Benefit-Cost Analysis of Santa Monica's Municipal Forest

by

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Executive Summary

"You can gauge a country's wealth, its real wealth, by its tree cover."
--- Dr. Richard St. Barbe Baker, *Man of the Trees*

The primary purpose of this report is to answer the question: *Do the accrued benefits from Santa Monica's urban forest justify an annual municipal budget that exceeds $1.5 million?* Our results indicate that the benefits residents obtain from Santa Monica's urban forest do exceed management costs by over 50%. Over the years Santa Monica has invested millions in its municipal forest. Citizens are now receiving a relatively large return on that investment. Continued investment in management is critical to insuring that residents continue to receive a healthy return on investment.

In Fiscal Year 1999-2000 (FY 1999) there were approximately 29,229 street and park trees in Santa Monica, or about one public tree for every three residents. Half of all California cities care for less than one tree for every four residents. The street tree stocking level was 96%, further indicating that city streets were well-treed. Although 215 different species of trees have been planted, laurel fig *(Ficus microcarpa* 'Nitida') was the dominant tree in terms of numbers and size. Deodar cedar (*Cedrus deodara*), Canary Island pine (*Pinus canariensis*), Southern magnolia (*Magnolia grandiflora*), and palms were other important street tree species by virtue of their size and numbers. Nearly ninety percent of all trees were in fair, good, and excellent condition, indicating that the overall population was healthy. The asset value of all public trees totaled $75.5 million, or $2,582/tree on average ($815/resident). This value indicates the replacement cost of trees that have come to thrive in Santa Monica as a result of the City's continuous investment in their planting and care.

The Santa Monica street and park tree population had a relatively even-age structure, indicating fewer young, replacement trees and more old, overmature trees than "ideal". Given this age structure it is not surprising that expenditures for mature tree care comprised 89% of Community Forest Operation's expenditures. Substantial funds were spent addressing other mature tree-related issues such as sidewalk repair and leaf clean-up. When considering total expenditures, Santa Monica spent $1.54 million for urban forestry ($53/resident, $17/tree). Survey results suggest that annual expenditures by Community Forest Operations were about twice the statewide average. Keeping old trees healthy, perpetuating the forest through planting, and providing a safe, healthful, and attractive environment for the public comes with a price.

During FY 1999 Santa Monica's municipal trees provided substantial property value, aesthetic, and other benefits. As trees grew they increased the value of nearby properties, enhanced scenic beauty, and produced other benefits with an estimated value of $1.9 million ($65/tree). Annual air pollutant uptake was 10.7 metric tonnes (0.8 lb/tree) with an implied value of $269,000 ($9/tree). The City's trees were providing important health benefits to residents. Cooling savings from building shade and cooler summertime temperatures, as well as heating savings attributed to street and park trees totaled 9,700 MBtu, valued at $148,000 (5 MBtu/tree, $5/tree). Smaller benefits resulted from reductions in stormwater runoff (205,000 m^3 or 1,856 gal/tree, $111,000 or $4/tree) and atmospheric carbon dioxide (2,000 metric tonnes or 151 lb/tree, $66,000 or $2/tree).

We estimated that total annual benefits from Santa Monica's urban forest were $2.5 million ($27/ resident, $85/tree). Deodar cedar, which made up 4% of all trees and 9% of all leaf area, accounted for 14% of all benefits by virtue of their size and numbers. Laurel fig (11%), Canary Island pine (8%), and eucalyptus (7%) were also important producers of benefits.

Net benefits (total benefits less costs) for FY 1999 were $945,000 ($10/resident, $32/tree). For each $1 invested in urban forest management, benefits valued at $1.61 were returned to the residents of Santa Monica.

Although Santa Monica's municipal forest is well maintained and appears to be as permanent as the City's streets and homes, it is a fragile resource. Without the intensive maintenance needed to keep many older trees healthy and safe, these trees would be producing fewer benefits and creating greater costs. Already predisposed to health problems because of their age, future stresses such as drought, disease/pest infestations, and the need for repeated root pruning could decimate many old trees. Combating these health problems, removing dead trees, and replanting could require increased expenditures by the City. Catastrophic loss and associated large-scale tree canopy cover reduction would translate into substantial loss of benefits. This scenario has played out in other U.S. communities that lost large numbers of American elms to disease within a few years. The peril is evident. From our perspective, it seems prudent to continue investing in intensive management that will create a more stable forest over the next 20 years, rather than risking large loss of tree cover and increased emergency expenditures to obtain short-term budget savings.

Looking toward the future, it may not be possible to maintain the high level of net benefits produced today by Santa Monica's municipal forest while at the same time increasing its stability. Creating a more stable forest may be a more appropriate goal than maximizing net benefits if it reduces the risk of catastrophic loss and lowers management costs on a per tree basis. Achieving a more stable forest will challenge management because of the forest's current structure. At least three factors are significant:

- Deodar cedar and laurel fig are responsible for 25% of all tree benefits, but many of these trees will be more costly to maintain. Keeping the best trees healthy and repairing their damage to sidewalks, while at the same time removing and replacing trees that are least valuable will require increased funding for the short-term. Gradual replacement of these large trees during the next 10 years will result in a short-term reduction of canopy cover and associated benefits. However, this loss is offset by the promise of increased net benefits in the long-term associated with more stable canopy cover.

- Many of the mature street trees planted 20-40 years ago that will be moving into the old tree class and replacing benefits lost by removal of Deodar cedar, laurel fig and other large, old trees will become more expensive to maintain due to conflicts between roots and sidewalks, curbs, and sewer lines. The predominant species in this age class appear to have relatively shallow rooting patterns. Trees located in front lawns will fare better than those in narrow planting strips.

- Forest benefits that our children's children will realize depend on the survival and growth of young trees planted within the last 20 years. About one-third of these are small-statured trees. Smaller trees can be less expensive to maintain than larger trees, but also produce fewer benefits. The implication here is that the future forest will consist of relatively fewer large-statured trees.

Recommendations to maximize future benefits while controlling management costs include:

- Front yard planting sites provide more space for tree roots to expand without conflict than narrow strips between curbs and sidewalks. Plant larger-statured trees in front yards where feasible. Where planting strips are narrow, consider moving sidewalks next to the curb or further from the sidewalk after trees are replaced to provide more space for roots.

- Continue experimenting with strategies to reduce root-hardscape conflicts and reduce repair costs. Meandering sidewalks around trees, resurfacing with rubberized "flexible" paving, and implementing other means of preserving healthy trees and their roots are necessary. In new design, structural soils should be evaluated as a long-term solution. Because of predominantly sandy soils, irrigation patterns influence rooting patterns, especially during establishment. Planting details and follow-up care that promote delivery of water deep into the soil may be an effective measure to reduce shallow roots and hardscape damage in cut-outs and other space-restricted sites.

