# CITY OF BERKELEY, CALIFORNIA
# MUNICIPAL TREE RESOURCE ANALYSIS

**By**

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## Table of Contents

# Executive Summary

Vibrant, renowned for its livability and cultural wealth, the city of Berkeley maintains trees as an integral component of the urban infrastructure. Research indicates that healthy trees can mitigate impacts associated with the built environment by reducing stormwater runoff, energy consumption, and air pollutants. Put simply, trees improve urban-life, making Berkeley a more enjoyable place to live, work, play, and study, while mitigating the city's environmental impact. Over the years, Berkeley has invested millions in its municipal forest. The primary question that this study asks is whether the accrued benefits from Berkeley's municipal forest justify the annual expenditures?

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information about Berkeley's urban forest resource (Maco 2003):

1. Structure: species composition, diversity, age distribution, condition, etc.

2. Function: magnitude of environmental and aesthetic benefits.

3. Value: dollar value of benefits realized.

4. Management needs: sustainability, maintenance, costs.

## *Urban Forest Resource Structure*

• Based on the municipal tree inventory, there were 36,485 actively managed street and park trees in Berkeley. Street trees accounted for 84% (30,779) of the total, and park trees comprised the remaining 16% (5,706).

• There are many opportunities to plant trees. Approximately 15,000 sites—33% of all street-tree sites—were unplanted; by management area, the percentage of unplanted sites ranged from 9–52%.

• Citywide, the municipal forest resource comprised 279 different tree species and diversity was high. However, management area 6 was dominated by only a few street-tree species, while management areas 1, 5 and 6 were dominated by only a few park-tree species. These areas should be of concern to managers.

• London plane and sweetgum, with the most leaf area and canopy cover, were found to be the two most important street trees. Coast live oak and coast redwood were the two most important park trees.

• The age structure for all municipal trees in Berkeley differed by management area, but, citywide, it was immature, lacking adequate numbers of functionally mature trees.

## *Urban Forest Resource Function and Value*

• Electricity saved annually in Berkeley from both shading and climate effects of municipal trees totaled 3,469 MWh, for a retail savings of $458,994 ($12.58/tree). Total annual savings of natural gas totaled 7,209 Mbtu, for a savings of $94,072 ($2.58/tree).

• Citywide, park-tree reduction of energy-plant $CO_2$ emissions and net sequestration rates were 228 tons and 480 tons, respectively, valued at $10,211. Street trees had an annual net sequestration rate of approximately 1,396 tons and reduced emissions by another 1,230 tons for a total savings of $39,391. These savings represent an average of $1.36 per tree annually.

• While air pollutants removed by trees and reduced due to lower energy consumption had an annual value of $143,228, significant emissions of biogenic volatile organic compounds (BVOCs) by several species meant the population as a whole produced a negative net air-quality benefit of $20,621. On average, the cost per tree was $0.57.

• The ability of Berkeley's municipal trees to intercept rain—thereby avoiding stormwater runoff—was substantial, estimated at 53.9 million gallons annually. The total value of this benefit to the City was $216,645. Citywide, the average street tree intercepted 1,478 gallons, valued at $5.91, annually.

• The estimated total annual benefit associated with property value increases and other less tangible benefits was approximately $2.4 million, or $67 per tree on average. American elm ($249/tree), sweetgum ($129/tree), and coast redwood ($108/tree) were the most valuable, while karo ($19/tree), cherry plums ($20/tree), and Victorian box ($20/tree) produced the least benefits.

• Overall, annual benefits were determined largely by tree size, with large trees typically producing greater benefits. For example, average small, medium, and large deciduous street trees produced annual benefits totaling $32, $79, and $96, respectively.

• The municipal tree resource of Berkeley is a valuable asset, providing approximately $3.25 million ($89/tree) in total annual benefits to the community. The City currently spends approximately $65 per tree on their care. Over the years, Berkeley has invested millions in its municipal forest. Citizens are now beginning to see a return on that investment—receiving $1.37 in benefits for every $1 spent on tree care. As the resource matures, continued investment in management is critical to insure that residents receive a greater return on investment in the future.

### *Urban Forest Resource Management Needs*

• Achieving resource sustainability requires that new plantings be well-adapted, long-lived species that maximize available growth space in order to provide the largest amount of leaf area and canopy coverage as the trees mature.

• Focusing planting efforts along streets where stocking levels are lowest will improve the distribution of benefits provided to all neighborhoods.

• Infrastructure repair costs are a concern in Berkeley because streetside planting sites are often narrow and susceptible to damage by tree roots. Selecting species with deep rooting patterns and testing mitigation strategies, such as rubber sidewalks, are ways to control costs and retain mature, functional trees.

Berkeley's municipal trees are a dynamic resource. Managers of this resource and the community alike can delight in knowing that municipal trees do improve the quality of life in Berkeley, but the resource is fragile and needs constant care to maximize and sustain the benefits through the foreseeable future. In a city where conflicts between hardscape and trees are high, this is no easy task. The challenge ahead is to better integrate the green infrastructure with the gray infrastructure by providing adequate space for trees and designing plantings to maximize net benefits over the long-term, thereby perpetuating a resource that is both functional and sustainable.

# Chapter One—Introduction

The Urban Forestry Unit of the Parks & Waterfront Department in Berkeley's Parks Division actively manages approximately 30,779 trees along streets and 5,706 trees in parks. The City believes that the public's investment in stewardship of the urban forest produces benefits that outweigh the costs to the community. Berkeley is a vibrant city, renowned for its livability and cultural wealth, and maintains trees as an integral component of the city infrastructure. Research indicates that healthy city trees can mitigate impacts associated with urban environs, such as polluted stormwater runoff, poor air quality, energy for heating and cooling buildings, and heat islands. Healthy street trees increase real estate values, provide neighborhood residents with a sense of place, and foster psychological health. Street and park trees are associated with other intangibles, too, such as increasing community attractiveness for tourism and business and providing wildlife habitat and corridors. Put simply, the urban forest makes Berkeley a more enjoyable place to live, work and play, while mitigating the city's environmental impact.

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

To answer this question, information is provided in order to following:

1. Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for Berkeley's urban forest.

2. Provide critical baseline information for evaluating program cost-efficiency and alternative management structures.

3. Highlight the relevance and relationship of Berkeley'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 four appendices:

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

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

**Chapter Three**—Costs of Managing Berkeley's Municipal Trees: Details management expenditures for publicly and privately managed trees.

**Chapter Four**—Benefits of Berkeley's 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 describes management challenges for street-tree maintenance.

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

**Chapter Seven**—References: Lists publications cited in the study.

**Appendix A**—Tree Distribution: Lists species and numbers of trees in street and park populations.

**Appendix B**—Methodology and Procedures: Describes benefits, procedures and methodology in calculating structure, function, and value of the street-tree resource.

# Chapter Two—Berkeley's Municipal Tree Resource

## *Tree Numbers*

Based on Berkeley's municipal tree inventory, there were 36,485 street and park trees actively managed in Berkeley (*Table 1*). Street trees accounted for 84% (30,779) of the total, while park trees comprised the remaining 16% (5,706).

Berkeley's entire municipal tree population is nearly evenly split among small, medium, and large trees, though park trees in general were larger than street trees (*Table 2*). At 59% of the total, deciduous trees were dominant citywide. However, at 49%, broadleaf evergreen trees were the prevalent tree type in parks. Conifers represented 4% of street trees and 25% of park trees, with a citywide total of only 7%. Palm species were relatively insignificant, representing only 1% of street and park trees.

## *Species Richness, Composition and Diversity*

There were 279 different tree species in the street tree inventory—an incredibly rich assemblage compared to other cities. McPherson and Rowntree (1989), in their nationwide survey of street-tree populations in 22 U.S. cities, reported a mean of 53 species. Moderate climates typically afford fewer growing restrictions and a greater plant palette from which to choose, but even San Francisco had only 115 street-tree species (Maco 2003); Modesto, CA had 184 municipal tree species (McPherson et al. 1999a).

The predominant street-tree species were London plane (*Platanus* x *acerifolia*, 8.6%), sweetgum (*Liquidambar styraciflua*, 7.5%) cherry plum *(Prunus cerasifera,* 4.7%), coast live oak (*Quercus agrifolia*, 4.6%), and

***Table 1****—Street and park tree numbers by management area.*

| Management area | Street | % of total street population | Park | % of total park population | Total | % of total population |
|---|---|---|---|---|---|---|
| 1 | 3,715 | 12 | 679 | 12 | 4,394 | 12 |
| 2 | 4,290 | 14 | 1,833 | 12 | 3,123 | 17 |
| 3 | 4,234 | 14 | 322 | 32 | 4,556 | 12 |
| 4 | 3,272 | 11 | 372 | 6 | 3,644 | 10 |
| 5 | 1,513 | 5 | 333 | 7 | 1,846 | 5 |
| 6 | 1,401 | 5 | 880 | 15 | 2,281 | 6 |
| 7 | 2,756 | 9 | 381 | 7 | 3,317 | 9 |
| 8 | 3,893 | 13 | 191 | 3 | 4,084 | 11 |
| 9 | 3,184 | 10 | 334 | 6 | 3,518 | 10 |
| 10 | 2,521 | 8 | 381 | 7 | 2,902 | 8 |
| Citywide total | 30,779 | - | 5,706 | - | 36,485 | - |

***Table 2****—Citywide street and park tree numbers by mature size class and tree type.*

| Tree Type | Street trees | | | | Park trees | | | | Total trees | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Small | Medium | Large | % of total | Small | Medium | Large | % of total | Small | Medium | Large | % of total |
| Deciduous | 5,321 | 8,707 | 6,078 | 65 | 663 | 435 | 312 | 25 | 5,984 | 9,142 | 6,390 | 59 |
| Broadleaf evergreen | 3,651 | 3,577 | 1,931 | 30 | 1,040 | 514 | 1,252 | 49 | 4,691 | 4,091 | 3,183 | 33 |
| Conifer | 100 | 437 | 602 | 4 | 26 | 18 | 1,411 | 25 | 126 | 455 | 2,013 | 7 |
| Palm | 339 | 0 | 36 | 1 | 18 | 0 | 17 | 1 | 357 | 0 | 53 | 1 |
| % of total | 31 | 41 | 28 | 100 | 31 | 17 | 52 | 100 | 31 | 38 | 32 | 100 |

*Table 3—Top five species in street and park populations listed in order by percent (in parentheses) of total tree numbers.*

| Management area | 1st | 2nd | 3rd | 4th | 5th | Total no. of trees |
|---|---|---|---|---|---|---|
| 1 | Camphor tree (10.6) | Cherry plum (10.4) | Coast live oak (10) | Cherry/plum species (5.5) | Flowering plum (4.4) | 3,715 |
| 2 | Coast live oak (15.7) | London plane (8) | Cherry/plum species (6.7) | Other (4.7) | Pine species (4.4) | 4,290 |
| 3 | London plane (24) | Sweetgum (8.3) | Cherry plum (7.1) | Camphor tree (4.1) | American elm (3.6) | 4,234 |
| 4 | Sweetgum (8.2) | Tulip tree (6.9) | London plane (6.8) | Cherry plum (6.3) | Camphor tree (5.2) | 3,272 |
| 5 | London plane (24) | Sweetgum (8.3) | Evergreeen pear (6.7) | Velvet ash (6.6) | Tulip tree (5.1) | 1,513 |
| 6 | London plane (39.3) | Evergreen pear (12.9) | Sweetgum (6.4) | Velvet ash (5.9) | Chinese elm (3.4) | 1,401 |
| 7 | Sweetgum (12.4) | Evergreen pear (10.9) | Purple-leaf plum (7) | London plane (5.2) | Ash species (4.5) | 2,756 |
| 8 | Ash species (15.6) | London plane (7.2) | Sweetgum (6.5) | White mulberry (6) | Purple-leaf plum (5.9) | 3,893 |
| 9 | Sweetgum (12) | London plane (6.8) | American elm (5.6) | Cherry plum (5.4) | Southern magnolia | 3,184 |
| 10 | California sycamore (14.5) | Sweetgum (13.5) | Cherry plum (6.8) | Victorian box (4.3) | Ash species (3.4) | 2,521 |
| Street Total | London plane (8.6) | Sweetgum (7.5) | Cherry plum (4.7) | Coast live oak (4.6) | Camphor tree (3.7) | 30,779 |
| Park Total | Coast live oak (16) | Coast redwood (8) | Monterey cypress (6.6) | Monterey pine (3.8) | Black acacia (3.5) | 5,706 |

camphor (*Cinnamomum camphora*, 3.7%) (*Table 3*). While no species exceeded the general rule that no single species should exceed 10% of the population (Clerk et al. 1997), this interpretation is belied by an examination of management areas. One species represented between 12 and 39% of the population total in all management areas except 3 and 4. These numbers suggest species composition is a potential concern at the area scale.

Considering only the park-tree population, coast live oak (16%) was the most common tree. Evergreen trees were dominant in parks, with coast redwood (*Sequoia sempervirens*, 8%), Monterey cypress (*Cupressus macrocarpa*, 7%), Monterey pine (*Pinus radiata*, 4%) and black acacia (*Acacia melanoxylon*, 4%) rounding out the top five most prevalent species.

As a measure of diversity, Simpson's diversity index, *C*, denotes the probability that two trees, chosen at random, will be of the same species; the lower the number, the more diverse the population (Simpson 1949). For example, *C*=0.10 can be interpreted as the equivalent of 10 species with equal proportions of each. Twenty species with equal proportions of each would have an index

*Table 4—Simpson's diversity index (C) for street- and park-tree populations by management area and citywide.*

| Management area | Street | Park |
|---|---|---|
| 1 | 0.05 | 0.17 |
| 2 | 0.05 | 0.09 |
| 3 | 0.03 | 0.04 |
| 4 | 0.04 | 0.04 |
| 5 | 0.08 | 0.14 |
| 6 | 0.18 | 0.12 |
| 7 | 0.05 | 0.06 |
| 8 | 0.05 | 0.05 |
| 9 | 0.04 | 0.03 |
| 10 | 0.06 | 0.06 |
| Citywide | 0.03 | 0.05 |

value of 0.05, equivalent to each species representing about 5% of the population.

Citywide, Berkeley's street and park trees had a diversity index of 0.03 and 0.05, respectively, indicating the populations were diverse (*Table 4*). However, a complete understanding of street-tree diversity must account for local vulnerability (Sanders 1981). Within the street-tree population, only management area 6 (*C*=0.18) is a concern. Here, London plane and evergreen pear (Pyrus kawakami) comprise over 50% of the population—a catastrophic loss of either species would leave a large structural and functional gap in the neighborhood. Park-tree diversity could improve in management areas 1, 5 and 6. Coast live oak dominates in area 1, growing predominantly in parks established in native oak groves, while Monterey cypress dominates populations in areas 5 and 6 in parks throughout the Marina.

### Species Importance

Importance values are particularly meaningful to managers because they suggest a community's reliance on the functional capacity of particular species. Importance value (IV) allows for a meaningful interpretation of the degree to which a city might depend on particular urban trees insofar as their environmental benefits are concerned. This evaluation takes into account not only total numbers, but their canopy cover, leaf area and spatial

***Table 5a****—Importance Values (IV) calculated as the mean of tree numbers, leaf area, and canopy cover for the most abundant street tree species.*

| | Species | No. of trees | % of total trees | Leaf area ($ft^2$) | % of total leaf area | Canopy cover ($ft^2$) | % of total canopy cover | Importance value |
|---|---|---|---|---|---|---|---|---|
| Street trees | London plane | 2,656 | 9 | 9,849,453 | 18 | 4,066,582 | 22 | 16 |
| | Sweetgum | 2,321 | 8 | 6,808,438 | 13 | 1,491,567 | 8 | 9 |
| | Cherry plum | 1,439 | 5 | 853,258 | 2 | 312,151 | 2 | 3 |
| | Coast live oak | 1,430 | 5 | 1,845,968 | 3 | 487,150 | 3 | 4 |
| | Camphor tree | 1,154 | 4 | 2,844,722 | 5 | 1,196,298 | 7 | 5 |
| | Ash species | 1,119 | 4 | 2,527,593 | 5 | 804,904 | 4 | 4 |
| | Cherry/plum species | 1,004 | 3 | 474,664 | 1 | 176,357 | 1 | 2 |
| | Evergreen pear | 998 | 3 | 967,601 | 2 | 348,832 | 2 | 2 |
| | Purple-leaf plum | 619 | 2 | 404,502 | 1 | 147,353 | 1 | 1 |
| | American elm | 584 | 2 | 4,827,345 | 9 | 1,265,287 | 7 | 6 |
| | Southern magnolia | 579 | 2 | 627,693 | 1 | 224,004 | 1 | 1 |
| | Velvet ash | 521 | 2 | 1,484,062 | 3 | 475,309 | 3 | 2 |
| | Chinese pistache | 517 | 2 | 227,438 | 0 | 88,148 | 0 | 1 |
| | Japanese maple | 503 | 2 | 366,101 | 1 | 105,534 | 1 | 1 |
| | Other | 493 | 2 | 308,624 | 1 | 89,464 | 0 | 1 |
| | Chinese elm | 490 | 2 | 1,141,723 | 2 | 602,749 | 3 | 2 |
| | Victorian box | 473 | 2 | 393,625 | 1 | 150,331 | 1 | 1 |
| | Ginkgo | 449 | 1 | 380,485 | 1 | 99,133 | 1 | 1 |
| | California sycamore | 439 | 1 | 1,416,356 | 3 | 572,347 | 3 | 2 |
| | Callery pear | 427 | 1 | 439,587 | 1 | 141,553 | 1 | 1 |
| | Tulip tree | 412 | 1 | 845,344 | 2 | 220,879 | 1 | 1 |
| | Black locust | 396 | 1 | 481,087 | 1 | 153,655 | 1 | 1 |
| | Cotoneaster | 358 | 1 | 151,456 | 0 | 41,465 | 0 | 1 |
| | Flowering plum | 353 | 1 | 190,606 | 0 | 70,981 | 0 | 1 |
| | Raywood ash | 322 | 1 | 446,932 | 1 | 134,470 | 1 | 1 |
| | Pine species | 322 | 1 | 848,342 | 2 | 219,852 | 1 | 1 |
| | Honeylocust | 314 | 1 | 328,262 | 1 | 113,748 | 1 | 1 |
| | Red maple | 308 | 1 | 130,931 | 0 | 40,500 | 0 | 0 |
| | Total | 21,000 | 68 | 41,612,192 | 78 | 13,840,603 | 76 | 74 |

