21 modeled species), 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 (DBH class). The inventory was used to group trees using the following classes:

1. 0-3 in (0-7.5 cm)
2. 3-6 in (7.6-15.1 cm)
3. 6-12 in (15.2-30.4 cm)
4. 12-18 in (30.5-45.6 cm)
5. 18-24 in (45.7-60.9 cm)
6. 24-30 in (61-76.2 cm)
7. 30-36 in (76.3-91.4cm)
8. 36-42 in (91.4-106.7 cm)
9. >42 in (106.7 cm)

Because DBH classes represented a range, the median value for each DBH class was determined and subsequently utilized as a single value representing all trees encompassed in each class. Linear interpolation was used to estimate resource unit values (Y-value) for each of the 21 modeled species for the 9 midpoints (X-value) corresponding to each of the DBH classes assigned to the city's street trees.

Applying Benefit Resource Units to Each Tree

Once categorized, the interpolated resource unit values were matched on a one-for-one basis. For example, the interpolated electricity and natural gas resource unit values for the class size midpoint (9 in [23 cm]) were 31.5 kWh/tree and 359.5 kBtu/tree, respectively. If there were 18 trees of this size, multiplying the size class resource units by 18 equals the magnitude of annual heating and cooling benefits produced by this segment of the population: 567 kWh in electricity saved and 6,471 kBtu natural gas saved.

Matching Species with Modeled Species

To infer from the 21 municipal species modeled and adjusted for growth in Glendale to the inventoried street tree population, each species representing over 1% of the population was matched directly with corresponding model species. Where there was no corresponding tree, the best match was determined by identifying which of the 21 species was most similar in leaf shape/type, structure and habit.

Grouping Remaining "Other" Trees by Type

The species that were less than 1.0% of the population were labeled "other" and were categorized according to tree type classes based on tree type (one of two 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)and small (CES).
- Palm – large (PEL), medium (PEM, and small (PES, based on crown size.

Large, medium, and small trees measured >50 ft (15.2 m), 30-50 ft (9.1-15.2 m), and <30 ft (<9.1 m) in mature height, respectively. A typical tree was chosen for each of the above 12 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = Honeylocust (*Gleditsia triacanthos*)

BDM Other = Ornamental pear (*Pyrus sp.*)

BDS Other = Crabapple (*Malus sp.*)

BEL Other = Cooliban gum (*Eucalyptus microtheca*)

BEM Other = Bottle tree (*Brachychiton populneus*)

BES Other = African sumac (*Rhus lancea*)

CEL Other = Blue spruce (*Picea pungens*)

CES Other = scaled at 1/3 Ponderosa pine (*Pinus ponderosa*)

PEL Other = Common date palm (*Phoenix dactylifera*)

PEM Other = scaled at 2/3 Common date palm (*Phoenix dactylifera*)

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

Calculating Net Benefits And Benefit-Cost Ratio

It is impossible to quantify all the benefits and costs produced by trees. For example, property owners with large street trees can receive benefits from increased property values, but they may also benefit directly from improved human 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, as with allergies and respiratory ailments related to pollen. The value 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.

Glendale 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:

$$B = \sum_{1}^{n} j\left(\sum_{1}^{n} i\left(e_{ij} + a_{j} + c_{j} + h_{ij} + p_{ij}\right)\right) \quad \text{(Equation 3)}$$

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 less 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. Annual costs for municipal (*C*) were summed:

$$C = p + t + r + d + e + s + c + l + a + q \quad \text{(Equation 4)}$$

where,

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

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

$$\text{Citywide Net Benefits} = B - C \quad \text{(Equation 5)}$$

$$\text{BCR} = B/C \quad \text{(Equation 6)}$$

Assessing Structure

Street tree inventory information, including species composition, DBH, health, total number of trees, were collected and analyzed using the adjusted city tree inventory.

Appendix B

Tree Distribution

Table B-1. Tree numbers by size class (DBH in inches) for all street and park trees. Tree types are BDL, BDM, and BDS for broadleaf deciduous large, medium, and small, respectively. BE, CE and PE signify broadleaf evergreen, coniferous evergreen, and palm evergreen.