- Discontinue extensive pruning of all trees to increase their growth, leaf area, and associated benefits. In general, trees in Santa Monica are smaller and have less leaf area than similar aged trees in other cities we studied. Heavy pruning of young trees reduces their vigor and growth. Lifting of older trees to 5 m or higher reduces crown size. Although extensive trimming may be necessary in certain situations (e.g., light penetration through laurel figs or traffic sign visibility) it should not be standard practice. For example, lifting of street trees in residential areas should respond to the progressive growth of the crown over the sidewalk and street. Reducing pruning frequency and intensity will promote healthier trees that provide greater benefits at less cost to the City.

• Diversify species composition by identifying 5-10% of new plantings as "experimental." Plant and monitor species that have proven successful in nearby cities but have not been fully evaluated in Santa Monica (e.g., ginkgo). Consider planting new introductions that merit evaluation because of deep rooting patterns, compact form, pest/disease resistance, or other attributes.

Santa Monica's urban forest is in an era of transition. Planning and managing the transition from a relatively fragile and unstable forest to one that is more diverse and stable will require careful thinking and new analysis tools. We look forward to continuing our association with the City of Santa Monica to both advance urban forest science and provide information that will assist decision-making.

Chapter I. Introduction

"I think that I shall never see
a heat pump lovely as a tree."
--- Adapted from Joyce Kilmer

At the end of the 20th century Santa Monica's Open Space Management Division managed approximately 29,229 trees along streets and in parks. The Division believes that the public's investment in stewardship of Santa Monica's urban forest produces benefits that are particularly relevant to the community. Santa Monica needs to maintain a vigorous local economy, while retaining the quality of life for which it is known. Research indicates that healthy city trees can mitigate impacts of development on air quality, climate, energy for heating and cooling buildings, and stormwater runoff. Healthy street trees increase real estate values, provide neighborhoods with a sense of place, and foster psychological well-being. Street and park trees are associated with other intangibles such as increased community attractiveness and recreational opportunities that make Santa Monica a more enjoyable place to work and play. Santa Monica's urban forest creates a setting that helps attract tourism and retain businesses and residents.

However, in an era of dwindling public funds and rising expenditures there is need to scrutinize expenditures that are "non-essential" such as planting and management of the municipal forest. Although the current program has demonstrated its efficiency, questions remain regarding the need for the level of service presently provided. Hence, the primary question that this study asks is:

Do the accrued benefits from Santa Monica's urban forest justify an annual municipal budget of $1.5 million?

In answering this question our purpose is to:

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

This report consists of 7 Chapters.

Chapter I. **Introduction** - Describes the purpose of this study.
Chapter II. **Santa Monica's Urban Forest** - Provides a brief history the urban forest, and describes its current structure, management, and asset value.
Chapter III. **Costs of Managing Santa Monica's Urban Forest** - Details management expenditures.
Chapter IV. **Benefits Produced by Santa Monica's Urban Forest** - Quantifies estimated value of tangible benefits, describes intangible benefits, and calculates net benefits and a benefit-cost ratio.
Chapter V. **Conclusions** - Evaluates relevancy of the current program, poses future management challenges and funding options, and identifies opportunities for future collaboration in research and development.
Chapter VI. **Acknowledgments and References -** Lists publications cited in the study and the contributions made by various participants not cited as authors.
Chapter VII. **Appendix** - Contains detailed information on trees in Santa Monica.

Chapter II. Santa Monica's Urban Forest

"We all know what trees are, of course – and certainly we know what they look like, and how and where they live, how big or small they can be, how old, how fast, or slowly they grow – we know all about trees. Hah! What pompous pipsqueaks we humans can be at times."

--- Russ Kinne

History and Current Management

Tree planting began in the City of Santa Monica soon after settlement. Early developers planted many trees, especially north of Wilshire (Hastings 1956). Nurseryman and private collectors took advantage of the area's excellent growing conditions and introduced a wide range of species. In 1952 street tree planting began in earnest. Many of Santa Monica's heritage trees are highlighted in the book *Trees of Santa Monica*, written by George Hastings and first published in 1944. The book describes specimen trees that give special character to each neighborhood. For example, it notes that trees began to be planted in Palisades Park in 1908 when the Park Commissioner stipulated that his salary be spent for park trees. Many of the original palms, eucalyptus, and New Zealand Christmas (*Metrosideros excelsus*) trees still make Palisades Park a special place.

The City of Santa Monica has one of the most comprehensive and highly regarded tree programs in the nation. This spring the City of Santa Monica received recognition as a Tree City USA for the 20^{th} consecutive year. It first received this award in 1981. Walter Warriner, the Community Forester has served in state and regional leadership positions for professional organizations such as the Western Chapter, International Society of Arboriculture and Street Tree Seminar. He is frequently requested to share expertise and success stories with other professionals and communities wishing to take their programs to a higher level. The City of Santa Monica has a proud tradition of excellence in urban and community forestry.

Community Forest Operations employees 10 full time staff to maintain approximately 29,229 street and park trees. The City plants, prunes, preserves, removes, and replaces dying and diseased trees to protect public safety and perpetuate net benefits from a healthy tree population. A street tree inventory was fully updated in 1997 and has been continually updated in a tree inventory management database. Approximately 9,600 street and park trees are trimmed each year, 70% by a contractor (West Coast Arborists, Inc.) and 30% by in-house services. Street trees are in one of six different trim cycles, depending on growth rate and location. Large trees in residential zones or high public-use areas are pruned annually. Laurel fig (*Ficus microcarpa* 'Nitida') is pruned biannually, and other species with moderate growth habits are pruned every 3-5 years. Slow growing species are trimmed every 6-8 years; however, regardless of species or growth patterns, trees in commercial zones may be pruned annually to maintain sign clearance and storefront visibility. Storm damage clean-up, control of certain pest problems, root pruning, and other emergency activities are performed on an as needed basis.

Approximately 100-150 trees are removed from City streets and parks each year. From 150-200 trees are planted annually following guidelines documented in the "Community Forest Management Plan 2000" (City of Santa Monica, Parks & Recreation Department 1999). Removed trees are replaced, usually with 24" boxed trees, unless there is insufficient space for a transplant. Trees are selected to fit the available space, match other growing conditions, insure a diverse mix of species to protect against catastrophic loss, and unify neighborhoods through planting of similar species on a limited basis.

Species Composition, Structure, Condition and Asset Value of Existing Trees

Methodology

Approach for Street Trees. In Fiscal Year 1999-2000 Santa Monica's street tree inventory database contained 29,229 trees belonging to 215 species. We sampled a portion of the street tree population in Santa Monica to 1) establish relations between tree age, size, leaf area and biomass for important species, 2) estimate growth rates, and 3) collect other data on tree health, site conditions, and sidewalk damage. Because resources were not available to sample trees belonging to every species, we sampled 20 of the most abundant species. The number of trees belonging to the species sampled account for 73.6% of the entire street tree population. To obtain information spanning the life cycle of each species the sample was stratified into planting age groups: 1949-1961, 1962-1974, 1975-1987, 1988-1999. Thirty randomly selected trees of each species were selected to survey, along with five alternates. We measured diameter at breast height (dbh, to nearest 0.1 cm by tape), tree and bole height (to nearest 0.5m by clinometer or range pole), crown diameter in two directions (maximum and minimum axis, to nearest 0.5m by tape), tree condition and location (as per CTLA tree appraisal guidelines), pruning level (percentage of crown removed by pruning), tree condition and location (as per CTLA tree appraisal guidelines), and site index. Replacement trees were sampled when trees from the original sample population could not be located. When we suspected that planting dates were inaccurate we contacted residents to determine actual planting dates and consulted with Tito Molina, whose tenure with the City of Santa Monica began in 1970. Field work was conducted July to August, 1999.