*__Table 5b__—Importance Values (IV) calculated as the mean of tree numbers, leaf area, and canopy cover for the most abundant park tree species.*

| | Species | No. of trees | % of total trees | Leaf area ($ft^2$) | % of total leaf area | Canopy cover ($ft^2$) | % of total canopy cover | Importance value |
|---|---|---|---|---|---|---|---|---|
| Park Trees | Coast live oak | 912 | 16 | 1,702,222 | 15 | 465,316 | 16 | 16 |
| | Coast redwood | 458 | 8 | 2,133,577 | 19 | 261,088 | 9 | 12 |
| | Monterey cypress | 374 | 7 | 1,330,296 | 12 | 170,527 | 6 | 8 |
| | Monterey pine | 219 | 4 | 638,185 | 6 | 160,775 | 6 | 5 |
| | Black acacia | 199 | 3 | 340,024 | 3 | 44,348 | 2 | 3 |
| | Cherry/plum species | 199 | 3 | 120,414 | 1 | 104,535 | 4 | 3 |
| | Blue gum eucalyptus | 142 | 2 | 778,672 | 7 | 210,285 | 7 | 6 |
| | Tarata pittosporum | 141 | 2 | 76,541 | 1 | 34,444 | 1 | 1 |
| | California laurel | 123 | 2 | 382,018 | 3 | 124,895 | 4 | 3 |
| | Cotoneaster | 109 | 2 | 54,698 | 0 | 15,503 | 1 | 1 |
| | Karo | 109 | 2 | 50,217 | 0 | 23,140 | 1 | 1 |
| | California buckeye | 107 | 2 | 88,550 | 1 | 22,645 | 1 | 1 |
| | Victorian box | 106 | 2 | 66,698 | 1 | 27,260 | 1 | 1 |
| | Canary Island pine | 98 | 2 | 299,545 | 3 | 77,673 | 3 | 2 |
| | Christmas berry | 73 | 1 | 52,498 | 0 | 16,965 | 1 | 1 |
| | Other | 71 | 1 | 148,160 | 1 | 45,229 | 2 | 1 |
| | Strawberry tree | 65 | 1 | 45,559 | 0 | 14,638 | 1 | 1 |
| | Arroya willow | 64 | 1 | 71,519 | 1 | 24,443 | 1 | 1 |
| | White alder | 63 | 1 | 156,115 | 1 | 49,429 | 2 | 1 |
| | Cherry plum | 62 | 1 | 35,870 | 0 | 13,077 | 0 | 1 |
| | Total | 3,694 | 65 | 8,571,376 | 75 | 1,906,214 | 66 | 69 |

distribution (frequency), providing a useful comparison to the total population distribution.

As a mean of three 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 28 most abundant street-tree species listed in *Table 5* constituted 68% of the total street-tree population, 78% of the total leaf area, and 76% of total canopy cover; park trees listed accounted for 65% of the total park-tree population, 75% of the leaf area, and 66% of total park canopy cover. In both cases, the total canopy cover and leaf area afforded by these same species was greater than population numbers alone would indicate.

As *Table 5* illustrates, not all species are as important as their population numbers suggest. For example, cherry plums account for 5% of all street trees. Because of their relatively small crowns, the amount of leaf area and canopy cover they provide is comparatively less, lowering their importance to the community by approximately 40% when all IV components are considered. Conversely, species such as London plane are much more important to the community than their numbers alone suggest.

London plane trees account for 9% of total street-tree numbers, 18% of total leaf area and 22% of the canopy cover; the IV index suggests Berkeley relies on this species for approximately 16% of total functionality. Coast redwoods provide similar functionality for park trees.

### Street Trees per Capita

Calculations of street trees per capita are important in determining how well forested a city is. Assuming a human population of 104,000 (CA Dept. of Finance 2004), Berkeley's ratio of street trees per capita is 0.35, approximately one tree for every three people, and on par with the mean ratio of 0.37 reported for 22 U.S. street tree populations (McPherson and Rowntree 1989).

*Table 6*—Recorded available planting spaces by numbers and planting site size.

| Management area | # of available planting sites | % of unplanted areas | Small tree (%) | Medium tree (%) | Large tree (%) | % of total planting sites |
|---|---|---|---|---|---|---|
| 1 | 1,666 | 0.31 | 72.51 | 24.31 | 3.18 | 11.12 |
| 2 | 448 | 0.09 | 93.53 | 6.03 | 0.45 | 2.99 |
| 3 | 1,373 | 0.24 | 91.55 | 8.01 | 0.44 | 9.16 |
| 4 | 1,897 | 0.37 | 94.36 | 5.17 | 0.47 | 12.66 |
| 5 | 1,665 | 0.52 | 73.51 | 22.82 | 3.66 | 11.11 |
| 6 | 1,371 | 0.49 | 95.55 | 4.38 | 0.07 | 9.15 |
| 7 | 1,555 | 0.36 | 91.83 | 7.85 | 0.32 | 10.38 |
| 8 | 2,381 | 0.38 | 99.37 | 0.63 | 0.00 | 15.89 |
| 9 | 1,123 | 0.26 | 91.36 | 5.88 | 2.76 | 7.49 |
| 10 | 1,506 | 0.37 | 98.94 | 0.00 | 1.06 | 10.05 |
| Citywide total | 14,985 | 0.33 | 90.21 | 8.56 | 1.23 | 100.00 |

## Stocking Level

There were 14,985 available street-tree planting sites in Berkeley (*Table 6*) and an additional 120 sites where stumps were present. Together, these sites represent 33% of the total recorded street-tree planting sites. Hence, 67% of all planting sites were filled with trees. Sites available for small trees (<25 ft tall) predominated, numbering 13,516. Sites available for medium trees (25-40 ft) numbered 1,288 and only 180 sites were available for large trees (>40 ft). Area 2, in northeast Berkeley, is largely residential and had the fewest unplanted sites, with a stocking rate of 91%. The greatest need for planting was in the largely commercial/industrial areas of 5 and 6 (west of San Pablo Avenue) where planting sites were only filled at a rate of approximately 50%. Available planting sites were not recorded for parks.

## 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 trans-

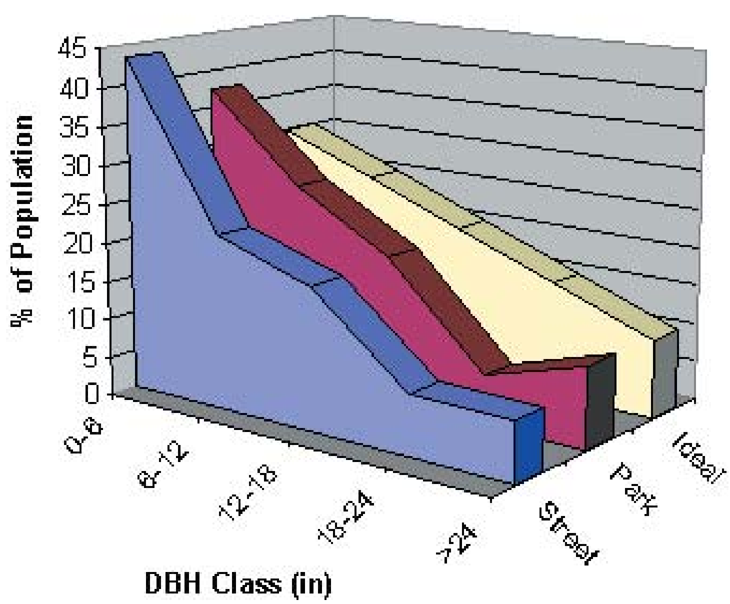


**Figure 1**—Ideal and existing relative age distribution shown for Berkeley's two tree populations.

plants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

The age structure for all actively managed park and street trees in Berkeley differed from the ideal in having more newly planted trees and fewer maturing, mature and old trees (*Fig. 1*). While the high proportion of very young trees demonstrates increased planting efforts over the past few years, the greatest population weakness in both populations is in the mature tree category (18–24 in DBH). These are the functionally mature trees that tend to produce the highest level of benefits. Over time, if new plantings keep pace, the populations will align with the ideal as the new plantings mature.

Age curves for different tree species help explain their relative importance and suggest how tree management needs may change as these species grow older. *Figure 2* shows the importance of understanding relative age at different scales. The populations of American elm, ash and London plane were largely mature. These trees have provided benefits over a long period of time, and, because of their leaf area, are particularly important. The intensity of newer plantings of small trees, such as cherry/purple-leaf plum (Prunus spp.) and evergreen pears, likely will not provide the level of benefits larger species afford.

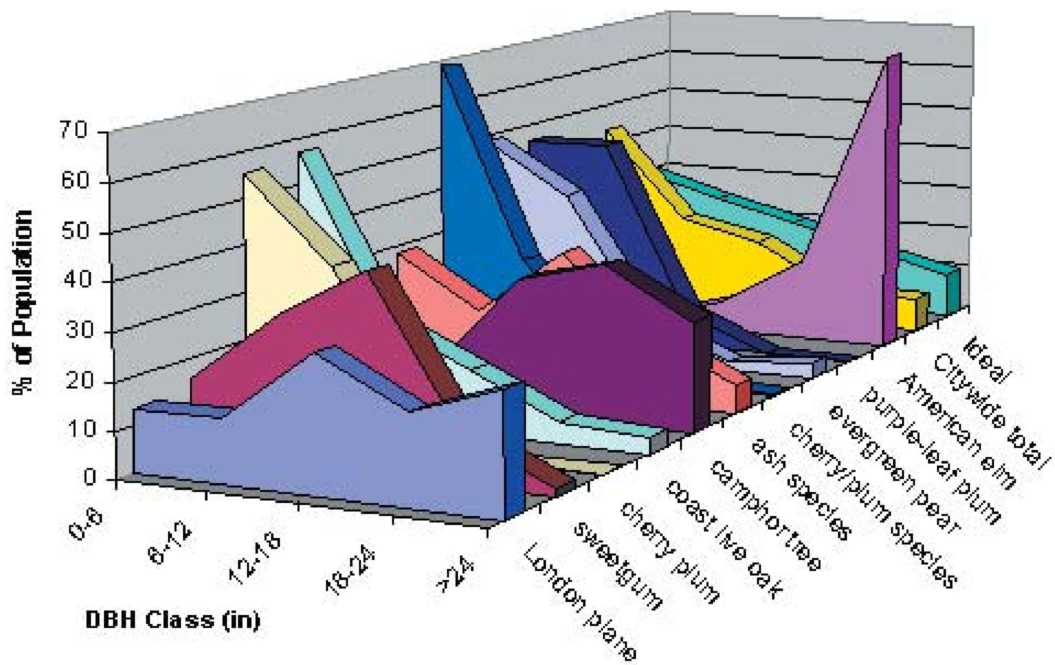


**Figure 2**—Relative age distribution for Berkeley's 10 most abundant street trees citywide shown with an ideal distribution.

As displayed in *Figure 3*, new park-tree plantings are dominated by mixture of small and large species: coast live oak, Monterey cypress, blackwood acacia, cherry plums, and tarata pittosporum (Pittosporum eugenioides). The mature population, on the other hand, is dominated entirely by large trees, including blue gum (Eucalyptus globulus), California laurel (Umbellularia californica), Monterey pine (Pinus radiata), Monterey cypress, and coast redwood (Sequoia sempervirens). The significant numbers of cherry plums and pittosporum will reduce future functionality on a per-tree basis, as these species will not provide the same level of canopy cover and leaf area as their predecessors have. Future benefits depend on the long-term health and the mature size of species currently planted.

Street-tree populations exhibited a general trend of numerous new plantings and lack of tree numbers in mature size classes (*Fig. 4*). One interpretation is that tree functionality will increase as these populations mature; however, an abundance of small-stature transplants suggests that large, mature trees will never be a substantial component of the population.

### Tree Condition

Tree condition indicates both how well trees are managed and their relative performance given site-specific conditions. Overall, little difference was found between street and park trees: approximately 75% were in "good"

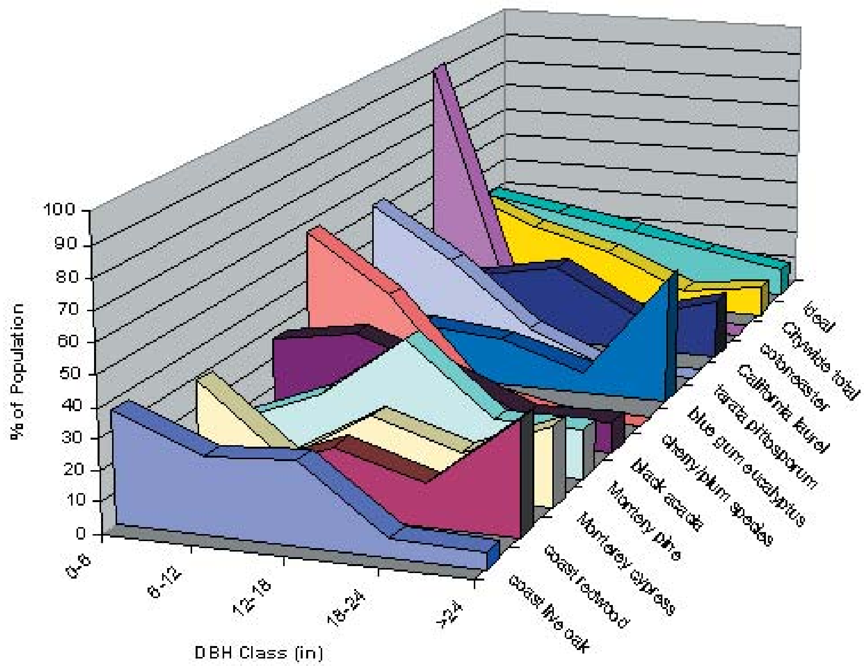


**Figure 3**—Relative age distribution for Berkeley's 10 most abundant park trees citywide shown with an ideal distribution.

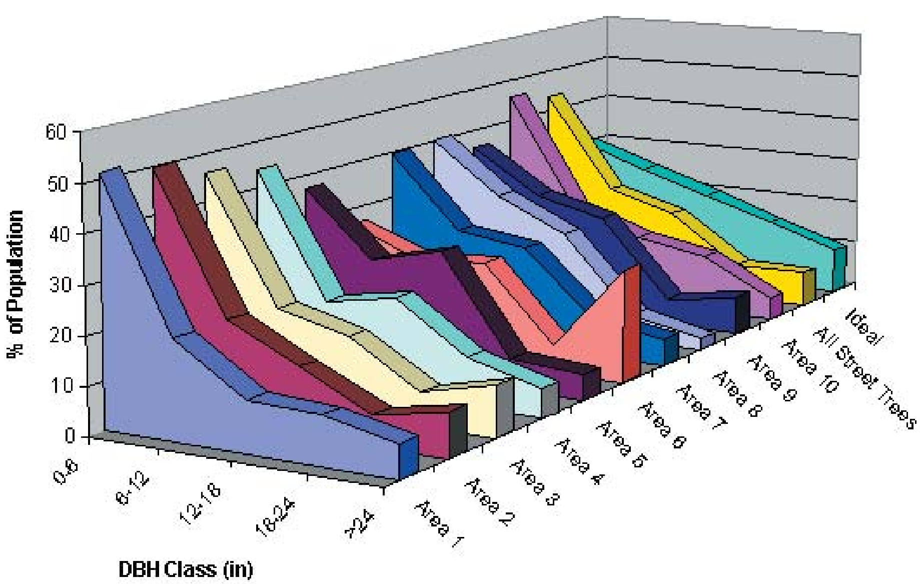


**Figure 4**—Relative age distribution of all street trees by management area.

or “very good” condition, 20% were classified as “fair”, and 5% were found to be in “poor” condition (*Fig. 5*).

Though municipal trees were healthy overall, examination of condition by management area highlighted areas of localized concern (*Table 7*). Populations needing attention include street trees in areas 1, 2, and 5, while park trees were rated below average in area 5.

The relative performance index (RPI) of each species provides an indication of its suitability to local growing conditions, as well as its performance. Species with larger percentages of their trees in good or better condition are likely to provide greater benefits at less cost than species with more trees in fair or poor condition. Abundant species rated as having the best performance overall were ginkgo, callery pear, evergreen pear, tulip tree (*Liriodendron tulipifera*), and ash species. These species were widely adapted to growing conditions throughout the city, whether in parks or on streets. Predominant species with the poorest performance included flowering plum (*Prunus blireiana*), American elm, camphor, Monterey cypress, and cherry plum species. Amongst these five, only cherry plums continue to be planted in high numbers.

### Tree Canopy

The combined street- and park-tree canopy was estimated at over 21 million $ft^2$, or 484 acres. Canopy cover from municipal trees covered 4.2% of the city given a city area of 18.08 $mi^2$; eighty-six percent of this coverage was due to street trees (418 ac), with the remaining cover (67 ac) attributed to park trees.