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% total
Large Deciduous											
Evergreen Ash	216	194	63	11	3	0	0	0	0	487	2.3%
BDL OTHER	52	37	54	65	41	24	3	2	1	279	1.3%
Total	268	231	117	76	44	24	3	2	1	766	3.6%
Medium Deciduous											0.0%
Chinese Elm	1,118	1,063	175	4	1	0	0	0	0	2,361	11.0%
Arizona Ash	290	386	448	58	16	16	3	0	1	1,218	5.7%
Chilean Mesquite	424	411	233	36	4	3	0	0	0	1,111	5.2%
Blue Palo Verde	169	163	120	53	7	0	0	0	0	512	2.4%
Chinese Pistache	219	176	80	7	1	1	0	0	0	484	2.3%
White Mulberry	5	32	75	84	23	15	2	2	0	238	1.1%
Jerusalem Thorn	16	27	100	76	6	2	0	0	0	227	1.1%
BDM OTHER	13	36	32	4	2	0	0	0	0	87	0.4%
Total	2,254	2,294	1,263	322	60	37	5	2	1	6,238	29.0%
Small Deciduous											0.0%
Sweet Acacia	217	334	127	10	0	0	0	0	0	688	3.2%
BDS OTHER	203	225	139	33	8	6	3	4	1	622	2.9%
Total	420	559	266	43	8	6	3	4	1	1,310	6.1%
Large Broadleaf Evergreen											0.0%
Coolibah Gum	143	281	182	42	11	3	0	0	0	662	3.1%
Eucalyptus	28	45	103	48	24	12	5	3	0	268	1.2%
BEL OTHER	50	78	85	61	17	3	3	1	0	298	1.4%
Total	221	404	370	151	52	18	8	4	0	1,228	5.7%
Medium Broadleaf Evergreen											0.0%
Willow Acacia	607	604	215	31	2	0	0	0	0	1,459	6.8%
Live Oak	932	301	34	0	0	0	0	0	0	1,267	5.9%
Bottle Tree	100	189	88	16	4	3	0	0	0	400	1.9%
Carob	148	150	3	1	0	0	0	0	0	302	1.4%
BEM OTHER	16	107	180	21	4	0	0	0	0	328	1.5%
Total	1,803	1,351	520	69	10	3	0	0	0	3,756	17.5%
Small Broadleaf Evergreen											0.0%
Olive	198	463	273	54	12	5	0	0	1	1,006	4.7%
Citrus Species	18	146	281	316	9	0	0	0	0	770	3.6%
African Sumac	78	196	201	43	9	0	0	0	0	527	2.5%
Feathertree	144	50	34	5	0	0	0	0	0	233	1.1%
BES OTHER	354	197	223	39	5	2	1	0	0	821	3.8%
Total	792	1,052	1,012	457	35	7	1	0	1	3,357	15.6%
Large Conifer											0.0%
Mondel Pine	705	483	355	64	8	0	0	0	0	1,615	7.5%
Aleppo Pine	57	118	253	119	40	10	2	0	0	599	2.8%
CEL OTHER	46	135	236	12	11	6	0	0	0	446	2.1%
Total	808	736	844	195	59	16	2	0	0	2,660	12.4%
Small Conifer											0.0%
CES OTHER	1	0	4	0	0	0	0	0	0	5	0.0%
Total	1	0	4	0	0	0	0	0	0	5	0.0%
Large Palm											0.0%
Date Palm	3	2	49	26	217	50	57	25	70	499	2.3%
PEL OTHER	0	0	0	0	0	0	0	0	0	0	0.0%
Total	3	2	49	26	217	50	57	25	70	499	2.3%
Medium Palm											0.0%
PEM OTHER	5	1	18	17	12	7	11	1	0	72	0.3%
Total	5	1	18	17	12	7	11	1	0	72	0.3%
Small Palm											0.0%
Mexican Fan Palm	107	107	36	70	80	92	216	131	221	1,060	4.9%
California Palm	35	27	88	62	45	27	92	46	42	464	2.2%
PES OTHER	19	10	22	13	0	1	0	0	0	65	0.3%
Total	161	144	146	145	125	120	308	177	263	1,589	7.4%
Citywide Total	6,736	6,774	4,609	1,501	622	288	398	215	337	21,480	

Appendix C

Tree Species List

Scientific Name	Common Name	TreeType
ACACIA ANEURA	Mulga	BES
ACACIA FARNESIANA	Sweet Acacia	BDS
ACACIA MINUTA	Scrub Wattle	BES
ACACIA SALICINA	Willow Acacia	BEM
ACACIA SALIGNA	Orange Wattle	BES
ACACIA SPECIES	Willow Acacia	BES
ACACIA STENOPHYLLA	Shoestring Acacia	BES
ALBIZIA JULIBRISSIN	Mimosa	BDM
ARECASTRUM ROMANZOFFIANUM	Queen Palm	PES
BAUHINIA VARIEGATA	Mountain Ebony	BDS
BRACHYCHITON POPULNEUM	Bottle Tree	BEM
BRAHEA ARMATA	Mexican Blue Palm	PES
CALLISTEMON VIMINALIS	Weeping Bottlebrush	BES
CARYA ILLINOENSIS	Pecan	BDL
CASUARINA EQUISETIFOLIA	Australian Pine	CEL
CERATONIA SILIQUA	Carob	BEM
CERCIDIUM FLORIDUM	Blue Palo Verde	BDM
CERCIDIUM MICROPHYLLUM	Foothills Palo Verde	BDS
CERCIDIUM PRAECOX	Sonoran Palo Verde	BDS
CHAMAEROPS HUMILIS	Mediterranean Fan Palm	PES
CHILOPSIS LINEARIS	Desert willow	BDS
CITRUS SPECIES	Citrus Species	BES
CUPRESSUS GUADALUPENSIS	Guadaluoe Cypress	CEL
CUPRESSUS SEMPERVIRENS	Italian Cypress	CEL
CYDONIA OBLONGA	Quince	BDS
DALBERGIA SISSOO	India Rosewood	BEL
EBENOPSIS EBANO	Texas Ebony	BES
EUCALYPTUS CAMALDULENSIS	Red Gum Eucalyptus	BEL
EUCALYPTUS LEUCOXYLON	White Ironbark	BEL
EUCALYPTUS MICROTHECA	Coolibah Gum	BEL
EUCALYPTUS POLYANTHEMOS	Sliver Dollar Gum Eucalyptus	BEL
EUCALYPTUS RUDIS	Desert Gum Eucalyptus	BEL
EUCALYPTUS SIDEROXYLON	Red Ironbark	BEL
EUCALYPTUS SPATHULATA	Narrow-Leaved Gimlet	BES
EUCALYPTUS SPECIES	Eucalyptus	BEL
EUCALYPTUS TORQUATA	Coral Gum	BEM
FICUS BENJAMINA	Bejamin Fig	BES
FICUS CARICA	Common Fig	BDS
FICUS RETUSA ssp. NITIDA	Indian Laurel Fig	BEM
FRAXINUS UHDEI	Evergreen Ash	BDL
FRAXINUS VELUTINA	Arizona Ash	BDM
GEIJERA PARVIFLORA	Australian Willow	BES
GLEDITSIA TRIACANTHOS	Honeylocust	BDL
GREVILLEA ROBUSTA	Silk Oak	BEL
JACARANDA MIMOSIFOLIA	Jacaranda	BDM
JUNIPEROUS SPECIES	Juniper	CES