Crown volume and leaf area were estimated from computer processing of images of tree crowns obtained using a digital camera. The method has shown greater accuracy than other techniques (±10 percent of actual leaf area) in estimating crown volume and leaf area of open-grown trees (Peper and McPherson 1998).

Three curve-fitting models were tested, with the logarithmic regression model providing the best fit for predicting all parameters except leaf area, for which the non-linear exponential model was used. Dbh was predicted as a function of tree age, then predictions for tree leaf area, crown diameter, and tree height were modeled as a function of dbh.

To infer from the 20 species sampled to the remaining 215 species, called Other Trees, we categorized each species based on life form and mature size. Ten tree type categories were created with 2-3 size classes for each of 4 life forms:

- Broadleaf deciduous - large (> 15m [50 ft]), medium (8-15m [25-50 ft]), small (<8m [25 ft]) mature height
- Broadleaf evergreen - large, medium, small mature height
- Conifer - large, small mature height
- Palm - medium, small mature crown spread

To obtain growth curves for Other Trees in each tree type category we selected a typical species by comparing leaf area estimates for all species sampled. Because we did not sample any broadleaf deciduous large trees in Santa Monica, we used growth data from Modesto for London plane (*Platanus acerifolia*). We selected sweetgum (*Liquidamber styraciflua*) and jacaranda *(Jacaranda mimosifolia*) as typical species for the broadlead deciduous medium and small tree types, respectively. . Other species selected were red-flowering gum (*Eucalyptus ficifolia*) for the broadleaf evergreen large category, camphor (*Cinnamomum camphora*) for the broadleaf evergreen medium group, Brazilian pepper (*Schinus terebinthifolius*) for the broadleaf small group, Deodar cedar (*Cedrus deodara*) and Japanese black pine (*Pinus thunbergiana*) data from Modesto for the conifer medium and small categories. Medium and small palms were represented by Canary Island date palm (*Phoenix canariensis*) and Mexican fan palm (*Washingtonia robusta*), respectively.

Approach for Calculating Asset Value. Santa Monica's urban forest today is the result of a series of investments made in the past. In one sense, the asset value of Santa Monica's urban forest is the current worth of previous investments. If all Santa Monica's street and park trees were to disappear the benefits resulting from those investments would be lost. One approach to estimating asset value is to calculate the cost of replacing all trees. This cost is depreciated to reflect any difference in the benefits that would flow from new trees compared to existing trees. The depreciated cost approach assumes that the cost of replacement indicates value. In reality, people are sometimes willing to pay more or less than replacement cost for goods.

We base our estimate of replacement cost on the Trunk Formula Method (CTLA 1992) to estimate the asset value of all street and park trees. We start with the replacement cost to buy and install the largest reasonably available tree, a 120 cm rootball (48" box). Using local market prices we determine the installed cost to be $1,805 and then calculate cost per unit trunk area for such a tree. The Basic Price BP is 60% of the wholesale cost per unit trunk area for each species group (species are grouped to account for different growth rates). The BP is multiplied by the tree's trunk area TA to calculate replacement cost for the idealized tree. This result is then reduced by a series of functional depreciation factors that reflect the difference, if any, between the cost to produce the idealized replacement tree and the benefits produced by the existing tree. The Species factor S reflects any differences due to growth characteristics, maintenance requirements, and aesthetics. Condition factor C and Location factor L account for factors related to the structural integrity and health of the tree and the extent to which humans benefit from the tree due to its setting in the landscape. The formula used to calculate Asset Value AV is:

$$AV = BP \times TA \times S \times C \times L$$

where

BP = basic price; cost per unit trunk area of replacement tree
TA = trunk area of the existing tree
S = species rating in percent from the Northern California Regional Tree Appraisal Group.
C = condition rating in percent
L = location rating in percent

Reduction factors C, and L were calculated as the mean value for each species sampled in the field. C, L, S values for Other Street Trees were calculated as a weighted average of values determined for sample species within each tree type. We assumed that values for Park Trees were the same as values for Other Street Trees.

Results

Tree Numbers and Species Composition. In Fiscal Year 1999-2000 there were approximately 29,229 street and park trees in Santa Monica. Street trees accounted for 87% (25,508) of the total, while park trees comprised the remaining 13% (15,550). Assuming Santa Monica's human population was 92,578 (California Department of Finance 1998), there was about one public tree for every three residents. Half of all California cities care for less than one tree for every four residents (Bernhardt and Swiecki 1993). However, Santa Monica's ratio of street trees per capita was 0.32, somewhat less than the mean ratio of 0.37 reported for 22 U.S. street tree populations (McPherson and Rowntree 1989).

Full stocking of street tree populations has been defined as spacing between stems of 15 m (50 ft) on average (McPherson and Rowntree 1989). We used this figure and the total number of street trees and street length (235 km or 146 miles) to calculate percentage of full stocking or "stocking level." The proportion of street length occupied by intersections and driveways was not included in the computation. There were an average of 54 trees per km of street (87/mile). Street trees have an average spacing of 18 m (60 ft) on each side of City streets. The stocking level was 83% of full stocking. Santa Monica's stocking level was very high compared to the mean stocking of 38% found for 22 U.S. street tree populations (McPherson and Rowntree 1989). The relatively close spacing of street trees in Santa Monica suggests that the City was nearly meeting its goal of filling every vacant planting site. There were about 2,000 vacant sites. Hence, 96% of all planting sites were filled with trees. These findings indicate that Santa Monica's streets were relatively well-treed.

Park tree densities averaged 52.5 trees/ha (21.3/ac), slightly greater than 34 trees/ha (14/ac) in Modesto, CA. Large- and small-statured trees were slightly more abundant in parks than streets. Large-statured trees made up 21% of all park trees and 18% of all street trees, while small-statured trees accounted for 41% of all park trees and 40% of all street trees. Medium-statured trees were relatively less abundant in parks (38%) than streets (40%). Compared to the street tree population, parks contained relatively more palms (43% vs 20%) and fewer broadleaf evergreens trees (41% vs 63%). Broadleaf deciduous trees were the least abundant tree-type in both parks (6%) and streets (7%). The distribution of all street and park trees by mature size class and life form is shown in **Table 1**.

Table 1 . Tree numbers by mature size class and life form.