Assuming Berkeley had 220 miles of street, and the average curb-to-curb distance was 36 ft, street trees covered 10.4% of total street area in Berkeley—on par with similar-sized, well-treed communities. For example, public street trees in Davis, CA, were reported to cover 11% of the cities total street area. Research has shown that by shading asphalt surfaces and parked vehicles, trees reduce hydrocarbon emissions from gasoline that

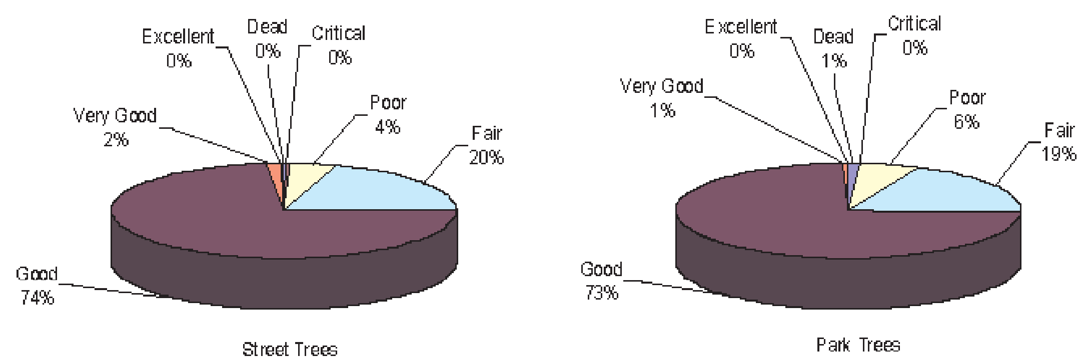


**Figure 5**—Distribution of condition of street and park trees citywide.

***Table** 7—Condition of street- and park-tree populations (%) by management area.*

| Management area | Street trees | | | | | | | Park trees | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | Critical | Poor | Fair | Good | Very good | Excellent | Dead | Critical | Poor | Fair | Good | Very good | Excellent |
| 1 | 1 | 1 | 8 | 37 | 52 | 2 | 0 | 0 | 0 | 7 | 21 | 71 | 0 | 0 |
| 2 | 0 | 0 | 5 | 37 | 58 | 0 | 0 | 1 | 0 | 5 | 17 | 77 | 0 | 0 |
| 3 | 0 | 0 | 5 | 19 | 73 | 2 | 0 | 0 | 0 | 4 | 14 | 82 | 0 | 0 |
| 4 | 0 | 0 | 4 | 20 | 70 | 6 | 0 | 2 | 0 | 7 | 19 | 69 | 3 | 0 |
| 5 | 1 | 0 | 10 | 28 | 58 | 4 | 0 | 1 | 0 | 10 | 19 | 71 | 0 | 0 |
| 6 | 0 | 0 | 1 | 2 | 96 | 0 | 0 | 2 | 0 | 6 | 22 | 70 | 1 | 0 |
| 7 | 0 | 0 | 2 | 5 | 93 | 0 | 0 | 2 | 0 | 6 | 21 | 71 | 1 | 0 |
| 8 | 0 | 0 | 1 | 3 | 95 | 0 | 0 | 1 | 0 | 4 | 24 | 70 | 1 | 0 |
| 9 | 0 | 0 | 4 | 21 | 74 | 1 | 0 | 1 | 0 | 5 | 17 | 75 | 1 | 0 |
| 10 | 1 | 1 | 5 | 20 | 73 | 0 | 1 | 2 | 0 | 2 | 20 | 72 | 3 | 0 |

evaporates out of leaky fuel tanks and worn hoses (Scott et al. 1999). These evaporative emissions are a principal component of smog, and parked vehicles are a primary source.

The additional benefits of shade provided by canopy cover include offsetting pavement management costs by protecting paving from weathering. The asphalt paving on streets contains stone aggregate in an oil binder. Tree shade lowers the street surface temperature and reduces the heating and volatilization of the oil. As a result, the aggregate remains protected for a longer period by the oil binder. When unprotected, vehicles loosen the aggregate, and much like sandpaper, the loose aggregate grinds down the pavement (Muchnick 2003).

## *Location and Land Use*

Ninety-eight percent of street trees in Berkeley were located in planting strips or sidewalk cutouts. Of the remaining trees, 129 were adjacent to pathways and 371 were in street medians. Our sample demonstrated that 68% of these trees were adjacent to single-family residences and others were on commercial/industrial (17%), multi-home residential (10%), and institutional (4%) property. The 5,706 actively managed park trees were distributed approximately 50/50, with half in recreational park areas and half on institutional grounds (city government and school grounds).

## *Maintenance Needs*

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

### Routine Maintenance

Based on the city's tree inventory, a significant 42 and 25% of street and park trees, respectively, had structural defects ranging from trunk cavities and decay to included bark and co-dominant leaders.

Our random sample of street and park trees included an assessment of maintenance needs, and showed that 61% of street trees and 53% of park trees were in need of routine maintenance. In order to promote continued good health and performance, trees need maintenance, including crown cleaning and thinning, removal of epicormic sprouts, and pruning for clearance or to maintain the structural integrity of the tree.

### Safety and Removals

Trees designated for a safety prune present a hazardous condition. Trees requiring removal have severe problems, although these are not necessarily related to safety hazards. They may simply be dead or dying newly planted trees, or they may reflect unmanageable tree defects and hazards. Regardless, trees classified as needing removal and replacement detract from aesthetic appearance at best, and represent substantial costs or public safety hazards at worst. Based on the random sample, citywide, there were approximately 32 park trees and 215 street trees requiring safety pruning. Trees needing removal were more numerous: 95 park trees and 1,046 street trees, 1.7 and 3.4% of the population totals, respectively.

### Sidewalk Heave

Root-infrastructure conflicts are of particular concern to street-tree managers due to the large costs associated with repairs. Sidewalk heave involves an additional burden associated with potential legal costs from trip-and-fall incidents. In Berkeley, where 98% of street trees were located in planting strips or sidewalk cutouts, the potential for these conflicts is high. As a result of our random sample, an estimated 21% (6,464 trees) of all street trees were associated with heave above the ¾ inch standard threshold (*Table 8*). Of these, approximately 34% were associated with heave greater than 1½ inches. Trees associated with heave also had a higher incidence of sidewalk repair history, suggesting that with many trees heave is a recurring problem; citywide, an estimated 33% of all street trees were adjacent to sidewalks with repair history.

***Table 8****—Estimated current sidewalk heave associated with Berkeley's street trees, shown with percent of trees adjacent to previous sidewalk repair.*

| Sidewalk heave category (in) | Estd. # of trees | % of total | % with or without repair history | |
|---|---|---|---|---|
| | | | With | Without |
| <.75 | 24,316 | 79 | 32 | 68 |
| .75-1.5 | 4,309 | 14 | 40 | 60 |
| >1.5 | 2,155 | 7 | 33 | 67 |
| Citywide Total | 30,779 | 100 | 33 | 67 |

# Chapter Three—Costs of Managing Berkeley's Municipal Trees

## *Program Expenditures*

### Costs of Managing Public Trees

Costs were based on a review of expenditures during fiscal year 2002. The yearly operating budget for the city of Berkeley municipal forestry program was approximately $1.15 million (Koch 2004). This amount represented 0.43% of the city's total 2002 operating budget ($257.9 million) and $10.72 per person (*Table 9*). With 36,485 actively managed street and park trees, the forestry division spent $30.48 per tree on average during the fiscal year. The per-tree expenditure was greater than the 1997 mean value of $19 per tree reported for 256 California cities (Thompson and Ahern 2000), but on par with other similar-sized communities outside California. For example, Fort Collins, CO, with a population of 135,000 and a municipal tree population of 31,000, spent $29.91 per tree (McPherson et al. 2004). An estimated additional $1.25 million was spent on tree-related matters by other city departments. These external expenditures involved hardscape repair, tree litter/debris clean-up, and legal issues. Overall, $2.37 million was spent on management of Berkeley's municipal urban forest ($22.81/capita, $64.84/tree). Forestry Division expenditures fell into three categories: tree planting and establishment, pruning and general tree care, and administration.

### Tree Planting and Establishment

Quality nursery stock, careful planting, and follow-up care are critical to perpetuation of a healthy urban forest. The city plants about 600 trees each year, 60% at new sites and 40% as replacements for removed trees. Costs are typically about $160 per tree, including $140 for planting (#15, 1" caliper) and $20 for initial staking and site preparation. These activities consume 8.5% of the program budget, or $95,000.

Approximately 1,800 small trees are pruned annually for structure and form. The majority of these are recently planted trees receiving a training prune ($10/tree); the remainder are small-tree prunings at a cost of $40 per tree. Adjacent property owners are responsible for establishment-related watering during the first five years.

### Pruning and General Tree Care

Berkeley's urban forest is large, including many mature and old trees. It is not surprising that about 75% ($840,000) of the program's budget was spent keeping these trees healthy and safe. Newly planted street trees are trained annually for the first three years. From then on, trees are pruned on a six-year rotating cycle by area. Street-side trees are lifted for clearance every three years. Park trees are trained twice during the establishment period, and once every 10 years thereafter on a rotating cycle. The Division contracts the removal of about 600 trees each year at a cost of $70,000 (including stump removal). Approximately 40% (240) are replaced with new plantings. On-site inspections and service requests cost the division approximately $80,000 per year. The Berkeley Forestry program does not use pesticides, and therefore, has no regular expenditure for pest management.

***Table 9****—Berkeley's annual municipal forestry-related expenditures.*

| **Program expenditures** | **Total ($)** | **$/Tree** | **$/Capita** |
|---|---|---|---|
| Planting | 95,000 | 2.60 | 0.91 |
| Pruning/maintenance | 770,000 | 21.05 | 7.40 |
| Removals | 70,000 | 1.91 | 0.67 |
| Inspection | 80,000 | 2.19 | 0.77 |
| Pest & disease control | 0 | 0.00 | 0.00 |
| Administration | 100,000 | 2.73 | 0.96 |
| Program subtotal | 1,115,000 | 30.48 | 10.72 |
| **External expenditures** | | | |
| Storm/litter clean-up | 195,000 | 5.33 | 1.88 |
| Hardscape repair | 1,030,000 | 28.15 | 9.90 |
| Claims and legal | 32,000 | 0.87 | 0.31 |
| Program subtotal | 1,257,000 | 34.36 | 12.09 |
| **Grand total expenditures** | **2,372,000** | **64.84** | **22.81** |

### Administration

Approximately 9% of all program expenditures were for administration, totaling $100,000. This item accounted for salaries and benefits of supervisory staff that performed planning and management functions, as well as contract development and supervision.

### External Tree-Related Expenditures

Tree-related expenditures accrue to the city that are not captured in the Forestry Program's budget. Litter and storm clean-up due to debris from public trees is a recurring expense. Annual costs for street clean-up due to annual leaf fall were approximately $155,000. Random storm events require an additional $40,000 in clean-up costs on average.

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 remediate the problem without removing the tree. Strategies include ramping the sidewalk over the root, grinding concrete to level surfaces, and removing and replacing concrete after root pruning. In total, approximately $1 million is spent on these measures. An additional $20,000 is spent on curb and gutter repair; $10,000 is spent on sewer/water line repairs.

# Chapter Four—Benefits of Berkeley's Municipal Trees

Estimates of benefits and costs are a starting point 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 penny. Rather, this approach was meant to be a general accounting of the benefits produced by municipal trees in Berkeley—an accounting with an accepted degree of uncertainty that can nonetheless provide a platform on which decisions can be made (Maco 2003). Methods used to quantify and price these benefits are described in Appendix B.

## *Energy Savings*

Trees modify climate and conserve 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 movement of outside air into interior spaces and conductive heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees and other vegetation within building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace (Chandler 1965). At the larger scale of 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 B provides additional information on specific contributions that trees make toward energy savings.

### Electricity and Natural Gas Results

Electricity saved annually in Berkeley from both shading and climate effects of municipal trees totaled 3,469 MWh, for a retail savings of $458,994 ($12.58/tree). Total annual savings of natural gas totaled 7,209 Mbtu, for a savings of $94,072 ($2.58/tree). Net energy savings were split with 17% for winter heating and 83% for summer air conditioning. Total citywide savings were valued at $553,066 (*Table 10*). Average savings per tree were $15.16, but exceeded $30 for large species like London plane and California sycamore (*Platanus racemosa*).

***Table 10****—Net annual energy savings produced by street and park trees by area.*

| Management area | Street | | | | Park | | | | All | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Electricity (MWh) | Natural gas (MBtu) | Total ($) | Avg. $/tree | Electricity (MWh) | Natural gas (MBtu) | Total ($) | Avg. $/tree | Total ($) | Avg. $/tree | % of total |
| 1 | 305.9 | 640.5 | 48,832 | 13.14 | 66.4 | 138.3 | 10,583 | 15.59 | 59,415 | 13.52 | 10.7 |
| 2 | 364.2 | 722.9 | 57,614 | 13.43 | 190.7 | 380.9 | 30,201 | 16.48 | 87,816 | 14.34 | 15.9 |
| 3 | 427.9 | 837.9 | 67,543 | 15.95 | 24.3 | 52.5 | 3,900 | 12.11 | 71,443 | 15.68 | 12.9 |
| 4 | 304.7 | 651.7 | 48,818 | 14.92 | 29.4 | 67.7 | 4,777 | 12.84 | 53,595 | 14.71 | 9.7 |
| 5 | 147.9 | 327.8 | 23,848 | 15.76 | 26.8 | 56.6 | 4,281 | 12.86 | 28,129 | 15.24 | 5.1 |
| 6 | 217.9 | 410.9 | 34,183 | 24.40 | 79.8 | 172.2 | 12,806 | 14.55 | 46,989 | 20.60 | 8.5 |
| 7 | 260.5 | 557.6 | 41,741 | 15.15 | 41.8 | 85.1 | 6,640 | 17.43 | 48,381 | 15.43 | 8.7 |
| 8 | 334.0 | 745.2 | 53,917 | 13.85 | 25.2 | 49.9 | 3,978 | 20.83 | 57,895 | 14.18 | 10.5 |
| 9 | 325.1 | 678.4 | 51,860 | 16.29 | 23.6 | 51.7 | 3,794 | 11.36 | 55,654 | 15.82 | 10.1 |
| 10 | 238.3 | 508.1 | 38,154 | 15.13 | 35.1 | 72.8 | 5,594 | 14.68 | 43,748 | 15.07 | 7.9 |
| Citywide total | 2,926.3 | 6,081.0 | 466,510 | 15.16 | 543.0 | 1,127.6 | 86,556 | 15.17 | 553,066 | 15.16 | 100 |

## *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 and consumption of natural gas.

On the other hand, $CO_2$ is released by vehicles, chain saws, chippers, and other equipment during the process of planting and maintaining trees. Eventually, all trees die and most of the $CO_2$ that has accumulated in their woody biomass is released into the atmosphere through decomposition unless recycled.

### Carbon Dioxide Reductions

As *Table 11* shows, the reductions in $CO_2$ are dependent on the species present and their age. Citywide, park-tree reduction of energy-plant $CO_2$ emissions and net sequestration rates were 228 and 480 tons, respectively, or 708 total tons at a value of $10,211. Coast live oak (17%), coast redwood (15%), and blue gum eucalyptus (11%) accounted for over 43% of the $CO_2$ benefits produced by park trees. Park trees with the highest per tree savings were blue gum eucalyptus ($7.72), coast redwood ($3.35), and California laurel ($3.16). Street trees had an annual net sequestration rate of approximately 1,396 tons and reduced emissions by another 1,230 tons for a total savings of $39,391. Street trees with the highest average per tree savings were American elm ($6.12), London plane ($2.44), California sycamore ($2.28), and camphor ($2.20). The combination of these park- and street-tree savings was valued at $49,602, annually, or $1.36 per tree.

Citywide, total sequestered $CO_2$ (1,876 t) was 29% greater than reduced $CO_2$ emissions (1,458 t). This can be explained by the fact that Berkeley has a relatively clean mix of fuels that produce energy to heat and cool buildings, influencing potential $CO_2$ emission reductions. Further, Berkeley's climate is moderated by San Francisco Bay and the Pacific Ocean, resulting in relatively lower cooling and heating loads compared to inland California locations.

## *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).

3. Reducing emissions from power generation by reducing energy consumption.

4. Releasing oxygen through photosynthesis.

***Table 11***—*Net $CO_2$ reductions produced by street and park trees by area.*

| Management area | Street | | | | Park | | | | All | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total $CO_2$ sequesered less releases (lbs) | Total $CO_2$ emissions avoided (lbs) | Total ($) | Avg. $/tree | Total $CO_2$ sequesered less releases (lbs) | Total $CO_2$ emissions avoided (lbs) | Total ($) | Avg. $/tree | Total (lbs) | Total ($) | Avg. $/tree | % of Total |
| 1 | 335,965 | 257,148 | 4,448 | 1.20 | 109,962 | 55,774 | 1,243 | 1.83 | 758,849 | 5,691 | 1.30 | 11.4 |
| 2 | 432,502 | 306,125 | 5,540 | 1.29 | 396,631 | 160,308 | 3,995 | 2.18 | 1,295,566 | 9,535 | 1.56 | 19.4 |
| 3 | 404,006 | 359,669 | 5,728 | 1.35 | 36,367 | 20,430 | 410 | 1.27 | 820,472 | 6,138 | 1.34 | 12.3 |
| 4 | 277,306 | 256,141 | 4,001 | 1.22 | 36,754 | 24,736 | 449 | 1.21 | 594,938 | 4,450 | 1.22 | 8.9 |
| 5 | 120,747 | 124,340 | 1,838 | 1.21 | 41,559 | 22,510 | 465 | 1.40 | 309,156 | 2,303 | 1.24 | 4.6 |
| 6 | 161,282 | 183,118 | 2,583 | 1.84 | 157,137 | 67,091 | 1,617 | 1.84 | 568,628 | 4,200 | 1.84 | 8.5 |
| 7 | 233,483 | 218,979 | 3,393 | 1.23 | 56,683 | 35,134 | 662 | 1.74 | 544,278 | 4,056 | 1.29 | 8.2 |
| 8 | 276,930 | 280,778 | 4,183 | 1.07 | 34,457 | 21,141 | 400 | 2.09 | 613,306 | 4,583 | 1.12 | 9.2 |
| 9 | 340,977 | 273,246 | 4,607 | 1.45 | 36,527 | 19,821 | 409 | 1.22 | 670,570 | 5,016 | 1.43 | 10.1 |
| 10 | 209,048 | 200,288 | 3,070 | 1.22 | 47,911 | 29,504 | 561 | 1.47 | 486,751 | 3,631 | 1.25 | 7.3 |
| Citywide total | 2,792,245 | 2,459,833 | 39,391 | 1.28 | 960,548 | 456,450 | 10,211 | 1.79 | 6,669,076 | 49,602 | 1.36 | 100.0 |

5. Transpiring water and shading surfaces, resulting in lower local air temperatures, thereby reducing ozone levels.

In the absence of the cooling effects of trees, higher air temperatures contribute to ozone formation. On the other hand, most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can 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 medium- and high-emitters would increase overall ozone concentrations (Taha 1996).