Scientific Name	Common Name	TreeType
LAGERSTROEMIA INDICA	Crape Myrtle	BDS
LIGUSTRUM LUCIDUM	Chinese Privet	BES
LYSILOMA MICROPHYLLUM	Feathertree	BES
MACHAERIUM TIPU	Tipu Tree	BDM
MAGNOLIA GRANDIFLORA	Southern Magnolia	BEM
MALUS SPECIES	Malus Species	BDS
MELIA AZEDARACH	Chinaberry	BDM
MORUS ALBA	White Mulberry	BDM
MYRTUS COMMUNIS	Myrtle	BES
NERIUM OLEANDER	Oleander	BES
OLEA EUROPAEA	Olive	BES
OLNEYA TESOTA	Tesota	BES
OTHER SPECIES	Other Species	BES
PARKINSONIA ACULEATA	Jerusalem Thorn	BDM
PHOENIX CANARIENSIS	Canary Island Date Palm	PEM
PHOENIX DACTYLIFERA	Date Palm	PEL
PINUS CANARIENSIS	Canary Island Pine	CEL
PINUS ELDARICA	Mondel Pine	CEL
PINUS HALEPENSIS	Aleppo Pine	CEL
PINUS ROXBURGHII	Chir Pine	CEL
PINUS SPECIES	Pine Other	CEL
PISTACIA CHINENSIS	Chinese Pistache	BDM
PLATANUS RACEMOSA	California Sycamore	BDL
PLATANUS WRIGHTII	Arizona Sycamore	BDL
PLATYCLADUS ORIENTALIS	Oriental Arbor Vitae	BES
POPLAR SPECIES	Poplar Other	BDL
POPULUS BALSAMIFERA	Balm Of Gilead	BDL
POPULUS FREMONTII	Fremont Cottonwood	BDL
PROSOPIS ALBA	Argentine Mesquite	BEM
PROSOPIS CHILENSIS	Chilean Mesquite	BDM
PROSOPIS GLANDULOSA	Honey Mesquite	BDS
PROSOPIS PUBESCENS	Screwbean Mesquite	BDS
PROSOPIS SPECIES	Mesquite	BDS
PROSOPIS VELUTINA	Velvet Mesquite	BDS
PRUNUS ARMENIACA	Apricot	BDS
PRUNUS CERASIFERA	Cherry Plum	BDS
PRUNUS DULCIS	Almond	BDS
PRUNUS PERSICA	Nectarine	BDS
PRUNUS SPECIES	Prunus Species	BDS
PYRUS COMMUNIS	Ornamental Pear	BDM
PYRUS KAWAKAMII	Evergreen Pear	BES
QUERCUS MUEHLENBERGII	Chinkapin Oak	BDL
QUERCUS SUBER	Cork Oak	BEL
QUERCUS VIRGINIANA	Live Oak	BEM
RHUS LANCEA	African Sumac	BES
SALIX SPECIES	Weeping Willow	BDS
SALIX X SEPULCRALIS	Weeping Willow	BDM
SCHINUS MOLLE	California Peppertree	BEM
SOPHORA SECUNDIFLORA	Mescalbean	BES
TAMARIX CHINENSIS	Salt Cedar	BDS
TAXODIUM MUCRONATUM	Montezuma Cypress	CEL
THEVETIA PERUVIANA	Luckynut	BES
ULMUS PARVIFOLIA	Chinese Elm	BDM
VITEX AGNUS-CASTUS	Chaste Tree	BDS
WASHINGTONIA FILIFERA	California Palm	PES
WASHINGTONIA ROBUSTA	Mexican Fan Palm	PES