	Street					Park					Total				
	Large	Mod	Small	Total	%Total	Large	Mod	Small	Total	%Total	Large	Mod	Small	Total	%Total
Brdleaf Dec.	72	739	835	1,646	6.5	67	124	23	214	5.8	139	863	858	1,860	6.4
Brdleaf Evg.	1,793	8,824	5,376	15,993	62.7	353	793	373	1,519	40.8	2,146	9,617	5,749	17,512	59.9
Conifer	2,806	0	46	2,852	11.2	352	0	45	397	10.7	3,158	0	91	3,249	11.1
Palm	0	1,109	3,908	5,017	19.7	0	506	1,085	1,591	42.8	0	1,615	4,993	6,608	22.6
Total	4,671	10,672	10,165	25,508	100.0	772	1,423	1,526	3,721	100.0	5,443	12,095	11,691	29,229	100.0
% Total	18.3	41.8	39.9	100.0		20.7	38.2	41.0	100.0		18.6	41.4	40.0	100.0	

There were 215 different species of trees in the tree inventory database. The mean number of species recorded for 22 U.S. street tree populations was 53, but Los Angeles and La Canada Flintridge, CA and Eugene, OR contained 77, 77, and 63 tree species, respectively (McPherson and Rowntree 1989). Compared to these cities, Santa Monica has a relatively rich assemblage of trees species along its streets.

Mexican fan palm was the most common street tree species, with nearly 5,000 trees accounting for 17% of the population (**Table 2**). Laurel fig (*Ficus microcarpa* 'Nitida' and other *Ficus species*) accounted for 12% all trees. These percentages exceed the customary guideline that no single species should exceed 10% of the population. However, these species seem relatively well-suited to growing conditions in Santa Monica. The next most abundant species was Southern magnolia (*Magnolia grandiflora*). It accounted for only 7% of the population. Other important species included date palms (5%), yew pine (*Podocarpus macrophyllus*, 5%), carob (*Ceratonia siliqua*, 3%), carrotwood (*Cupaniopsis anarcardioides*, 3%), and Canary Island pine (*Pinus canariensis*, 3%).

Importance and Age Structure. Although fan palms accounted for 17% of all trees, they accounted for less than 5% of total leaf area and canopy cover. The importance of laurel fig as the dominant component of the City's urban forest is illustrated in **Table 2**. Laurel fig accounted for 20% of all tree canopy cover, 13% of all leaf area, and 12% of all trees. Many of the benefits and costs associated with Santa Monica's urban forest were associated with this species. Deodar cedar and Canary lsand pine were relatively more important than their numbers indicate because of their age and size. Some species were very abundant but relatively unimportant. For example, yew pine's and lemon bottlebrush's *(Callistemon citrinus*) small mature size explain why these species accounted for relatively small percentages of total leaf area and canopy cover, despite being among the most abundant trees.

The distribution of ages within a tree population influences present and future costs as well as the flow of benefits. An uneven-aged population allows managers to allocate annual maintenance costs uniformly over many years and assure continuity in overall tree canopy cover. An ideal distribution has a high proportion of new transplants to offset establishment-related mortality (40%), while the percentage of older trees declines with age (30% maturing, 20% mature, 10% old) (Richards 1982/83).

Table 2. Structural features of Santa Monica's street and park trees in Fiscal Year 1999-2000.

	Tree No.	% Total	LA	% Total	CC	% Total	IV
Washingtonia palms	4,993	17	117	3	54	4	8
Ficus microcarpa 'Nitida'+	3,460	12	546	13	248	19	15
Magnolia grandiflora	1,892	6	249	6	105	8	7
Phoenix palms	1,615	6	299	7	103	8	7
Podocarpus macrophyllus	1,395	5	68	2	26	2	3
Cedrus deodara	1,084	4	361	9	96	8	7
Other Brdleaf Evgrn Small	968	3	33	1	18	1	2
Ceratonia siliqua	923	3	135	3	60	5	4
Pinus canariensis	905	3	577	14	55	4	7
Cupaniopsis anacardioides	893	3	58	1	31	2	2
Eucalyptus ficifolia+	804	3	149	4	53	4	4
Liquidambar styraciflua	781	3	117	3	26	2	3
Callistemon citrinus	760	3	29	1	14	1	1
All other trees	8,756	30	1,369	33	387	30	31
Total (FY 1999-2000)	29,229	100	4,107	100	1,276	100	100

LA = leaf area in m2
CC = canopy cover in m2
IV = Importance Value, sum of relative numbers, leaf area, and canopy cover divided by 3.
+ indicates that this total includes other similar cultivars or species

The age structure for all public trees in Santa Monica has a relatively high number of mature and old trees among age classes (**Fig. 1**). Young trees less than 10 years old accounted for only 15% of the population compared to the "ideal" of 40%. The difference is partially due to limited availability of new planting sites. The pattern for all trees shows a relatively large number of mature trees (40% 20-40 years old) that were planted from 1960-1980 to fill out Santa Monica's urban forest.

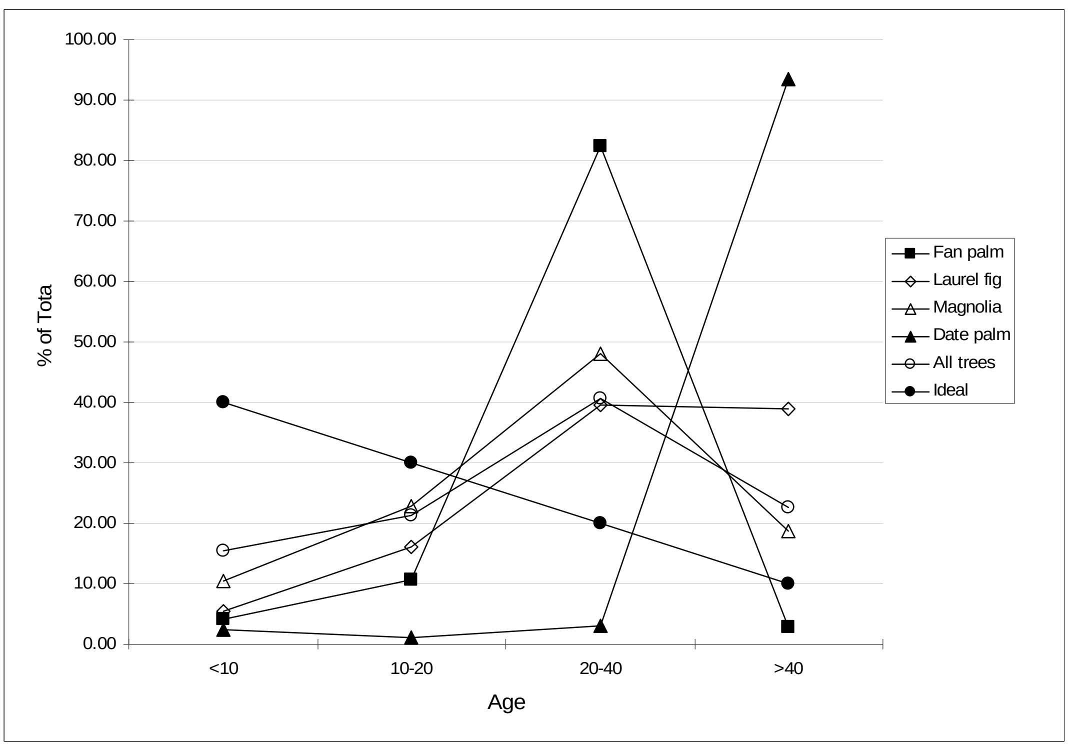

Figure 1. Age structure of selected species, all trees, and an "ideal" distribution that allows for higher

mortality rates for younger trees.