## *Avoided Pollutants*

Energy savings resulted in reduced air-pollutant emissions of nitrogen dioxide ($NO_2$), small particulate matter ($PM_{10}$), volatile organic compounds (VOCs), and sulfur dioxide ($SO_2$) (*Table 12*). Together, 1.9 tons of pollutants valued at $31,643 were avoided annually.

### Deposition and Interception

Annual pollutant uptake by tree foliage (pollution deposition and particulate interception) in Berkeley was 5.3 tons (*Table 12*) with a total value of $111,585 or $3.06 per tree. Ozone uptake accounted for approximately 48% of the total benefit, while $PM_{10}$ (32%), $NO_2$ (19%), and $SO_2$ (1%) accounted for the remainder.

### BVOC Emissions

Biogenic volatile organic compound (BVOC) emissions from trees were significant. At a total of 11.3 tons, these emissions were a cost to the city of $163,849. On an average dollar-per-tree basis, high-cost/high-emitting street trees included sweetgum ($19.20), coast live oak ($7.97), London plane ($6.87), and California sycamore ($5.98). High-emitting park trees were blue gum eucalyptus ($139.85 [sic]), California laurel ($19.97), and coast live oak ($11.53).

### Net Air-Quality Improvement

Though the air pollutants removed and avoided had a substantial value at $143,228 annually, the releases of BVOCs meant trees produced a negative net air-quality benefit, at a cost to the city of $20,621 (*Table 12*). On average, the cost per tree was $0.57. Trees, however, varied dramatically in their ability to produce net air-quality benefits; those without high BVOC emissions produced significant benefits. Large-canopied trees with large leaf surface areas and low BVOC emissions produced the greatest benefits. Annually, on a per-tree basis, valuable street trees included American elm ($18.97), camphor ($8.55), and Chinese elm ($7.69). Amongst park trees, white alder (Alnus rubra), coast redwood, Monterey pine, Canary Island pine (*Pinus canariensis*), and arroyo willow (*Salix lasiolepis*) all produced annual benefits in excess of $3 per tree (*Table 13*).

## *Stormwater-Runoff Reductions*

Urban stormwater runoff is an increasing concern as a significant pathway for contaminants entering local waterways. In an effort 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

***Table 12****—Net air-quality benefits produced by street and park trees by management area.*

| Management area | Deposition | | | | Avoided | | | | Releases | Net total (lbs) | Total ($) | Avg. $/tree |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $O_3$ (lb) | $NO_2$ (lb) | $PM_{10}$ (lb) | $SO_2$ (lb) | $NO_2$ (lb) | $PM_{10}$ (lb) | VOC (lb) | $SO_2$ (lb) | BVOC (lb) | | | |
| 1 | 512 | 213 | 306 | 42 | 207 | 52 | 27 | 108 | -2,142 | -675 | -885 | -0.20 |
| 2 | 892 | 374 | 526 | 73 | 305 | 77 | 39 | 161 | -6,168 | -3,720 | -20,081 | -3.28 |
| 3 | 824 | 329 | 462 | 65 | 254 | 64 | 33 | 133 | -2,267 | -103 | 5,302 | 1.16 |
| 4 | 463 | 187 | 268 | 37 | 191 | 47 | 24 | 99 | -2,133 | -817 | -2,341 | -0.64 |
| 5 | 214 | 87 | 128 | 17 | 102 | 25 | 13 | 53 | -1,014 | -375 | -1,008 | -0.55 |
| 6 | 526 | 216 | 306 | 43 | 168 | 42 | 22 | 88 | -1,907 | -498 | 344 | 0.15 |
| 7 | 436 | 178 | 255 | 35 | 172 | 43 | 22 | 89 | -1,987 | -757 | -2,114 | -0.67 |
| 8 | 428 | 170 | 251 | 33 | 213 | 52 | 27 | 109 | -1,529 | -244 | 1,623 | 0.40 |
| 9 | 486 | 194 | 282 | 39 | 200 | 50 | 26 | 104 | -1,883 | -503 | 93 | 0.03 |
| 10 | 367 | 149 | 216 | 29 | 156 | 39 | 20 | 81 | -1,665 | -609 | -1,553 | -0.54 |
| Citywide total | 5147 | 2097 | 3001 | 412 | 1967 | 490 | 252 | 1024 | -22,694 | -8,302 | -20,621 | -0.57 |

*Table 13*—Net annual air-quality benefits for the 20 most common street and park trees.

| Street | | Park | |
|---|---|---|---|
| **Species** | **$/Tree** | **Species** | **$/Tree** |
| London plane | 4.34 | Coast live oak | -8.52 |
| Sweetgum | -15.44 | Coast redwood | 3.05 |
| Cherry plum | 1.36 | Monterey cypress | 2.14 |
| Coast live oak | -6.01 | Montery pine | 3.19 |
| Camphor tree | 8.55 | Black acacia | -0.09 |
| Ash species | 3.62 | Cherry/plum species | 1.39 |
| Cherry/plum species | 1.06 | Blue gum eucalyptus | -122.43 |
| Evergreen pear | 3.08 | Tarata pittosporum | 2.51 |
| Purple-leaf plum | 1.50 | California laurel | -10.77 |
| American elm | 18.97 | Cotoneaster | 0.70 |
| Southern magnolia | -1.16 | Karo | 2.11 |
| Velvet ash | 5.06 | California buckeye | 2.58 |
| Chinese pistache | 0.37 | Victorian box | 2.90 |
| Japanese maple | 1.10 | Canary Island pine | 3.88 |
| Other | 0.73 | Christmas berry | 1.41 |
| Chinese elm | 7.69 | Other | 3.64 |
| Victorian box | 3.83 | Strawberry tree | 1.32 |
| Ginkgo | 1.16 | Arroyo willow | 3.14 |
| California sycamore | 2.30 | White alder | 3.99 |
| Callery pear | 2.65 | Cherry plum | 1.40 |
| Other Street Trees | -1.58 | Other Park Trees | 0.69 |
| Citywide | -0.04 | Citywide | -3.39 |

loading in receiving waters in three 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 reduce overland flow.

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

### Stormwater Runoff Reductions Results

The ability of Berkeley's municipal trees to intercept rain was substantial, estimated at 7.2 million $ft^3$ annually (*Table 14*). The total value of this benefit to the city was $215,645 when all trees were considered. Street-tree interception (5.6 million $ft^3$) was 77% of the total, having a lower per-tree average interception rate than park trees. This difference was attributable to the larger leaf surface area associated with the park-tree population, where trees had an average interception rate of 2,117 gals ($8.57). By comparison, street trees averaged only 1,355 gals ($5.42) per tree.

When averaged across the entire street-tree population, certain species were much better at reducing stormwater runoff than others. Leaf type and area, branching pattern and bark, as well as tree size and shape all affect the amount of precipitation trees can intercept and hold to avoid direct runoff. The effect of predominant species was most evident in management area 6 where trees intercepted rainfall at nearly twice the rate of trees in area 8. Ranging from $15–27 in annual benefits, trees that performed well included coast redwood, Monterey cypress, American elm, and blue gum. Poor performers were small species such as Victorian box and purple-leaf plum which had stormwater-runoff reduction values of approximately $1.50–3 per tree.

## *Property Values and Other Benefits*

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place and well-being are products that are

*Table 14—Annual stormwater reduction benefits produced by street and park trees by area.*

| Management area | Street | | | Park | | | All | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total rainfall intercep-tion ($ft^3$) | Total ($) | Avg. $/tree | Total rainfall intercepti-on ($ft^3$) | Total ($) | Avg. $/tree | Total rainfall intercepti-on ($ft^3$) | Total ($) | Avg. $/tree | % of total $ |
| 1 | 622,539 | 18,628 | 5.01 | 188,521 | 5,641 | 8.31 | 811,060 | 24,269 | 5.52 | 11.25 |
| 2 | 841,512 | 25,180 | 5.87 | 635,199 | 19,006 | 10.37 | 1,476,711 | 44,186 | 7.22 | 20.49 |
| 3 | 774,407 | 23,172 | 5.47 | 66,212 | 1,981 | 6.15 | 840,619 | 25,153 | 5.52 | 11.66 |
| 4 | 562,407 | 16,828 | 5.14 | 69,970 | 2,094 | 5.63 | 632,376 | 18,922 | 5.19 | 8.77 |
| 5 | 270,183 | 8,084 | 5.34 | 85,290 | 2,552 | 7.66 | 355,473 | 10,636 | 5.76 | 4.93 |
| 6 | 386,477 | 11,564 | 8.25 | 272,222 | 8,145 | 9.26 | 658,699 | 19,710 | 8.64 | 9.14 |
| 7 | 516,609 | 15,458 | 5.61 | 108,494 | 3,246 | 8.52 | 625,103 | 18,704 | 5.96 | 8.67 |
| 8 | 550,634 | 16,476 | 4.23 | 57,939 | 1,734 | 9.08 | 608,573 | 18,210 | 4.46 | 8.44 |
| 9 | 611,775 | 18,306 | 5.75 | 65,298 | 1,954 | 5.85 | 677,072 | 20,259 | 5.76 | 9.39 |
| 10 | 435,446 | 13,029 | 5.17 | 85,760 | 2,566 | 6.74 | 521,206 | 15,596 | 5.37 | 7.23 |
| Citywide total | 5,571,988 | 166,726 | 5.42 | 1,634,905 | 48,920 | 8.57 | 7,206,893 | 215,645 | 5.91 | 100.00 |

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, research that compares differences in sales prices of houses is used to statistically quantify the difference associated with trees. The difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with trees. This approach has the virtue of capturing what buyers perceive as both the benefits and costs of trees in the sales price. Some limitations to using this approach in Berkeley include the difficulty associated with determining the value of individual street trees adjacent to private properties and 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).

### Property Values and Other Benefits Results

The estimated total annual benefit associated with property value increases and other less tangible benefits was approximately $2.5 million, or $67 per tree on average (*Table 15*). This value appeared on par with other California communities where median home values were high. For example, municipal trees in Santa Monica averaged $65 per tree in annual property value increases (McPherson and Simpson 2002) and street trees in San Francisco averaged $70 per tree (Maco et al. 2003). In Berkeley, street trees were responsible for 87% of this benefit, with per-tree averages between $19 and $249; park trees averaged $54, but ranged between $19 and $108, citywide. Generally, street trees had a greater impact on property values than park trees; however, the proximity of multi-use parks and greenbelts may also contribute to an increase in property values of entire neighborhoods.

Tree species adding the largest amount of leaf area over the course of a year tend to produce the highest average annual benefit. American elm ($249/tree), sweetgum ($129/tree), and coast redwood ($108/tree) were most valuable, while karo ($19/tree), cherry plums ($20/tree), and Victorian box ($20/tree) were examples of trees that produced the least benefits. Consequently, management areas dominated by stands of fast-growing trees had property values increasing upwards of $70 per tree, while those with slower-growing trees produced benefits of approximately $60 per tree.

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

Total annual benefits produced by Berkeley's street and park trees were estimated to have a value of $3.2 million, about $89 per tree and $31 per resident (*Table 16*). Street trees produced benefits valued at $2.8 million ($91/tree, $27/capita), while park tree benefits were valued at about $433,000 ($76/tree, $4/capita). Over the same period, tree-related expenditures were estimated

*Table 15—Total annual increases in property value produced by street and park trees by area.*

| Management area | Street | | | | Park | | | | All | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total ($) | % of city tree population | % of total ($) | Avg. $/tree | Total ($) | % of city tree population | % of total ($) | Avg. $/tree | Total ($) | % of city tree population | % of total ($) | Avg. $/tree |
| 1 | 226,955 | 12.1 | 10.6 | 61.09 | 33,889 | 11.9 | 11.1 | 49.91 | 260,844 | 12.0 | 10.6 | 59.36 |
| 2 | 290,296 | 13.9 | 13.5 | 67.67 | 107,633 | 32.1 | 35.1 | 58.72 | 397,929 | 16.8 | 16.2 | 64.99 |
| 3 | 289,735 | 13.8 | 13.5 | 68.43 | 14,546 | 5.6 | 4.7 | 45.17 | 304,281 | 12.5 | 12.4 | 66.79 |
| 4 | 217,829 | 10.6 | 10.2 | 66.57 | 17,246 | 6.5 | 5.6 | 46.36 | 235,075 | 10.0 | 9.6 | 64.51 |
| 5 | 113,209 | 4.9 | 5.3 | 74.82 | 18,487 | 5.8 | 6.0 | 55.52 | 131,696 | 5.1 | 5.4 | 71.34 |
| 6 | 106,225 | 4.6 | 5.0 | 75.82 | 50,396 | 15.4 | 16.4 | 57.27 | 156,621 | 6.3 | 6.4 | 68.66 |
| 7 | 200,893 | 9.0 | 9.4 | 72.89 | 20,493 | 6.7 | 6.7 | 53.79 | 221,386 | 8.6 | 9.0 | 70.57 |
| 8 | 256,436 | 12.6 | 12.0 | 65.87 | 9,064 | 3.3 | 3.0 | 47.45 | 265,500 | 11.2 | 10.8 | 65.01 |
| 9 | 258,217 | 10.3 | 12.0 | 81.10 | 16,763 | 5.9 | 5.5 | 50.19 | 274,980 | 9.6 | 11.2 | 78.16 |
| 10 | 183,436 | 8.2 | 8.6 | 72.76 | 18,135 | 6.7 | 5.9 | 47.60 | 201,570 | 8.0 | 8.2 | 69.46 |
| Citywide total | 2,143,231 | 100.0 | 100.0 | 69.63 | 306,653 | 100.0 | 100.0 | 53.74 | 2,449,884 | 100.0 | 100.0 | 67.15 |

at nearly $2.4 million. Net annual benefits were therefore calculated at $876,000, or $24 per managed tree. The Berkeley municipal forest returned $1.37 to the community for every $1 spent on management.

Berkeley municipal trees have beneficial effects on the environment. Approximately 25% of the annual benefits were environmental. Energy savings were 69% of this value, a substantial sum of about $15 per tree. Benefits associated with stormwater-runoff reduction represented 27% ($5.91/tree) of the total benefits, while carbon dioxide reductions ($1.36/tree) account for the remaining 4% of estimated total annual benefits. As in most cities, annual increases in property value were the largest benefit produced by trees in Berkeley, accounting for an annual value of $2.4 million.

While species vary in their ability to produce benefits, common characteristics of trees within tree-type classes aid in identifying the most beneficial street trees in Berkeley (*Fig. 6*). Without exception, Berkeley's larger trees produced the most benefits. When considering total benefits, large trees provided the highest average return for the investment dollar—average annual benefits increased from less than $50 per tree for small deciduous trees to over $100 per tree for large trees. This was primarily due to increased property value benefits associated with high leaf area. When considering environmental benefits, large coniferous and large deciduous trees provided the highest level of benefits on Berkeley's streets; large conifers and large broadleaf evergreens provided the greatest benefits in parks. Small palm and small deciduous species produced the fewest benefits of all tree types.

*Figure 7* describes the average annual benefits per tree according to management area and is a reflection of tree type and population age. For example, area 1, the North

*Table 16—Benefit–cost summary for street, park, and all municipal trees.*

| Benefit | Street | | | Park | | | All | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total ($) | $/Capita | $/Tree | Total ($) | $/Capita | $/Tree | Total ($) | $/Capita | $/Tree |
| Energy | 466,510 | 4.49 | 15.16 | 86,556 | 0.83 | 15.17 | 553,066 | 5.32 | 15.16 |
| $CO_2$ | 39,391 | 0.38 | 1.28 | 10,211 | 0.10 | 1.79 | 49,602 | 0.48 | 1.36 |
| Air quality | -1,302 | -0.01 | -0.04 | -19,318 | -0.19 | -3.39 | -20,620 | -0.20 | -0.57 |
| Stormwater | 166,725 | 1.60 | 5.42 | 48,920 | 0.47 | 8.57 | 215,645 | 2.07 | 5.91 |
| Property/other | 2,143,230 | 20.61 | 69.63 | 306,652 | 2.95 | 53.74 | 2,449,882 | 23.56 | 67.15 |
| Total benefits | 2,814,554 | 27.06 | 91.44 | 433,021 | 4.16 | 75.89 | 3,247,575 | 31.23 | 89.01 |
| Total costs | | | | | | | 2,372,000 | 22.81 | 65.01 |
| Net benefits | | | | | | | 875,575 | 8.42 | 24.00 |
| Benefit-Cost Ratio | | | | | | | 1.37 | | |

Hills neighborhood, produced the lowest average annual benefits of any management area, approximately $81 per tree. In contrast, trees in area 6, southwest Berkeley, produced the highest average annual benefits per tree ($112). While both areas had a broad range of tree types present, the disparity can be explained by prevailing tree size. In area 1, over 50% of the trees were young (less than 6 inches in DBH) and there were few mature trees. Area 6, conversely, had a large population of maturing and mature trees with fewer trees (26%) in young size classes.