If private trees comprise the remaining 9% of Santa Monica's tree canopy cover and their average crown diameter is equivalent to the mean size for public trees (7.5 m), there could be 50,000 trees on non-municipal land in Santa Monica.

Condition of Existing Trees. We infer from our sample of 606 trees to the entire municipal tree population to evaluate the condition of existing trees. Overall, the municipal urban forest appears healthy. Twenty-one percent of the trees were in excellent condition, 44% were in good condition, and 23% were in fair condition (**Fig. 2**). About 13 % of the trees were in poor condition, dying, or dead. During our field work we found very few trees that were candidates for immediate removal.

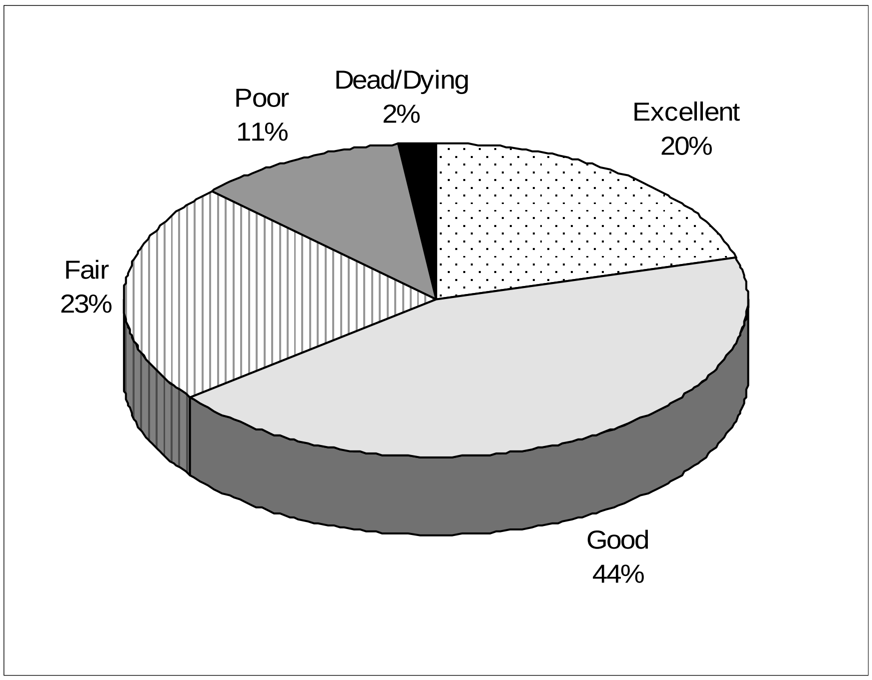

Figure 2. Distribution of public trees by condition class.

Age curves for different tree species help explain their relative importance and suggest how tree management needs may change as these species grow older. Over 90% of Santa Monica's date palms were greater than 40 years old and 80% of the fan palms were mature. These trees have provided benefits over a long period of time. About 40% of all the laurel fig were planted over 40 years ago, and another 40% were mature. This species was particularly important because of its size associated with leaf area. A similar situation exists for Southern magnolia, 70% were mature or old. The relatively large percentage of older trees suggests that future benefits will be closely linked to the health of these trees.

Tree Canopy Cover. We estimate tree canopy cover for the entire City to be 15% based on our NDVI (Normalized Difference Vegetation Index) analysis of Landsat 5 Thematic Mapper data for Santa Monica (30 m resolution). Given City area of 9,065 ha (8.4 mile^2), street and park tree canopy covers 784 ha (1,937 ac) or 6% of the entire City. Street trees provide 90% and park trees 10% of the total canopy cover from public trees. Santa Monica's street trees shade approximately 25% of all street paving. This calculation assumes that 40% of all street tree canopy cover was shading street surfaces, there were 235 km (146 miles) of street, and the average curb-to-curb distance was 12 m (40 ft).

The relative condition of tree species provides an indication of their suitability to local growing conditions, as well as their performance. Species with larger percentages of trees in excellent and good condition were likely to provide greater benefits at less cost than species with more trees in fair and poor condition. Species rated as having the best condition were laurel fig, date palm, New Zealand Christmas tree, and Deodar cedar (**Table 3**). These species were widely adapted to growing conditions throughout the City. Palms and New Zealand Christmas tree were planted in large numbers. Species with the lowest condition rating were Carolina laurel (*Prunus caroliniana*), Victorian box (*Pittosporum undulatum*), Brisbane box (*Tristania conferta*), Southern magnolia, and carob (*Ceratonia siliqua*). Very few of these species are planted today.

Asset Value. We applied a version of the CTLA Trunk Formula Method (CTLA 1992) to estimate the asset value of Santa Monica's municipal urban forest. Mean condition and location factors, as well as species factors (Western Chapter ISA 1992) that were used in the analysis are shown in **Table 3** for each street tree species that we sampled. Results indicate that the total replacement cost of Santa Monica's municipal forest was approximately $75.5 million, or $2,582 per tree and $815 per resident on average. It would cost about this amount of money to replace trees that have come to thrive in Santa Monica as a result of the City's continuous investment in their planting and care. Street trees accounted for 91% of total asset value, although they accounted for 87% of total tree numbers. Species contributing the most to asset value were laurel fig (26%, $5,578/tree), Canary Island pine (8%, $6,694/tree), eucalyptus (8%, $7,271/tree), and Deodar cedar (6%, $4,268/tree). Tree species with relatively low average asset values were the fan palms and Brisbane box, at $232 and $585 per tree, respectively.

In assessing whether $75.5 million is a reasonable indication of the urban forest's asset value it is important to recognize that the approach used to obtain this figure equates value with replacement cost. Actual value, as defined as the "ability of the urban forest to satisfy human wants, needs, or desires" may be less than or greater than cost. Residents may not be willing to pay full replacement cost for City trees. In reality, dollars will never be exchanged on a large scale to test the public's willingness to pay for replacement of the urban forest. The value of the urban forest lies in its utility and this value may exceed its hypothetical value in exchange.

Table 3. Species, condition, and location factors used to calculate asset value.

	Species	Condition	Location	Asset Value ($1,000s)	% Total	Avg $/tree
Platanus acerifolia	0.50	0.75	0.75	102	0.1	1,014
Other Brdleaf Decid Large (15 sp.)	0.50	0.75	0.75	74	0.1	1,954
Liquidambar styraciflua	0.90	0.77	0.61	1,730	2.3	2,215
Other Brdleaf Decid Medium (7 sp.)	0.90	0.77	0.61	51	0.1	618
Jacaranda mimosifolia	0.90	0.78	0.54	1,030	1.4	1,535
Other Brdleaf Decid Small (20 sp.)	0.90	0.78	0.54	109	0.1	581
Eucalyptus ficifolia	0.70	0.70	0.79	5,846	7.7	7,271
Other Brdleaf Evgrn Large (16 sp.)	0.70	0.70	0.79	5,117	6.8	8,403
Podocarpus gracilior	0.90	0.70	0.79	1,449	1.9	2,529
Grevillea robusta	0.30	0.70	0.79	603	0.8	3,770
Ficus microcarpa 'Nitida'	0.90	0.85	0.73	19,301	25.6	5,578
Magnolia grandiflora	0.90	0.64	0.58	2,625	3.5	1,387
Ceratonia siliqua	0.70	0.65	0.68	2,475	3.3	2,681
Metrosideros excelsus	0.90	0.79	0.70	2,554	3.4	3,475
Melaleuca quinquenervia	0.90	0.76	0.69	1,477	2.0	2,086
Cinnamomum camphora	0.90	0.77	0.67	2,814	3.7	4,145
Brachychiton populneus	0.70	0.77	0.67	1,639	2.2	2,917
Pittosporum undulatum	0.90	0.56	0.66	1,896	2.5	3,983
Other Brdleaf Evgrn Medium (15 sp.)	0.90	0.77	0.67	324	0.4	1,783
Podocarpus macrophyllus	0.90	0.73	0.55	1,741	2.3	1,248
Other Brdleaf Evgrn Small (46 sp.)	0.70	0.68	0.69	841	1.1	869
Cupaniopsis anacardioides	0.90	0.72	0.54	651	0.9	729
Callistemon citrinus	0.90	0.78	0.54	1,034	1.4	1,361
Tristania conferta	0.90	0.61	0.48	330	0.4	585
Schinus terebinthifolius	0.70	0.68	0.69	2,638	3.5	5,372
Nerium oleander	0.70	0.78	0.54	404	0.5	911
Prunus caroliniana	0.70	0.48	0.58	220	0.3	934
Cedrus deodara	0.90	0.78	0.59	4,627	6.1	4,268
Pinus canariensis	0.90	0.76	0.65	6,058	8.0	6,694
Casuarina cunninghamiana	0.50	0.76	0.65	1,767	2.3	2,451
Pinus halepensis	0.70	0.76	0.65	884	1.2	2,554
Other Conifer Evgrn Large (11 sp.)	0.90	0.78	0.59	188	0.2	1,841
Other Conifer Evgrn Small (7 sp.)	0.70	0.71	0.71	190	0.3	2,088
Palm Palm Evgrn Medium	0.70	0.82	0.73	1,529	2.0	947
Palm Palm Evgrn Small	0.90	0.78	0.55	1,159	1.5	232
Total				75,477	100.0	2,582

Chapter III. Costs of Managing Santa Monica's Urban Forest

The wrongs done to trees, wrongs of every sort, are done in the darkness of ignorance and unbelief, for when light comes, the heart of people is always right.
--- John Muir, Naturalist

Fiscal Year 1999 Program Expenditures

The Fiscal Year 1999 operating budget for Community Forest Operations of the Open Space Management Division was approximately $1.1 million (personal communication, Walter Warriner, City of Santa Monica, August, 1999). This amount represented 0.39% of the City's total operating budget ($288.8 million) and $12 per person (92,578 pop.). Assuming our figure of 29,229 street and park trees, Community Forestry spent $38.04 per tree on average during the fiscal year. Community Forestry's per tree expenditure was twice the 1997 mean value of $19 per tree reported for 256 California cities (Thompson and Ahern 2000). We estimate that an additional $432,000 was spent on tree-related matters by other city departments. These external expenditures involved clean-up of tree litter, hardscape repair, and legal issues. Overall, about $1.5 million was spent on management of Santa Monica's municipal urban forest. Community Forest Operations expenditures fell into three categories: tree establishment, mature tree care, and administration.

Tree Establishment

The production of quality nursery stock, its planting, and follow-up care are critical to perpetuation of a healthy urban forest. The city planted and established 150-200 trees each year. These activities consumed 2% of the tree program budget, or $22,900. Within this category, tree planting was the single largest cost category, followed by pruning, irrigation of young trees, and basin repairs.

Mature Tree Care

Santa Monica's urban forest contained a preponderance of mature and old trees so it is not surprising that 89% ($986,644) of the tree program's budget was spent keeping these trees healthy and safe. Inspection and pruning accounted for most of this amount ($973,144). These funds were used for programmed pruning, as well as service request pruning and low pruning to lift branches overhanging sidewalks and streets. The Division removed 100-150 trees each year at a cost of $49,500 (includes stump removal). Clean-up after storms occurred on a periodic basis, so this budget item was variable.

Pest infestations can pose a serious threat to the health and survival of susceptible tree species, and drip from aphids and other insects is a nuisance to residents. Expenditures for pest and disease control were usually small and occurred on an as-needed basis.

Administration

Approximately one-half of all program expenditures were contracted. Contract supervision is critical to insure that trees and citizens receive quality work. This item accounted for 3% ($31,404) of the total budget. Salaries and benefits of supervisory staff who perform planning and management functions totaled $71,000, or 6% of the budget.

Other Tree-Related Expenditures External to the Community Forestry Program

Tree-related expenses accrued to the City that were not captured in the Community Forest Operation's budget. These expenditures for sidewalk and curb repair, leaf clean-up, and claims are described below.

Sidewalk and Curb Repair

Shallow roots that heave sidewalks, crack curbs, and damage driveways are an important aspect of mature tree care. To protect sidewalks and private property from this type of damage, Public Works and city arborists conducted preventative root pruning at an annual cost of $12,481. Once problems occur the city attempts to remediate the problem without removing the tree. Strategies include ramping the sidewalk over the root, meandering or narrowing the sidewalk, replacing concrete with more flexible materials like unit pavers, decomposed granite, or rubberized surfaces, root pruning, and installation of root barriers. Approximately $22,000 was spent on these measures. The largest expenditure, $236,025, was for repair of damaged curbs and gutters.

Leaf Clean-Up

The city spent approximately $2.1 million for street sweeping (1-2 times per week). After discussion with city staff we assumed that 5% of this cost ($105,000) was related to leaves and other street tree litter. In FY 1999 approximately $27,000 was spent on landfill fees for green-waste from street and park trees. Hence, the total expenditure for litter clean-up was $132,900.

Property and Personal Claims

Although the Community Forestry Program has an excellent service record, damage occasionally occurs to private property due to limb failure, inaccurately located irrigation or sewer lines, or conflicting landscaping. Expenditures for property claims were reported to be $27,808 during FY 1999.

Fiscal Year 1999 Total Expenditures

Net expenditures for the Community Forestry Division during FY 1999 were $1,544,000 (**Table 4**). Program costs were responsible for 70% of the total, while external expenditures accounted for the remaining 30%. The average annual costs per tree and per capita were $52.82 and $16.68, respectively.