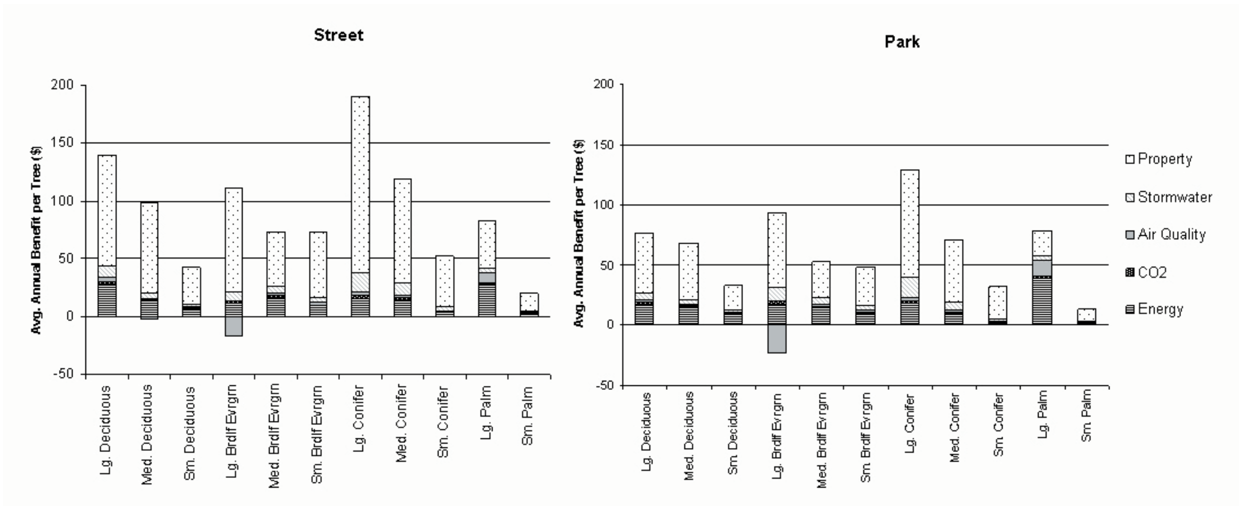


**Figure 6**—Average annual street and park benefits per tree by tree types.

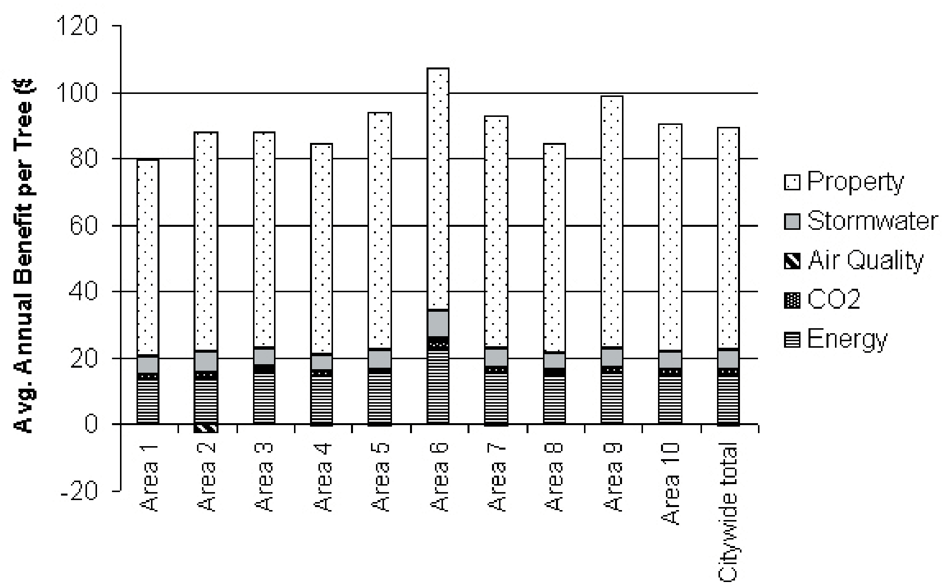


**Figure 7**—Average annual benefits of all municipal trees by management area.

# Chapter Five—Management Implications

Street and park trees are only one component of a functional urban forest. In some cities, they are the most important component, defining the values of the community, thereby providing a portal to different neighborhoods and shopping districts. In other cities, street trees are treated with less concern than are parks, greenbelts, and private plantings. In any case, cities must seek to maintain a functional municipal forest that is both healthy and safe. In Berkeley, with an actively managed municipal tree population of more than 36,000, there is no doubt that trees are valued as an integral component of the city.

Berkeley'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 over 50 years ago and, at the same time, constantly changing as new trees are planted and others mature. Although this study provides a "snapshot" of the resource in time, it also serves as an opportunity to speculate about the future. Given the status of Berkeley's municipal tree population, what future trends are likely and what management challenges will need to be met to achieve urban forest sustainability?

Achieving resource 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 cost-efficient management. Focusing on these components—resource complexity, resource extent, pruning and maintenance—refines broader municipal tree management goals.

### *Resource Complexity*

Species diversity was adequate when viewed on a city-wide scale, but planting for population stability requires more than simply planting "other trees" when a single species is planted beyond a set threshold (e.g., 10% of total population). *Figure 8* displays trends in new and replacement trees, with the smallest trees being most common. Many of these species have not proven to be well adapted or do not have the longevity in Berkeley to produce the benefits the community depends upon. Only London plane had individuals present in large-DBH classes. Coast live oak, sweetgum, and the various ash species are only beginning to move into to their func-

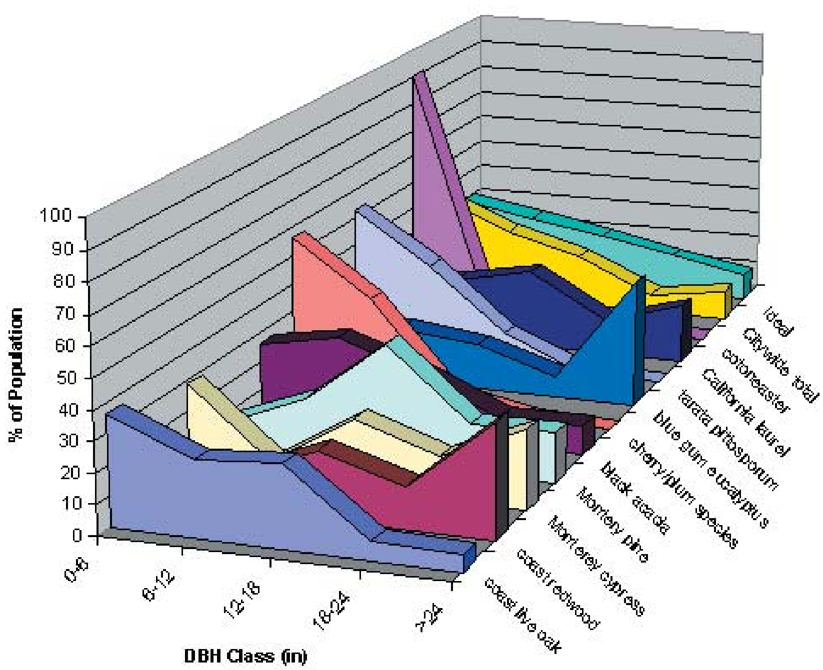


**Figure 8**—Municipal trees being planted in the highest numbers.

tional years. These species, along with the evergreen pear, Chinese pistache, Japanese maple (*Acer palmatum*), ginkgo, and black locust (*Robinia pseudoacacia*) are largely absent from the larger size classes, suggesting that their suitability for Berkeley may not be well tested.

*Figure 9* shows Berkeley's most important large-stature tree species. Higher numbers of individuals in large DBH classes indicate adaptability and longevity. Some of these species are no longer planted in large numbers, for example, American elm, coast redwood, Monterey cypress, velvet ash, California sycamore, and camphor. While planting site constraints and costs associated with infrastructure repair must be considered and balanced with resource needs, the shift towards planting small species of trees that have not proven to be long-lived may reduce the future benefits afforded the community. Further evaluation of species performance over the long term is recommended.

Recent pruning and stand age may be factors in the health of trees, but condition class is the best indicator for selecting well-adapted and appropriate trees.

*Table 17* displays relative performance index (RPI) values based on the weighted proportion of each municipal tree's condition classification. An RPI value of 1 indicates trees of average condition for Berkeley [4.7 on a 1–7 scale with 7 indicating the best ("excellent") condition]. RPI values higher than "1" indicate species that had proportionately better than average condition ratings. Likewise, index values lower than 1 were species with below-average condition ratings when compared with other Berkeley municipal trees.

While RPI values can be used to indicate trees well suited to Berkeley conditions, it is important to remember that some species with low values may simply represent populations with an even-age distribution that were senescing. An example is American elm. Though most of these trees' functional lives are past, they have served the city well throughout their long lives and to not replant these species based on current condition would be shortsighted; many improved varieties resistant to Dutch elm disease are available and could be considered as replacements.

Conversely, cherry plums, with an RPI of less than 1, have been heavily planted in recent years suggesting that managers are limited by planting site restrictions and are putting faith in some species unlikely to provide stability or cost-effective functionality over a long period of time. When species exhibit relatively poor condition at young ages it suggests that they will not age well. How-

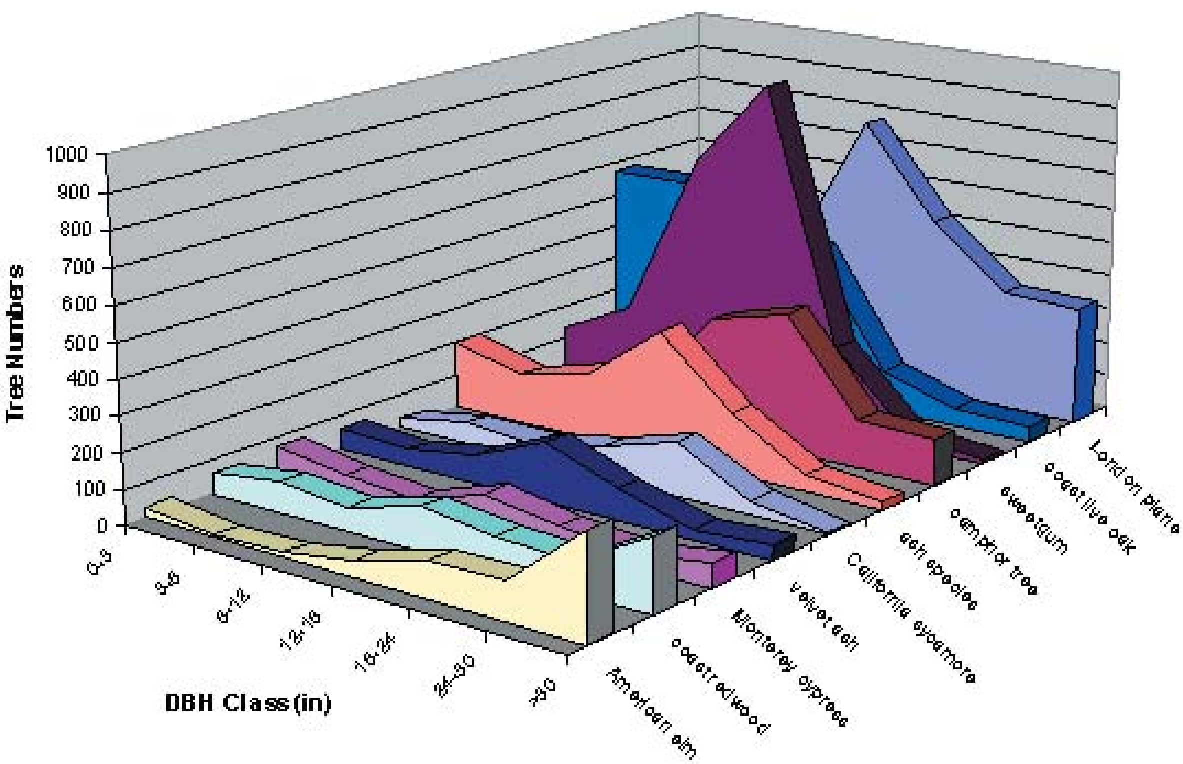


**Figure 9**—Age distribution of Berkeley's most important large-stature trees. These trees are amongst those that produce the largest average annual benefits on a per tree basis.

*__Table 17__—Relative performance index (RPI) for all municipal tree species listed in descending order of prevalence.*

| Species | RPI | Species | RPI | Species | RPI | Species | RPI |
|---|---|---|---|---|---|---|---|
| London plane | 1.02 | Norway maple | 0.96 | Queensland pittosporum | 0.91 | Sydney golden wattle | 1.14 |
| Sweetgum | 1.03 | Italian cypress | 1.05 | Peruvian peppertree | 0.94 | King palm | 1.06 |
| Coast live oak | 0.99 | Bronze loquat | 1.02 | Common linden | 0.94 | Silver dollar eucalyptus | 1.03 |
| Cherry plum | 0.98 | Tallowtree | 1.01 | Catalina cherry | 0.87 | Rose-of-sharon | 0.99 |
| Cherry/plum species | 0.96 | Black poplar | 1.00 | Nectarine | 0.83 | Paradise apple | 0.99 |
| Camphor tree | 0.92 | Blue blossom | 0.96 | Aleppo pine | 0.93 | Tipu tree | 1.06 |
| Ash species | 1.04 | Red ironbark | 0.94 | Common pear | 1.05 | New Zealand Christmas tree | 0.99 |
| Evergreen pear | 1.04 | Giant dracaena | 0.96 | Chinese holly | 0.93 | Date palm | 1.03 |
| Coast redwood | 1.04 | Mexican fan palm | 1.05 | California juniper | 0.98 | Apricot | 0.99 |
| Purple-leaf plum | 1.03 | Paper mulberry | 0.96 | Yew podocarpus | 1.02 | Scarlet oak | 1.03 |
| Southern mag-nolia | 1.02 | Saucer magnolia | 1.02 | Quaking aspen | 0.86 | River birch | 0.81 |
| American elm | 0.90 | California black oak | 1.06 | Tree of heaven | 1.02 | Scot’s broom | 1.02 |
| Victorian box | 0.97 | Firethorn | 1.03 | White ironbark | 1.05 | Cajeput tree | 1.06 |
| Other | 0.97 | Eastern redbud | 1.02 | Common fig | 1.04 | Melaleuca | 0.98 |
| Chinese pistache | 1.03 | Holly-leaf cherry | 1.03 | Flamegold | 0.94 | Australian pine | 0.85 |
| Velvet ash | 0.97 | Deodar cedar | 1.03 | Aloe yucca | 1.05 | Floss silk tree | 0.90 |
| Japanese maple | 1.01 | Siberian elm | 0.94 | Italian alder | 0.96 | Cider gum eucalyptus | 0.96 |
| Chinese elm | 1.04 | Arroyo willow | 1.02 | Avocado | 1.03 | Silver dollar gum eucalyptus | 1.06 |
| Callery pear | 1.04 | Green acacia | 1.01 | Cape cheesewood | 1.05 | California flannel bush | 1.12 |
| Cotoneaster | 0.98 | Japanese pittosporum | 0.96 | Windmill palm | 1.04 | Coulter pine | 0.96 |
| Ginkgo | 1.05 | Mimosa | 1.03 | English walnut | 0.98 | Japanese black pine | 1.06 |
| Black locust | 1.03 | Chinese flame tree | 1.05 | Common crapemyrtle | 1.04 | Bird of paradise tree | 1.06 |
| California sycamore | 0.97 | Oleander | 1.03 | Blue spruce | 1.06 | Japanese tree lilac | 0.96 |
| Tulip tree | 1.04 | Willow-leaved gimlet | 1.04 | White poplar | 0.89 | Maple species | 0.92 |
| Black acacia | 0.98 | Pink melaleuca | 1.07 | Fir species | 1.01 | Gold medallion tree | 1.06 |
| Monterey cypress | 0.96 | Ngaio tree | 1.04 | Lime | 0.96 | European hackberry | 0.99 |
| Flowering plum | 0.87 | Australian willow | 0.97 | Smoke tree | 1.05 | Pacific dogwood | 1.06 |
| Raywood ash | 1.07 | Willow species | 0.99 | Evergreen ash | 0.93 | Leyland cypress | 1.06 |
| Pine species | 0.98 | Western redbud | 0.96 | Common elderberry | 0.84 | Desert gum eucalyptus | 1.06 |
| Honeylocust | 1.04 | Fraser photinia | 1.00 | Common persimmon | 0.99 | Coral gum | 0.92 |
| Red maple | 1.04 | Brisbane box | 1.04 | Punk tree | 0.91 | Wavyleaf silktassel | 0.92 |
| White mulberry | 1.02 | Chinaberry | 1.06 | Water gum | 1.06 | French plantain | 0.99 |
| Glossy privet | 0.93 | Douglas fir | 1.01 | Aromo del país | 0.94 | Northern catalpa | 1.06 |
| Karo | 1.02 | Pineapple guava | 1.00 | Pacific madrone | 1.00 | Southwestern redbud | 0.96 |
| Horsechestnut | 1.05 | Cajeput tree | 1.06 | Silk oak | 1.02 | Black hawthorn | 1.17 |
| Tarata pittosporum | 0.97 | Brazilian peppertree | 1.06 | Pin oak | 0.94 | Lilly pilly tree | 1.06 |