Table 4. Santa Monica Fiscal Year 1999 Expenditures

Program Expenditures	$ Total
Pruning	$863,380
Planting	$22,900
Removals	$49,500
Inspection	$73,764
Planning & Management	$71,000
Contract Supervision	$31,404
Total Program Expenditures	$1,111,948
Non-Program Expenditures	
Hardscape repair/root pruning*	$271,344
Liability & Legal	$27,808
Litter clean-up/Green waste	$132,900
Total Non-Program Expenditures	$432,052
Grand Total	$1,544,000
Avg $ / tree/ yr	$52.82

*90% of total hardscape repairs plus root pruning

Chapter IV. Benefits Produced by Santa Monica's Urban Forest

"You can gauge a country's wealth, its real wealth, by its tree cover."
--- Dr. Richard St. Barbe Baker, *Man of the Trees*

Introduction

In this chapter we present estimated benefits provided by Santa Monica's street and park trees. Our estimates of benefits are initial approximations. Some benefits are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). The state of knowledge about the physical processes at work and their interactions vary, and is being added to all the time. For example, we advance the state of urban forest benefit-cost analysis in this study by incorporating comprehensive data on the growth of Santa Monica's street trees. Nevertheless, our estimates of benefits remain imprecise because there are many areas where we have insufficient information (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Our estimates provide a general understanding of the benefits provided by Santa Monica's public trees over the course of one year. The next section describes some of the assumptions and procedures used to quantify these benefits.

Approach

We estimated annual benefits for Santa Monica's park and street trees for the year 1999. Our approach uses growth rate information to "grow" the existing tree population one year and account for the associated annual benefits. This "snapshot" assumes that no trees are added to or removed from the existing population during any given year. The approach directly connects benefits with tree size variables such as trunk diameter at breast height (dbh) and leaf surface area. Many functional benefits of trees are related to leaf-atmosphere processes (e.g., interception, transpiration, photosynthesis), and therefore benefits increase as tree canopy cover and leaf surface area increase.

Prices are assigned to each benefit (e.g., heating/cooling energy savings, air pollution absorption, stormwater runoff reduction) through direct estimation and implied valuation of benefits as environmental externalities. Findings from computer simulations are used in this study to directly estimate energy savings (McPherson and Simpson 1999). Implied valuation is used to price society's willingness to pay for the air quality and stormwater runoff benefits trees produce. For example, air quality benefits are estimated using transaction costs, which reflect the typical market value of pollutant emission credits for 1998 for the South Coast Air Pollution Control Management District. If a corporation is willing to pay $1 per kg for a credit that will allow it to increase future emissions, then the air pollution mitigation value of a tree that absorbs or intercepts 1 kg of air pollution should be $1.

Environmental Benefits

Energy Savings

Buildings and paving increase the ambient temperatures within a city. Rapid growth of California cities during the past 50 years is associated with a steady increase in downtown temperatures of about 0.4 °C (0.7°F) per decade. Because electric demand of cities increases about 3-4% per °C (1-2% per °F) increase in temperature, approximately 3-8% of current electric demand for cooling is used to compensate for this urban heat island effect (Akbari et al. 1992). Warmer temperature in cities compared to surrounding rural areas has other implications, such as increases in carbon dioxide emissions from fossil fuel power plants, municipal water demand, unhealthy ozone levels, and human discomfort and disease. These problems are accentuated by global climate change, which may double the rate of urban warming. Accelerating urbanization in Southern California hastens the need for energy efficient landscapes.

Urban forests modify climate and conserve building energy use through 1) shading, which reduces the amount of radiant energy absorbed and stored by built surfaces, 2) evapotranspiration, which converts liquid water in plants to vapor, thereby cooling the air, and 3) wind speed reduction, which reduces the infiltration of outside air into interior spaces (Simpson 1998). Trees and other greenspace within individual building sites may lower air temperatures 3°C (5°F) compared to outside the greenspace. At the larger scale of urban climate (10 km square or 6 miles), temperature differences of more than 5°C (9°F) have been observed between city centers and more vegetated suburban areas.

The relative importance of these effects depends on the size and configuration of vegetation and other landscape elements (McPherson 1993). Generally, large greenspaces affect climate at farther distances (100 to 500 m distance) than do smaller greenspaces. 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. For individual buildings, solar angles and infiltration are important. Because the summer sun is low in the east and west for several hours each day, shade to protect east and especially west walls helps keep buildings cool. Rates at which outside air infiltrates into a building can increase substantially with wind speed. In cold windy weather the entire volume of air in a poorly sealed home may change two to three times per hour. Even in newer or tightly sealed homes, the entire volume of air may change every two to three hours.

Because of Santa Monica's moderate summer weather, potential cooling savings from trees are lower than those that would be found in warmer inland locations. Computer simulation of annual cooling savings for an energy efficient home indicated that the typical household spends about $50 each year for air conditioning (418 kWh, 2.1 kW peak). Shade from two 7.5 m (25-ft tall) trees on the west and one on the east was estimated to save $25 (206 kWh, 0.21 kW) each year (Simpson and McPherson 1996). Evapotranspirational cooling from these three trees were estimated to produce savings of approximately the same order of magnitude provided that a large enough number of trees were planted to reduce summertime temperatures in the neighborhood.

Electricity and Natural Gas Methodology. Annual building energy use per residential unit (Unit Energy Consumption, or UEC) are based on computer simulations that incorporate building, climate and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs from 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 here. Typical meteorological year (TMY) weather data for Los Angeles International Airport were used. Shading effects for different tree type categories (large, medium, and small tree, deciduous and evergreen, see Chapter II), at 3 tree-building distances, 8 orientations and 4 tree ages were simulated. Deciduous trees had a visual density of 80% from April to November, and 20% from December to March; evergreen trees had an 80% visual density all year.

Three prototype buildings were used in the simulations to represent pre-1950, 1950 and post-1980 construction practices (Ritschard et al. 1992). Building footprints were square, which was found to be reflective of average impacts for a large building population (McPherson and Simpson 1999). Buildings are simulated with 0.45-m (1.5-ft) overhangs. Blinds had visual density of 37%, and assumed closed when the air conditioner is operating. Summer and winter thermostat settings were 25 °C (78 °F) and 20 °C (68 °F) during the day, respectively, and 16 °C (60 °F) at night. UECs were adjusted to account for saturation of central air conditioners, room air conditioners, and evaporative coolers.

Simulation results were tabulated and an algorithm developed relating energy savings for each possible location (distance and direction from building) and leaf pattern (deciduous and evergreen) to tree size, the latter determined by tree type (small, medium, and large) and age (5, 15, 25, and 35 years after planting). Tree size was quantified by crown silhouette area (the two-dimensional horizontal projection of the tree crown onto a plane vertical surface). Savings for Santa Monica were found by substituting these silhouette areas into the savings algorithm for each tree species and tree age.

Next, tree distribution by location (e.g. frequency of occurrence at each location) specific to Santa Monica was determined to calculate average energy savings per tree as a function of distance and direction. Tree - building distance was assumed equal to building setback from the street, and occurrence of street trees proportional to street length. Setback and orientation was based on analysis of 1:1500 black and white aerial photographs. Sample points were selected for analysis by overlaying each aerial photo with a transparent mylar sheet containing two randomly located dots. Analysis consisted of locating the street nearest each dot, then measuring the average building setback along that street and the street length between the two nearest intersections. Land use (single family residential, multifamily residential, commercial, other) nearest each dot was based on photo interpretation. Tree-building distances (e.g. setbacks) were assigned to three distance classes, 3-6 m (10-20), 6-12 m (20-40 ft), and 12-18 m (40-60 ft). It was assumed that street trees within 18 m (60 ft) of homes provided direct shade on walls and windows. Savings per tree at each location were multiplied by tree distribution, then summed over type and age for all trees to derive totals for the entire city.