*Table 17, cont.—Relative performance index (RPI) for all municipal tree species listed in descending order of prevalence.*

| Species | RPI | Species | RPI | Species | RPI | Species | RPI |
|---|---|---|---|---|---|---|---|
| Mayten tree | 0.99 | Curveleaf yucca | 0.98 | Chinese hackberry | 1.08 | Benjamin fig | 1.06 |
| Monterey pine | 0.95 | Canary island date palm | 1.07 | Sweet hakea | 0.93 | Mexican flannelbush | 0.96 |
| Hawthorn species | 0.99 | Northern hackberry | 1.06 | Chinese juniper | 1.03 | Mexican pinyon | 1.06 |
| Oak species | 1.00 | Dawn redwood | 0.98 | Almond | 0.98 | Yoshino flowering cherry | 0.74 |
| Silver maple | 1.02 | Giant sequoia | 0.98 | Pussy willow | 0.93 | Canyon live oak | 1.06 |
| Malus species | 0.98 | Italian stone pine | 0.99 | Princess-flower | 1.06 | Rhododendron species | 0.64 |
| Kwanzan cherry | 1.00 | Speading bamboo | 1.15 | Norfolk Island pine | 1.05 | Shining willow | 1.06 |
| Northern red oak | 1.06 | Fern pine | 1.04 | Arizona cypress | 0.92 | Schefflera | 1.06 |
| European white birch | 0.96 | Washington hawthorn | 1.04 | Cork oak | 1.01 | Scarlett wisteria | 0.85 |
| Common cra-bapple | 1.00 | Black walnut | 0.98 | Atlas cedar | 0.99 | Tamarisk | 1.06 |
| California buckeye | 1.01 | Torrey pine | 0.98 | Western hackberry | 1.04 | Tree aloe | 1.06 |
| Eucalyptus species | 1.00 | Spanish dagger | 1.03 | Nymansay' eucryphia | 1.06 | Jelly palm | 1.06 |
| Blue gum euca-lyptus | 1.00 | Australian tea tree | 0.98 | Northern white cedar | 1.03 | European hornbeam | 1.06 |
| California pep-pertree | 0.93 | Palm species | 1.03 | Torrey yucca | 1.01 | Purple toned catalpa | 1.06 |
| Littleleaf linden | 0.95 | Lemon | 1.03 | Queen palm | 1.04 | Mourning cypress | 0.64 |
| Common plum | 0.90 | Western juniper | 1.00 | Guadalupe palm | 1.06 | Mediterranean fan palm | 1.06 |
| Christmas berry | 1.01 | Valley oak | 0.94 | Holly oak | 1.00 | Grapefruit | 0.85 |
| California laurel | 0.99 | California privet | 0.93 | Corkscrew willow | 0.96 | Carrotwood | 1.06 |
| Sugar maple | 1.02 | White bottlebrush | 1.04 | Port Orford cedar | 0.88 | Tree dahlia | 1.06 |
| Brush cherry | 1.02 | Red-flowering gum | 1.01 | Lemon-scented gum | 0.99 | Bushy yate | 1.06 |
| Japanese privet | 1.04 | Trident maple | 1.05 | Pacific bayberry | 0.69 | Bluebush | 1.06 |
| Grecian Laurel | 1.02 | Boxelder | 0.96 | Balsam poplar | 1.02 | Rubber plant | 0.85 |
| Black tupelo | 1.04 | Southern live oak | 0.95 | Indian hawthorn | 1.04 | Sweetshade | 1.06 |
| Lemon bottlebrush | 1.02 | African sumac | 1.02 | Japanese viburnum | 0.99 | Jasmine species | 1.06 |
| Strawberry tree | 1.02 | Western redcedar | 1.03 | Cape chestnut | 1.06 | Primrose tree | 0.85 |
| Canary Island pine | 0.95 | Bailey acacia | 1.00 | Dragon tree | 0.98 | Chinese sweet gum | 1.06 |
| Bigleaf maple | 1.00 | Carolina cherry laurel | 0.88 | Tanbark oak | 0.85 | Daisy tree | 1.06 |
| California palm | 1.06 | Orange | 1.03 | English yew | 1.06 | Tree tobacco | 1.06 |
| Red alder | 1.03 | Sycamore maple | 1.00 | Xylosma | 1.06 | Tuna cactus | 1.06 |
| Loquat | 1.04 | Florida hopbush | 1.01 | Prickly moses | 0.76 | Pygmy date palm | 1.06 |
| European beech | 1.07 | Lyon tree | 0.97 | Peppermint tree | 1.06 | Mexican weeping pine | 0.85 |
| Jacaranda | 1.02 | Pittosporum species | 0.92 | Chinese birch | 0.97 | Common hoptree | 1.06 |
| Japanese zelkova | 0.96 | Wilson holly | 1.04 | Camellia | 0.97 | English oak | 1.28 |
| Incense cedar | 1.00 | Paraguay nightshade | 1.04 | Carob | 1.00 | Indian hawthorn | 1.06 |
| White alder | 0.98 | Fremont cottonwood | 0.97 | Indian laurel fig | 1.06 | Sugar sumac | 1.06 |
| Juniper species | 0.98 | Weeping willow | 0.89 | Star magnolia | 1.00 | Flowering sage | 1.06 |
| Olive | 1.03 | Weeping bottle brush | 1.01 | Prairie crabapple | 1.06 | Pink trumpet tree | 1.06 |
| All municipal trees | | | | | | | 1.00 |

ever, the majority of newly planted species had high RPI values, indicating species selection for adaptability was being well conducted. Using the RPI and relative-age data, managers can further combine their knowledge of site limitations to select other trees that are well-adapted, long-lived, and have the potential to provide reasonable levels of benefits. Examples of such species include European beech (*Fagus sylvatica*) and European hornbeam (*Carpinus betulus*).

### Resource Extent

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

Increasing the street-tree canopy cover requires a multifaceted approach in Berkeley. Plantable spaces must be filled and use of large trees must be encouraged wherever sites allow. The inventory used in this analysis puts the number of available planting spaces at approximately 15,000. Canopy cover and associated benefits would be increased substantially if all these sites were filled. In order to improve tree-provided benefits over time, sites for large street trees should be planted first wherever possible, followed by those for medium and then small trees. Management areas 5 and 6 have the lowest stocking levels and should take precedence.

### Maintenance

The Forestry Unit cares for Berkeley's municipal trees within the recommended cycle of 3–6 years (Miller 1997), a practice that appears to be paying off. Trees were producing sizeable benefits ($89/tree) and were in relatively good condition with approximately 75% of the citywide population categorized as in good or better condition. However, in the short term, the City will likely face new maintenance challenges.

The citywide age distribution of all trees does not correspond to the "ideal" distribution as described above, having elevated numbers of young trees and lower numbers of early functional and functionally mature trees (*Fig. 2*, *3*, and *4*). This distribution suggests that a strong young-tree-care program is imperative as is targeted maintenance for functionally mature trees. These priorities will insure that the many young trees will transition through their lifecycle in good health, minimizing the resources needed to maintain them as they mature, while functionally mature trees will perform at their peak to compensate for their lack in numbers.

Maintenance of current stands is not the only challenge the city faces. Berkeley spends more on external expenditures than on departmental expenditures. At an estimated $28.15 per tree, expenditures on hardscape repair are the single costliest component of tree maintenance, exceeding programmed pruning by 34%. Presumably, the bulk of this expenditure goes to repairing sidewalk heave. Looking to the future, cost-effective strategies for dealing with this problem must be addressed. Planting new trees in larger cutouts or planting strips and increasing their soil rooting volume are viable mitigation measures, but the lowest cost approach is to avoid planting species prone to surface rooting in restrictive sites (Costello and Jones 2003). Prominent species with high percentages of individuals associated with sidewalk heave included American elm (46%), camphor (37%), velvet ash (*Fraxinus velutina*) (33%), sweetgum (32%), and tulip tree (29%). These species had a much higher than average rate of sidewalk heave.

## Chapter Six—Conclusion

The approach used in this analysis not only provided sufficient data to describe structural characteristics of the street-tree population, but, by using tree growth data modeled for the Berkeley, assessed the environmental benefits trees provide the city and its residents. In addition, the benefit–cost ratio was calculated and management needs were identified. This approach was based on established statistical methods and was intended to provide a general accounting of the benefits produced by street trees in Berkeley that can be utilized to make informed management and planning decisions.

Berkeley's municipal trees are a valuable asset, providing approximately $3.25 million in annual benefits. The benefits to the community were most pronounced in increased local property values, but environmental benefits were also significant with energy savings and stormwater interception notably high. Thus, street and park trees were found to play a particularly important role in maintaining the environmental and aesthetic quality of the city.

Berkeley's municipal trees are a tremendously dynamic resource. Managers of this resource and the community alike can delight in knowing that street trees do improve the quality of life in Berkeley, but the trees are also a fragile resource that needs constant care to maximize and sustain their benefits into the future. The challenge will be to maximize net benefits from available planting spaces over the long term, providing an urban forest resource that is both functional and sustainable.

This analysis has provided the information necessary for resource managers to weigh the citywide needs using the more specific needs of park trees, street trees, and individual management areas. The structural indices outlined above—diversity index, relative performance values, importance values, condition values, and age distribution tables—along with benefit data, provide the requisite understanding for short- and long-term resource management.

Management recommendations derived from this analysis are fourfold:

1. Focus new plantings on proven, long-lived species that make the most of available growth space.

2. Plant management areas where stocking levels are the lowest to provide a more equitable distribution of benefits.

3. Recognize that adequate young and mature tree care will be especially important through the near future in order to maintain current benefits and reduce long-term costs.

4. Limit future hardscape repair expenditures through cost-effective strategies such as limiting planting of species prone to sidewalk heave in space-restricted sites.

# Chapter Seven—References


Akbari, H.; Davis, S.; Dorsano, S.; Huang, J.; Winnett, S., eds. 1992. **Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing.** Washington, DC: U.S. Environmental Protection Agency.; 26 p.

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

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

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

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

California Air Resources Board. 2002. **Emission Reduction Offsets Transaction Cost Summary Report for 2001.** State of California, California Environmental Protection Agency.

California Air Resources Board. 2003. **Emission Reduction Offsets Transaction Cost Summary Report for 2002.** State of California, California Environmental Protection Agency.

California Air Resources Board. 2004. **Emission Reduction Offsets Transaction Cost Summary Report for 2003.** State of California, California Environmental Protection Agency.

California Air Resources Board. 2004b. **California Air Quality Data** (CD-ROM PTSD-04-019-CD). State of California, California Environmental Protection Agency. http://www.arb.ca.gov/aqd/aqdcd/aqdcd.htm

California Department of Finance. 2004. **E-1 City/County Population Estimates with Annual Percent Change—January 1, 2003 and 2004.** Accessed via the World Wide Web at http://www.dof.ca.gov/HTML/DEMOGRAP/E-1text.htm.

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

CIMIS. 2004. Accessed via the World Wide Web <http://wwwcimis.water.ca.gov/cimis/data.jsp> on October 27, 2004.

City of Berkeley. 2004a. **Sanitary Sewer Program Background Information**. Accessed via the World Wide Web < http://www.ci.berkeley.ca.us/pw/Storm/stormala.html> on November 9, 2004.

City of Berkeley. 2004b. **Sanitary Sewer Program Background Information.** Accessed via the World Wide Web <http://www.ci.berkeley.ca.us/pw/sewers/sewinfo.html> on November 9, 2004.

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

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

CO2e.com. 2002. **Market Size and Pricing.** Accessed via the World Wide Web. http://www.co2e.com/stratagies/AdditionalInfo.asp?PageID=273#1613 on October 23, 2002.

DataQuick. 2004. **California Home Sale Activity by City.** Accessed via the World Wide Web <http:www.dqnews.com/ZIPCAR2003.shtm> on November 15, 2004.

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

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

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

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

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

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

Koch, J. 2004. Personal communications on April 9, 2004. Senior Forestry Supervisor, City of Berkeley, Dept. of Parks, Recreation, and Waterfront.

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

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

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

Maco, S.E., McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao. 2003. **City of San Francisco California Street Tree Resource Analysis**. Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station, CUFR-3.

Marion, W. and K. Urban. **User's manual for TMY2s - typical meteorological years.** National Renewable Energy Laboratory, 1617 Cole Blvd, Golden, Colorado, 80401, 1995.

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

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

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

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

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

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

McPherson, E.G., J.R. Simpson, P.J. Peper and Q. Xiao. 1999. **Tree guidelines for San Joaquin Valley communities**. Sacramento, CA: Local Government Commission. 63.

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

McPherson, E.G., J.R. Simpson, P.J. Peper, K.I. Scott and Q. Xiao. 2000. **Tree guidelines for coastal Southern California communities**. Sacramento, CA: Local Government Commission. 98.

McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao, D.R. Pettinger and D.R. Hodel. 2001.**Tree Guidelines for Inland Empire Communities**. Local Government Commission, Sacramento, CA. pp. 115.

McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao, D.R. Pittenger and D.R. Hodel. 2001. **Tree guidelines for Inland Empire communities**. Sacramento, CA: Local Government Commission. 116.

McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao, S.E. Maco, and P.J. Hoefer. March 2003a. **Northern mountain and prairie community tree guide: benefits, costs and strategic planting.** Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station. 92.

McPherson, E.G., J.R. Simpson, P.J. Peper, S.E. Maco, Q. Xiao. 2003b. **Benefit-cost analysis of Fort Collin's Municipal Forest**. Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station.

McPherson, E.G., K.I. Scott and J.R. Simpson. 1998. **Estimating cost effectiveness of residential yard trees for improving air quality in Sacramento, California, using existing models**. Atmospheric Environment 32(2):75-84.

McPherson, E.G., S.E. Maco, J.R. Simpson, P.J. Peper, Q. Xiao, A.M. VanDerZanden and N. Bell. 2002. **Western Washington and Oregon Community Tree Guide: Benefits, Costs, and Strategic Planting**. Silverton, OR: International Society of Arboriculture, Pacific Northwest: Chapter 76.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., and Q. Xaio. 2004. **Benefit-Cost Analysis of Fort Collins' Municipal Forest**. Internal Report, CUFR-2, Davis, CA: Center for Urban Forest Research; 39 p.

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

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

Muchnick, J. 2003. **Effects of Tree Shade on Asphalt Concrete Pavement Performance**. M.S. Thesis, University of California, Davis. pp. 82.

Pacific Gas and Electric. 2003a. **Electric rates: current and historic electric rates**. Accessed via the World Wide Web http://www.pge.com/tariffs/ResElecCurrent.xls on May 1, 2003.

Pacific Gas and Electric. 2003b.**Gas rates: current and historic gas rates, residential**. Accessed via the World Wide Web <http://www.pge.com/tariffs/Res_Current.xls> on May 1, 2003.

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

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

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

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

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

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

Sanders, R.A. 1981. **Diversity in the street trees of Syracuse, New York**. Urban Ecol., 5:33-43.

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

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

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

Simpson, E.H. 1949. **Measurement of diversity.** Nature. 163:688.

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

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

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

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

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

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

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

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

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

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

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

Wolf, K.L. 1999. Nature and commerce: human ecology in business districts. In C. Kollin (Ed), **Building Cities of Green: Proceedings of the 1999 National Urban Forest Conference**. Washington, D.C. American Forests; 56-59.

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

## Appendix A—Tree Distribution

***Table A1****—Distribution of most common street trees by DBH class.*

| Species | DBH class (in) | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-3 | 3-6 | 6-12 | 12-18 | 18-24 | 24-30 | 30-36 | 36-42 | 42+ | |
| Broadleaf deciduous large | | | | | | | | | | |
| London plane | 136 | 211 | 362 | 764 | 507 | 343 | 185 | 76 | 72 | 2,656 |
| American elm | 24 | 5 | 6 | 42 | 105 | 109 | 139 | 94 | 60 | 584 |
| Chinese elm | 19 | 22 | 156 | 248 | 26 | 13 | 5 | 0 | 1 | 490 |
| California sycamore | 27 | 59 | 51 | 92 | 158 | 44 | 8 | 0 | 0 | 439 |
| Tulip tree | 10 | 23 | 102 | 226 | 21 | 13 | 17 | 0 | 0 | 412 |
| BDL other | 472 | 253 | 302 | 309 | 74 | 39 | 37 | 8 | 3 | 1,497 |
| Total | 688 | 573 | 979 | 1,681 | 891 | 561 | 391 | 178 | 136 | 6,078 |
| Broadleaf deciduous medium | | | | | | | | | | |
| Sweetgum | 125 | 233 | 711 | 962 | 246 | 31 | 11 | 2 | 0 | 2,321 |
| Ash species | 195 | 128 | 194 | 359 | 174 | 46 | 14 | 9 | 0 | 1,119 |
| Velvet ash | 59 | 48 | 77 | 171 | 92 | 31 | 38 | 4 | 1 | 521 |
| Chinese pistache | 283 | 165 | 68 | 1 | 0 | 0 | 0 | 0 | 0 | 517 |
| Other | 240 | 159 | 67 | 19 | 4 | 0 | 3 | 1 | 0 | 493 |
| Ginkgo | 203 | 102 | 89 | 54 | 1 | 0 | 0 | 0 | 0 | 449 |
| Callery pear | 89 | 173 | 111 | 46 | 8 | 0 | 0 | 0 | 0 | 427 |
| Black locust | 174 | 101 | 39 | 41 | 26 | 13 | 2 | 0 | 0 | 396 |
| Raywood ash | 39 | 132 | 82 | 44 | 17 | 7 | 1 | 0 | 0 | 322 |
| Honeylocust | 131 | 46 | 106 | 30 | 0 | 1 | 0 | 0 | 0 | 314 |
| BDM other | 624 | 299 | 502 | 293 | 61 | 34 | 12 | 2 | 1 | 1,828 |
| Total | 2,162 | 1,586 | 2,046 | 2,020 | 629 | 163 | 81 | 18 | 2 | 8,707 |
| Broadleaf deciduous small | | | | | | | | | | |
| Cherry plum | 335 | 457 | 531 | 111 | 4 | 1 | 0 | 0 | 0 | 1,439 |
| Cherry/plum species | 357 | 332 | 253 | 54 | 5 | 2 | 1 | 0 | 0 | 1,004 |
| Purpleleaf plum | 106 | 180 | 286 | 47 | 0 | 0 | 0 | 0 | 0 | 619 |
| Japanese maple | 258 | 119 | 69 | 20 | 22 | 13 | 1 | 1 | 0 | 503 |
| Flowering plum | 67 | 156 | 114 | 14 | 0 | 1 | 1 | 0 | 0 | 353 |
| BDS other | 589 | 473 | 298 | 40 | 2 | 1 | 0 | 0 | 0 | 1,403 |
| Total | 1,712 | 1,717 | 1,551 | 286 | 33 | 18 | 3 | 1 | 0 | 5,321 |

*Table A1, cont.—Distribution of most common street trees by DBH class.*

| **Species** | **DBH class (in)** | | | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| | **0-3** | **3-6** | **6-12** | **12-18** | **18-24** | **24-30** | **30-36** | **36-42** | **42+** | |
| Broadleaf evergreen large | | | | | | | | | | |
| Coast live oak | 413 | 403 | 314 | 191 | 62 | 23 | 12 | 6 | 6 | 1,430 |
| BEL other | 108 | 72 | 85 | 109 | 67 | 27 | 14 | 5 | 14 | 501 |
| Total | 521 | 475 | 399 | 300 | 129 | 50 | 26 | 11 | 20 | 1,931 |
| Broadleaf evergreen medium | | | | | | | | | | |
| Camphor tree | 19 | 37 | 91 | 339 | 396 | 142 | 88 | 31 | 11 | 1,154 |
| Southern magnolia | 102 | 131 | 207 | 116 | 16 | 6 | 0 | 1 | 0 | 579 |
| Victorian box | 50 | 93 | 193 | 115 | 16 | 4 | 1 | 0 | 1 | 473 |
| BEM other | 441 | 326 | 285 | 211 | 54 | 26 | 17 | 9 | 2 | 1,371 |
| Total | 612 | 587 | 776 | 781 | 482 | 178 | 106 | 41 | 14 | 3,577 |
| Broadleaf evergreen small | | | | | | | | | | |
| Evergreen pear | 212 | 272 | 374 | 90 | 16 | 21 | 13 | 0 | 0 | 998 |
| Cotoneaster | 169 | 167 | 18 | 4 | 0 | 0 | 0 | 0 | 0 | 358 |
| BES other | 756 | 683 | 492 | 277 | 55 | 24 | 6 | 1 | 1 | 2,295 |
| Total | 1,137 | 1,122 | 884 | 371 | 71 | 45 | 19 | 1 | 1 | 3,651 |
| Conifer evergreen large | | | | | | | | | | |
| CEL other | 65 | 124 | 68 | 77 | 76 | 65 | 52 | 29 | 46 | 602 |
| Total | 65 | 124 | 68 | 77 | 76 | 65 | 52 | 29 | 46 | 602 |
| Conifer evergreen medium | | | | | | | | | | |
| Pine species | 42 | 26 | 68 | 69 | 53 | 29 | 25 | 4 | 6 | 322 |
| CEM other | 45 | 35 | 23 | 7 | 1 | 2 | 1 | 1 | 0 | 115 |
| Total | 87 | 61 | 91 | 76 | 54 | 31 | 26 | 5 | 6 | 437 |
| Conifer evergreen small | | | | | | | | | | |
| CES other | 22 | 25 | 16 | 18 | 4 | 4 | 6 | 0 | 5 | 100 |
| Total | 22 | 25 | 16 | 18 | 4 | 4 | 6 | 0 | 5 | 100 |
| Palm evergreen large | | | | | | | | | | |
| PEL other | 9 | 2 | 8 | 2 | 3 | 4 | 7 | 0 | 1 | 36 |
| Total | 9 | 2 | 8 | 2 | 3 | 4 | 7 | 0 | 1 | 36 |
| Palm evergreen small | | | | | | | | | | |
| PES other | 28 | 59 | 103 | 55 | 79 | 12 | 0 | 3 | 0 | 339 |
| Total | 28 | 59 | 103 | 55 | 79 | 12 | 0 | 3 | 0 | 339 |
| Citywide total | 7,043 | 6,331 | 6,921 | 5,667 | 2,451 | 1,131 | 717 | 287 | 231 | 30,779 |

*Table A2—Distribution of most common park trees by DBH class.*

| Species | DBH Class (in) | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-3 | 3-6 | 6-12 | 12-18 | 18-24 | 24-30 | 30-36 | 36-42 | >42 | |
| Broadleaf large deciduous | | | | | | | | | | |
| BDL Other | 78 | 52 | 73 | 65 | 20 | 4 | 7 | 3 | 10 | 312 |
| Total | 78 | 52 | 73 | 65 | 20 | 4 | 7 | 3 | 10 | 312 |
| Broad deciduous medium | | | | | | | | | | |
| Other | 3 | 21 | 26 | 10 | 7 | 0 | 0 | 1 | 3 | 71 |
| White alder | 2 | 12 | 11 | 24 | 12 | 0 | 1 | 1 | 0 | 63 |
| BDM other | 49 | 95 | 104 | 46 | 4 | 2 | 0 | 0 | 1 | 301 |
| Total | 54 | 128 | 141 | 80 | 23 | 2 | 1 | 2 | 4 | 435 |
| Broadleaf deciduous small | | | | | | | | | | |
| Cherry plum species | 28 | 84 | 74 | 12 | 1 | 0 | 0 | 0 | 0 | 199 |
| Arroya willow | 3 | 10 | 24 | 22 | 2 | 2 | 1 | 0 | 0 | 64 |
| Cherry plum | 15 | 24 | 16 | 6 | 1 | 0 | 0 | 0 | 0 | 62 |
| BDS other | 76 | 137 | 107 | 18 | 0 | 0 | 0 | 0 | 0 | 338 |
| Total | 122 | 255 | 221 | 58 | 4 | 2 | 1 | 0 | 0 | 663 |
| Broadleaf evergreen large | | | | | | | | | | |
| Coast live oak | 162 | 171 | 226 | 249 | 55 | 28 | 14 | 2 | 5 | 912 |
| Blue gum eucalyptus | 5 | 14 | 27 | 23 | 11 | 6 | 10 | 11 | 35 | 142 |
| California laurel | 12 | 10 | 27 | 34 | 15 | 9 | 5 | 8 | 3 | 123 |
| BEL other | 3 | 13 | 31 | 18 | 6 | 2 | 2 | 0 | 0 | 75 |
| Total | 182 | 208 | 311 | 324 | 87 | 45 | 31 | 21 | 43 | 1,252 |
| Broadleaf evergreen medium | | | | | | | | | | |
| Black acacia | 22 | 31 | 63 | 44 | 19 | 7 | 11 | 1 | 1 | 199 |
| Victorian box | 18 | 31 | 37 | 16 | 4 | 0 | 0 | 0 | 0 | 106 |
| BEM other | 32 | 51 | 56 | 44 | 11 | 5 | 6 | 3 | 1 | 209 |
| Total | 72 | 113 | 156 | 104 | 34 | 12 | 17 | 4 | 2 | 514 |
| Broadleaf evergreen small | | | | | | | | | | |
| Tarata pittosporum | 7 | 67 | 49 | 17 | 1 | 0 | 0 | 0 | 0 | 141 |
| Cotoneaster | 31 | 68 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 109 |
| Stiffleaf cheesewood | 16 | 50 | 32 | 11 | 0 | 0 | 0 | 0 | 0 | 109 |
| California buckeye | 38 | 24 | 32 | 9 | 1 | 1 | 1 | 1 | 0 | 107 |
| Christmas berry | 6 | 45 | 21 | 1 | 0 | 0 | 0 | 0 | 0 | 73 |
| Strawberry tree | 7 | 38 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 65 |
| BES other | 38 | 147 | 190 | 56 | 5 | 0 | 0 | 0 | 0 | 436 |
| Total | 143 | 439 | 354 | 94 | 7 | 1 | 1 | 1 | 0 | 1,040 |

***Table A2, cont.****—Distribution of most common park trees by DBH class.*

| Species | DBH Class (in) | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-3 | 3-6 | 6-12 | 12-18 | 18-24 | 24-30 | 30-36 | 36-42 | >42 | |
| Conifer evergreen large | | | | | | | | | | |
| Coast redwood | 41 | 26 | 52 | 102 | 64 | 49 | 38 | 35 | 51 | 458 |
| Monterey cypress | 70 | 39 | 23 | 88 | 54 | 34 | 24 | 23 | 19 | 374 |
| Monterey pine | 11 | 6 | 41 | 88 | 36 | 16 | 9 | 8 | 4 | 219 |
| Canary island pine | 1 | 8 | 22 | 27 | 18 | 9 | 8 | 2 | 3 | 98 |
| CEL other | 25 | 40 | 77 | 59 | 19 | 11 | 13 | 7 | 11 | 262 |
| Total | 148 | 119 | 215 | 364 | 191 | 119 | 92 | 75 | 88 | 1,411 |
| Conifer evergreen medium | | | | | | | | | | |
| CEM other | 2 | 7 | 5 | 2 | 0 | 1 | 0 | 1 | 0 | 18 |
| Total | 2 | 7 | 5 | 2 | 0 | 1 | 0 | 1 | 0 | 18 |
| Conifer evergreen small | | | | | | | | | | |
| CES other | 1 | 8 | 15 | 2 | 0 | 0 | 0 | 0 | 0 | 26 |
| Total | 1 | 8 | 15 | 2 | 0 | 0 | 0 | 0 | 0 | 26 |
| Palm evergreen large | | | | | | | | | | |
| PEL other | 5 | 0 | 0 | 0 | 3 | 6 | 1 | 2 | 0 | 17 |
| Total | 5 | 0 | 0 | 0 | 3 | 6 | 1 | 2 | 0 | 17 |
| Palm evergreen small | | | | | | | | | | |
| PES other | 1 | 1 | 12 | 4 | 0 | 0 | 0 | 0 | 0 | 18 |
| Total | 1 | 1 | 12 | 4 | 0 | 0 | 0 | 0 | 0 | 18 |
| Citywide Total | 808 | 1,330 | 1,503 | 1,097 | 369 | 192 | 151 | 109 | 147 | 5,706 |

## Appendix B—Methodology and Procedures

This analysis combines results of a citywide inventory with benefit–cost modeling data to produce four types of information (Maco 2003):

1. Resource structure (species composition, diversity, age distribution, condition, etc.)

2. Resource function (magnitude of environmental and aesthetic benefits)

3. Resource value (dollar value of benefits realized)

4. Resource management needs (sustainability, pruning, planting, and conflict mitigation)

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

### *Growth Modeling*

A stratified random sample of street and park trees, drawn from Berkeley's municipal tree database, was inventoried to establish relations between tree age, size, leaf area and biomass; in turn, estimates for determining the magnitude of annual benefits were derived. The sample was composed of the 21 most abundant species, and was used to estimate growth of all street and park trees.

To obtain information spanning the life cycle of predominant tree species, the sample was stratified into nine diameter-at-breast height (DBH) classes: 0–3 in, 3–6 in, 6–12 in, 12–18 in,18–24 in, 24–30 in, 30–36 in, 36–42 in, and >42 in. Thirty-five to seventy trees of each species were randomly selected for surveying, 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 0.5 m, by hypsometer), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5m by tape), tree condition and location, and crown density. Replacement trees were measured when trees from the original sample population could not be located. Tree age was determined from interviews with residents, the city's senior forestry supervisor, historical planting records and aerial photos from the Berkeley Historical Society. Fieldwork was conducted in summer 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% of actual leaf area) for estimating crown volume and leaf area of isolated trees (Peper and McPherson 2003).

Linear and nonlinear regression was used to fit predictive models with DBH as a function of age, for each of the 21 sampled species. Predictions of leaf surface area (LSA), crown diameter, and height metrics were modeled as a function of DBH using best-fit models (Peper and McPherson 2003).

### *Identifying and Calculating Benefits*

Annual benefits for Berkeley's municipal trees were estimated for the fiscal 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. However, calculations of $CO_2$ released due to decomposition of wood from removed trees did consider average annual mortality. This approach directly connects benefits with tree-size variables such DBH and LSA. Many functional benefits of trees are related to processes that involve interactions between leaves and the atmosphere (e.g., interception, transpiration, photosynthesis); therefore, benefits increase as tree canopy cover and leaf surface area increase.

For each of the modeled benefits, an annual resource unit was determined on a per-tree basis. Resource units are measureds as kWh of electricity saved per tree, kBtu of natural gas conserved per tree, lbs of atmospheric $CO_2$ reduced per tree, lbs of $NO_2$, $PM_{10}$, and VOCs reduced per tree, $ft^3$ of stormwater runoff reduced per tree, and $ft^2$ of leaf area added per tree to increase property values.

Prices were assigned to each resource unit (e.g., heating/cooling energy savings, air-pollution absorption, stormwater-runoff reduction) using economic indicators of society's willingness to pay for the environmental benefits trees provide. Estimates of benefits are initial approximations as some benefits are difficult to quantify (e.g., impacts on psychological health, crime, and violence). In addition, limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Therefore, this method of quantification provides first-order approximations. It is meant to be a general accounting of the benefits produced by urban trees—an accounting with an accepted degree of uncertainty that can, nonetheless, provide a science-based platform for decision-making (Maco 2003).

## Energy Savings

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

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

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

Trees reduce air movement into buildings and conductive heat loss from buildings. The rates at which outside air moves into a building can increase substantially with wind speed. In cold, windy weather, the entire volume of air, even in newer or tightly sealed homes, may change every two to three hours. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). 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

### Calculating Electricity and Natural Gas Benefits

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per-tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950–1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same floor area, and other construction characteristics. Weather data for a typical meterological year (TMY2) from San Francisco International Airport were used (Marion and Urban 1995). Shading effects for each of the 21 tree species were simulated at three tree-to-building distances, for eight orientations and for nine tree sizes.

The shading coefficients of the trees in leaf (gaps in the crown as a percentage of total crown silhouette) were estimated using a photographic method that has been shown to produce good estimates (Wilkinson 1991). Crown areas were obtained using the method of Peper and McPherson (2003) from digital photographs of trees from which background features were digitally removed. Values for tree species that were not sampled, and leaf-off values for use in calculating winter shade, were based on published values where available (McPherson 1984; Hammond et al. 1980). Where published values were not available, visual densities were assigned based on taxonomic considerations (trees of the same genus were assigned the same value) or observed similarity to known species. Foliation periods for deciduous trees were obtained from the literature (McPherson 1984; Hammond et al. 1980) and adjusted for Berkeley's climate based on consultation with the senior forestry supervisor (Koch 2004).

Average energy savings per tree were calculated as a function of distance and direction using tree location distribution data specific to Berkeley [i.e. frequency of trees located at different distances from buildings (setbacks) and tree orientation with respect to buildings]. Setbacks were assigned to four distance classes: 0–20 ft, 20–40 ft, 40–60 ft and >60 ft. It was assumed that street trees within 60 ft of buildings provided direct shade on walls and windows. Savings per tree at each location were multiplied by tree distribution to determine location-weighted savings per tree for each species and DBH class, independent of location. Location-weighted savings per tree were multiplied by number of trees of each species and DBH class and then summed to find total savings for the city. Tree locations were based on the stratified random sample conducted in summer 2003.

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

Three prototype buildings were used in the simulations to represent pre-1950, 1950–1980, and post-1980 construction practices for Berkeley (Pacific South census region, San Francisco) (Ritschard et al. 1992). Building footprints were modeled as square, which was found to be reflective of average impacts for a large number of buildings (Simpson 2002). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37%, and were assumed to be closed when the air conditioner was operating. Summer and winter thermostat settings were 78 and 68°F during the day, respectively, and 60°F at night. Unit energy consumptions were adjusted to account for equipment saturations (percentage of structures with different types of heating and cooling equipment such as central air conditioners, room air conditioners, and evaporative coolers) (*Table B-1*).

**Single-Family Residence Adjustments**

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

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

where

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

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

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

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

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

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

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

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

In addition to localized shade effects, which were assumed to accrue only to street trees within 18–60 ft of buildings, lowered air temperatures and wind speeds due to neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for summer cooling and winter heating. Reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances. To estimate climate effects on energy use, air-temperature and wind-speed reductions as a function of neighborhood canopy cover were estimated from published values following McPherson and Simpson (1999), then used as input for the building-energy-use simulations described earlier. Peak summer air temperatures were assumed to be reduced by 0.4°F for each percentage increase in canopy cover. Wind-speed reductions were based on the change in total tree plus building canopy cover resulting from the addition of the particular tree being simulated (Heisler 1990). A lot size of 10,000 $ft^2$ was assumed.

Dollar values for electrical and natural gas energy savings were based on electricity and natural gas prices of $0.1323 per kWh (Pacific Gas and Electric Company 2004a) and $1.305 per therm (Pacific Gas and Electric Company 2004b), respectively. Cooling and heating effects were reduced based on the type and saturation of air conditioning (*Table B-1*) or heating (*Table B-2*) equipment by vintage. Equipment factors of 33 and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (*Table B-3*). Heating loads were converted to fuel use based on efficiencies in *Table B-2*. The “other” and “fuel oil” heating

*Table B1—Saturation adjustments for cooling (%).*

| | **Single family detached** | | | **Mobile homes** | | | **Single-family attached** | | | **MF 2-4 units** | | | **MF 5+ units** | | | **Commercial/ industrial** | | **Institutional/ Transportation** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **Small** | **Large** | |
| 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 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| Evaporative cooler | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wall/window unit | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| None | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adjusted cooling saturation | 24 | 46 | 80 | 24 | 46 | 80 | 24 | 46 | 80 | 24 | 46 | 80 | 24 | 46 | 80 | 88 | 88 | 88 |

*Table B2—Saturation adjustments for heating (%).*

| | Single family detached | | | Mobile homes | | | Single-family attached | | | MF 2-4 units | | | MF 5+ units | | | Commercial/ industrial | | Institutional/ Transportation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pre-1950 | 1950-1980 | post-1980 | pre-1950 | 1950-1980 | post-1980 | pre-1950 | 1950-1980 | post-1980 | pre-1950 | 1950-1980 | post-1980 | pre-1950 | 1950-1980 | post-1980 | Small | Large | |
| Equipment efficiencies | | | | | | | | | | | | | | | | | | |
| AFUE | 75 | 78 | 78 | 75 | 78 | 78 | 75 | 78 | 78 | 75 | 78 | 78 | 75 | 78 | 78 | 78 | 78 | 78 |
| HSPF | 680 | 680 | 800 | 680 | 680 | 800 | 680 | 680 | 800 | 680 | 680 | 800 | 680 | 800 | 800 | 800 | 800 | 800 |
| HSPF | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 | 341 |
| Electric heat saturations | | | | | | | | | | | | | | | | | | |
| Electric resistance | 3 | 6 | 9 | 3 | 6 | 9 | 3 | 6 | 9 | 3 | 6 | 9 | 3 | 6 | 9 | 5 | 5 | 5 |
| Heat pump | 6 | 13 | 20 | 6 | 13 | 20 | 6 | 13 | 20 | 6 | 13 | 20 | 6 | 13 | 20 | 5 | 5 | 5 |
| Adjusted electric heat saturations | 2 | 4 | 5 | 2 | 4 | 5 | 2 | 4 | 5 | 2 | 4 | 5 | 2 | 4 | 5 | 2 | 2 | 2 |
| Natural gas and other heating saturations | | | | | | | | | | | | | | | | | | |
| Natural gas | 70 | 61 | 52 | 70 | 61 | 52 | 70 | 61 | 52 | 70 | 61 | 52 | 70 | 61 | 52 | 90 | 90 | 90 |
| Oil | 8 | 2 | 2 | 8 | 2 | 2 | 8 | 2 | 2 | 8 | 2 | 2 | 8 | 2 | 2 | 0 | 0 | 0 |
| Other | 14 | 18 | 17 | 14 | 18 | 17 | 14 | 18 | 17 | 14 | 18 | 17 | 14 | 18 | 17 | 0 | 0 | 0 |
| NG heat saturations | 91 | 81 | 71 | 91 | 81 | 71 | 91 | 81 | 71 | 91 | 81 | 71 | 91 | 81 | 71 | 90 | 90 | 90 |

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

| | **Single family detached** | | | **Mobile homes** | | | **Single-family attached** | | | **MF 2-4 units** | | | **MF 5+ units** | | | **Commercial/ industrial** | | **Institutional/ Transportation** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **pre-1950** | **1950-1980** | **post-1980** | **Small** | **Large** | |
| Vintage distribution by building type | 60 | 34 | 7 | 60 | 34 | 7 | 60 | 34 | 7 | 60 | 34 | 7 | 60 | 34 | 7 | 100 | 100 | 100 |
| Tree distribution by vintage and building type | 30 | 17 | 3 | 0 | 0 | 0 | 2 | 1 | 0 | 2 | 1 | 0 | 3 | 2 | 0 | 12 | 7 | 19 |
| Combined vintage, equipment saturation factors for cooling | | | | | | | | | | | | | | | | | | |
| Cooling factor: shade | 7 | 8 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 0 |
| Cooling factor: climate | 7 | 8 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 14 | 0 |
| Combined vintage, equipment saturation for heating | | | | | | | | | | | | | | | | | | |
| Heating factor, natural gas: shade | 27 | 13 | 2 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 4 | 1 | 0 |
| Heating factor, electric: shade | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heating factor, natural gas: climate | 28 | 14 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 12 | 23 | 0 |
| Heating factor, electric: climate | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

equipment types were assumed to be natural gas for the purpose of this analysis. Building vintage distributions were combined with adjusted saturations to compute combined vintage/saturation factors for natural gas and electric heating (*Table B-3*).

**Multi-Family Residence Analysis**

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

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

**Commercial and Other Buildings**

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

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

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

## Atmospheric Carbon Dioxide Reduction

Sequestration (the net rate of $CO_2$ storage in above- and below-ground biomass over the course of one growing season) is calculated for each species using the tree-growth equations for DBH and height, described above, to calculate either tree volume or biomass. Equations from Pillsbury et. al (1998) are used when calculating volume. Fresh weight (kg/m3) and specific gravity ratios from Alden (1995, 1997) are then applied to convert volume to biomass. When volumetric equations for urban trees are unavailable, biomass equations derived from data collected in rural forests are applied (Tritton and Hornbeck 1982; Ter-Mikaelian and Korzukhin 1997).

Carbon dioxide released through decomposition of dead woody biomass varies with characteristics of the wood itself, the fate of the wood (e.g., amount left standing, chipped, or burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. Calculations were conservative because they assumed that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as $CO_2$ in the same year. Total annual decomposition is based on the number of trees in each species and age class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. Tree mortality for Berkeley was 3.0% per year for the first five years after planting and 1.2% every year thereafter for street trees, and 1.0% per year for the first five years after planting and 0.4% every year thereafter for park trees (Koch 2004). Finally, $CO_2$ released during tree maintenance was estimated to be 0.14 kg $CO_2$/cm DBH based on U.S. national average figures (McPherson and Simpson 1999).

### Methodology for Calculating Avoided $CO_2$ Emissions

Reducing building energy use reduces emissions of $CO_2$. Emissions were calculated as the product of energy use and $CO_2$ emission factors for electricity and heating. Heating fuel is largely natural gas and electricity in Berkeley. The overall fuel mix for electrical generation based on the California eGRID subregion was primarily natural gas (45%), hydroelectric (17%), nuclear (16%) and coal (12%) (U.S. EPA 2003).

Emissions factors for electricity (lb/MWh) and natural gas (lb/MBtu) weighted for the regional fuel mixes are given in *Table B-4*. The monetary value of avoided $CO_2$ was $0.0075/lb based on average high and low estimates for emerging carbon trading markets (CO2e.com 2002) (*Table B-4*).

***Table B4****—Emissions factors and monetary values for $CO_2$ and criteria air pollutants. (California Air Resources Board 2002, 2003, 2004)*

| | Emission Factor | | Implied value ($/lb) |
|---|---|---|---|
| | Electricity (lb/MWh) | Natural gas (lb/MBtu) | |
| $CO_2$ | 841 | 118 | 0.0075 |
| $NO_2$ | 0.97 | 0.102 | 10.31 |
| $SO_2$ | 0.595 | 0.0006 | 3.67 |
| $PM_{10}$ | 0.272 | 0.0075 | 11.79 |
| VOCs | 0.138 | 0.0054 | 7.22 |
| Ozone | | | 10.31 |

## *Improving Air Quality*

### Methodology for Calculating Other Avoided Emissions

Reductions in building energy use also result in reduced emissions of criteria air pollutants (those for which a national standard has been set by the EPA) from power plants and space-heating equipment. This analysis considered volatile organic hydrocarbons (VOCs) and nitrogen dioxide ($NO_2$)—both precursors of ozone (O3) formation—as well as sulfur dioxide ($SO_2$) and particulate matter of <10 micron diameter ($PM_{10}$). Changes in average annual emissions and their monetary values were calculated in the same way as for $CO_2$, again using utility specific emission factors for electricity and heating fuels (U.S. Environmental Protection Agency 2003). Values for criteria air pollutants were based on average (2001–2003) emission reduction offset transaction costs for the San Francisco Bay area (California Air Resources Board 2002, 2003, 2004) (*Table B-4*).

### Methodology for Calculating Deposition and Interception

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of the deposition velocity $V_d = 1/(R_a+R_b+R_c)$, pollutant concentration (C), canopy projection (CP) area, and time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances $R_a$, $R_b$, and $R_c$ estimated for each hour over a year using formulations described by Scott et al. (1998). Data from 2001 were selected as representative for modeling deposition based on a review of mean $PM_{10}$ and $O_3$ concentrations for the years 1996–2004. Data for air monitoring stations closest in proximity and climate to Berkeley were used—$O_3$, $NO_2$, and $SO_2$ from Oakland and $PM_{10}$ from San Pablo (California Air Resources Board 2004b).

Deposition was determined for deciduous species only when trees were in-leaf. A 50% re-suspension rate was applied to $PM_{10}$ deposition. Methods described in the section "Methodology for Calculating Avoided Emissions" were used to value emissions reductions; $NO_2$ prices were used for ozone since ozone control measures typically aim at reducing $NO_2$. Hourly meteorological data for Berkeley (air temperature, wind speed, solar radiation and precipitation) were used (CIMIS 2004).

### Methodology for Calculating BVOC Emissions

Emissions of biogenic volatile organic carbon (sometimes called biogenic hydrocarbons or BVOCs) associated with increased ozone formation were estimated for the tree canopy using methods described by McPherson et al. (1998). In this approach, the hourly emissions of carbon in the form of isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or simply temperature (monoterpene). Hourly emissions were summed to get annual totals. This is a conservative approach, since the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from biogenic as well as anthropogenic sources were not accounted for. The cost of these emissions is based on control cost estimates and was valued at $7.22/lb for Berkeley (California Air Resources Board 2002, 2003, 2004).

## Reducing Stormwater Runoff

### Methodology for Calculating Stormwater Runoff Reductions

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 on canopy leaf and bark surfaces. Once the storage capacity of the tree canopy is exceeded, rainwater temporarily stored on the tree surface will drip from the leaf surface and flow down the stem surface to the ground. Some of the stored water will evaporate. Tree canopy parameters related to stormwater-runoff reductions include species, leaf and stem surface area, shade coefficient (visual density of the crown), tree height, and foliation data. Wind speeds were estimated for different heights above the ground; from this, rates of evaporation were estimated.

The volume of water stored in the tree crown was calculated from crown projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and water depth on the canopy surface. Species-specific shade coefficients and tree-surface saturation values influence the amount of projected throughfall. Hourly meteorological data for 2000 from CIMIS (California Irrigation Management Information System) Oakland Foothills station (station ID 49; latitude: 41°10′N; longitude: 104°49′W) were selected to best represent a typical meteorological year and were used for this simulation. Annual precipitation during 2000 was 22.2 in. A more complete description of the interception model can be found in Xiao et al. (1998).

Recently, Berkeley's Stormwater/Drainage Construction Program was not funded. As a result, the City has not been able to meet its regulatory requirements under the Alameda Countywide Clean Water Program (ACCWP). Contaminated stormwater runoff in Berkeley receives no treatment of any kind (City of Berkeley 2004a). As such, only costs associated with conveyance could be directly applied. Compliance with ACCWP, however, requires treatment to prevent contaminated runoff from entering local waterways. Therefore, to estimate the combined value of rainfall intercepted and potential cost reductions in regulated stormwater management control—a value that includes the cost of collection, conveyance and treatment—single-family residential sewer service fees were used ($3.02/Ccf/dwelling unit) (City of Berkeley 2004b). Sewer service fees cover capital, operation, and improvements of the citywide sewer system. While this value is not the current assessed cost of stormwater management in Berkeley, the sewer service fee is a conservative proxy for a desired level of service. At $0.004 per gallon this fee is below the average price for stormwater runoff reduction ($0.01/gallon) assessed in similar studies (McPherson et al. 2003a, 2003b, 2002, 2001, 2000, 1999b; Maco et al. 2003).

## Property Value & Other Benefits

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

Well-maintained trees increase the "curb appeal" of properties. Research comparing sales prices of residential properties with different numbers and sizes of trees suggests that people are willing to pay 3–7% more for properties with ample trees versus few or no trees. One of the most comprehensive studies on the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1% increase in sales price (Anderson and Cordell 1988). Depending on average home sale prices, the value of this benefit can contribute significantly to 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 play in cities. Physical and emotional stress has both short-term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving showed that views of nature reduce the stress response of both body and mind (Parsons et al. 1998). City nature also appears to have an "immunization effect," in that people show less stress response if they've had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, have a better outlook, and recover more quickly than patients without connections to nature (Ulrich 1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

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

Urban forests can be oases, sometimes containing more biological diversity than neighboring 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 materials, work with area schools, and offer hands-on training in the care of trees.

**Methodology for Calculating Changes in Property Values and Other Benefits**

In an Athens, GA, study (Anderson and Cordell 1988), a large front-yard tree was found to be associated with an 0.88% increase in average home resale values. In our study, the annual increase in leaf surface area of a typical mature large tree (40-year-old London plane, average leaf surface area 4,417 $ft^2$) was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the City of Berkeley, each large tree would be worth $4,620 based on the 2003 average single-family-home resale price in Berkeley ($525,000) (DataQuick 2004). However, not all trees are as effective as front-yard trees in increasing property values. For example, trees adjacent to multifamily housing units will not increase the property value at the same rate as trees in front of single-family homes. Therefore, citywide street- and park-tree reduction factors (0.82 and 0.5, respectively) were applied to prorate trees' value based on the assumption that trees adjacent to different land-uses make different contributions to property sales prices. For this analysis, the street reduction factor reflects the distribution of street trees in Berkeley by land-use. Reductions factors were: single-home residential (100%), multi-home residential (75%), commercial/industrial (50%), vacant (25%), park (50%) and institutional (50%) (McPherson et al. 2001).

Given these assumptions, a typical large street tree was estimated to increase property values by $0.86/$ft^2$ of LSA, while a typical park tree increased the value by $0.52/$ft^2$ of LSA. For example, it was estimated that a single, street-side Chinese pistache tree added about 74.6 $ft^2$ of LSA per year when growing in the DBH range of 12–18 in. Therefore, during this period of growth, pistache trees effectively added $63.92, annually, to the value of an adjacent home, condominium, or business property (74.6 $ft^2$ × $0.86/$ft^2$ = $63.92).

## *Estimating Magnitude of Benefits*

Resource units describe the absolute value of the benefits of Berkeley's street and park trees on a per-tree basis. They include kWh of electricity saved per tree, kBtu of natural gas conserved per tree, lbs of atmospheric $CO_2$ reduced per tree, lbs of $NO_2$, $PM_{10}$, and VOCs reduced per tree, $ft^3$ of stormwater runoff reduced per tree, and $ft^2$ of leaf area added per tree to increase property values. A dollar value was assigned to each resource unit based on local costs.

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

**Categorizing Trees by DBH Class**

The first step in accomplishing this task involved categorizing the total number of street trees by relative age (as a function of DBH class). The inventory was used to group trees into the following classes: 0–3 in, 3–6 in, 6–12 in , 12–18 in, 18–24 in, 24–30 in, 30–36 in, 36–42 in, >42 in.

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

**Applying Resource Units to Each Tree**

The interpolated resource-unit values were used to calculate the total magnitude of benefits for each DBH class and species. For example, there were 139 American elms citywide in the 30–36 in DBH class. The interpolated electricity and natural gas resource unit values for the class midpoint (33 in) were 348 kWh and 578.1 kBtu per tree, respectively. Therefore, multiplying the resource units for the class by 139 trees equals the magnitude of annual heating and cooling benefits produced by this segment of the population: 54,984 kWh of electricity saved and 91,340 kBtu of natural gas saved.

**Matching Significant Species with Modeled Species**

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

**Grouping Remaining "Other" Trees by Type**

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

• Broadleaf deciduous large (BDL), medium (BDM), and small (BDS).

• Broadleaf evergreen large (BEL), medium (BEM), and small (BES).

• Coniferous evergreen large (CEL), medium (CEM), and small (CES).

• Palm evergreen large (PEL), medium (PEM), and small (PES).

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

BDL Other = London plane (*Platanus acerifolia*)

BDM Other = velvet ash (*Fraxinus velutina*)

BDS Other = cherry plum (*Prunus cerasifera*)

BEL Other = coast live oak (*Quercus agrifolia*)

BEM Other = camphor (*Cinnamomum camphora*)

BES Other = evergreen pear (*Pyrus kawakamii*)

CEL Other = coast redwood (*Sequoia sempervirens*)

CEM Other = Scaled @ 2/3 coast redwood

CES Other = Scaled @ 1/3 coast redwood

PEL Other = Canary Island date palm (P*hoenix canariensis*)

PEM Other = Scaled @ 2/3 Canary Island date palm

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

Because palms were not sampled in Berkeley, growth data from Claremont, CA were used. Where modeled species did not exist for specific categories (CEM Other, CES Other, and PEM other) larger species were scaled-down in size metrics to be used as surrogates for trees falling into these categories.

## *Calculating Net Benefits and Benefit–Cost Ratio*

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

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

**Net Benefits and Costs Methodology**

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

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

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 – releases + $CO_2$ avoided from reduced energy use

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

*p* = price of aesthetics = annual increase in property value

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

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

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

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

Citywide Net Benefits = $B – C$ (Equation 5)

BCR = $B – C$ (Equation 6)