In addition to localized shade effects, which we assumed to accrue only to street trees within 18 m (60 ft) of buildings, lowered air temperatures and wind speeds from increased neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for summer cooling (reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances) and winter heating. 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). We assumed that peak summer air temperatures were reduced by 0.1°C (0.2 °F) for each percentage increase in canopy cover. Our estimates were based on existing canopy cover from all trees of 31%, and 8% for street and park trees alone (see Chapter II). Effects of wind and air temperature reductions on energy use were simulated as described previously, but with no shading. Climate effects are produced by both street and park trees.

Dollar value of electrical energy savings (California Energy Commission 1999) and natural gas savings (California Energy Commission 1998) were based on electricity and natural gas prices of $0.114 per kWh and $0.693 per therm, respectively. Cooling and heating effects were reduced based on the type and saturation of air conditioning (**Table 5**) or heating (**Table 6**) equipment by vintage. Equipment factors of 33% and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Changes in energy use due to shade were increased by 15% to account for shading of adjacent structures (McPherson and Simpson 1999). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (**Table 7**). Heating loads were converted to fuel use based on efficiencies in **Table 7**. The “other” and “fuel oil” heating equipment types were assumed to be natural gas for the purpose of this analysis. Building vintage distributions were combined with adjusted saturations to compute combined vintage/saturation factors for natural gas and electric heating (**Table 7**).

Multi-Family Residential Analysis. ΔUECs for multi-family residential buildings due to tree planting were estimated by adjusting single family ΔUEC for differences in energy use, shading, and climate effects between building types using the expression,

$$\Delta UEC_x = \Delta UEC^{sh}_{SFD} \times F_{sh} + \Delta UEC^{cl}_{SFD} \times F_{cl} \qquad (1)$$

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

and $F_{equipment} = Sat_{CAC} + Sat_{window} \times 0.25 + Sat_{evap} \times 0.33$ for cooling and 1.0 for heating
$F_{UEC} = UED_x/UED_{SFD} \times CFA_x/CFA_{SFD}$.

Total change in energy use or peak demand for a particular region and land use was found by multiplying change in UEC per tree by the number of trees (N),

Total change = $N \times \Delta UEC_x$.

Subscript *x* refers to residential structures with 2-4 or 5 or more units, *SFD* to single family detached structures for which simulation results are available, and *sh* to shade and *cl* to climate effects. *UED* is unit energy density (sometimes referred to as unit energy use intensity), defined as UEC/CFA. UED and *CFA* (conditioned floor area) data were taken from DOE/EIA (1993) for climate zone 4. Similar adjustments were used to account for UEC and CFA differences between single-family detached residences for which simulations were done, and attached residences and mobile homes.

ΔUECs from shade for multi-family residences (MFRs) were calculated from single-family residential UEC's adjusted by average potential shade factors (APSF's) to account for reduced shade resulting from common walls and multi-story construction. APSF's were estimated from potential shade factors (PSF's), defined as ratios of exposed wall or roof (ceiling) surface area to total surface area, where total surface area includes common walls and ceilings between attached units in addition to exposed surfaces (Simpson 1998). PSF=1 indicates that all exterior walls and roof are exposed and could be shaded by a tree, while PSF=0 indicates that no shading is possible (i.e., the common wall between duplex units). PSF's are estimated separately for walls and roofs for both single and multi-story structures. APSF's were 0.74 for land use MFR 2-4 units and 0.41 for MFR 5+ units.

Estimated shade savings for all residential structures were further adjusted by factors that accounted for shading of neighboring buildings, and reductions in shading from overlapping trees. Homes adjacent to those with shade trees may benefit from their shade. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an estimated energy savings equal to 15% of that found for program participants. This value is 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 (in press) estimated that the fractional reduction in average cooling and heating energy use per tree were approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5 to 3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% was used here, equivalent to approximately three existing trees per residence.

UEC's were also adjusted for climate effects to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes with respect to single family detached residences. Since estimates for these Potential Climate Factors (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. ΔUECs for C/I and I/T land uses due to presence of trees were determined in a manner similar to that used for multi-family land uses. C/I and I/T UEDs (equation 1) were based on total electricity and natural gas usage per unit floor area for climate zone 6 (CEC 2000). Cooling and heating UED's were then derived as the product of these values with statewide ratios of cooling and heating UEDs to total UEDs for electricity and natural gas (CEC 2000). These ratios were 16.9%, 12.4%, and 17.5% for small C/I, large C/I and I/T, respectively. Resulting UED_x/UED_{SFD} ratios for C/I and I/T structures ranged from 6.0 to 9.2 for cooling and 2.1 to 8.2 for heating.

ΔUECs tend to increase with 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 areas of mature trees (approximately 700 to 3,500 ft^2) are often larger than the building surface areas being shaded. Consequently, more area is shaded with increased surface area. However, for larger buildings, a point is reached at which no additional area is shaded as surface area increases. Therefore, ΔUECs will approach a constant value as CFA increases. Since information on the precise relationships between change in UEC, CFA, and tree size are not known, it was assumed that the ratio CFA_x/CFA_{SFD} = 1 in equation 1 for C/I and I/T land uses.

PSFs 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 glazed area. APSFs for I/T structures were estimated to lie between these extremes; a value of 0.15 was used here. A multiple tree reduction factor of 0.85 was used. No benefit was assigned for shading of buildings on adjacent lots.

Table 5. Saturation adjustments for cooling.

	Equipment factors	Equipment Adjusted Saturations pre-1950	1950-1980	post-1980
Central air/heat pump	100%	50%	80%	95%
Evaporative cooler	33%	0%	0%	0%
Wall/window unit	25%	40%	20%	0%
None	0%	20%	10%	5%
		60%	85%	95%

Saturations based on EIA (1990), adjustments on Sarkovich 1996.

Table 6. Saturation adjustments for heating.

a. Electric heating:		Equipment efficiencies pre-1950	1950-1980	post-1980
Natural gas	AFUE[a]	0.75	0.78	0.78
Heat pump	HSPF[b]	6.8	6.8	8
Electric resistance	HSPF	3.412	3.412	3.412
	Equipment factors	Saturation factors		
Electric resistance	100%	6%	13%	20%
Heat pump	100%	3%	6%	9%
Adj elec heat saturations		1.6%	3.7%	5.4%

[a]Annual Fuel Utilization Efficiency, a measure of space heating equipment efficiency defined as the fraction of energy output/energy input
[b]Heating Seasonal Performance Factor, the ratio of heating output to power consumption.
Electric heat saturations are adjusted to convert NG results that were simulated to kWh

b. NG and other heating[c]:		pre-1950	1950-1980	post-1980
Natural gas	100%	70%	61%	52%
Oil	100%	8%	2%	2%
Other	100%	14%	18%	17%
NG Heat saturations:		91%	81%	71%

[c]Oil and "Other" heating categories treated as NG; all residences assumed to be heated

Table 7. Residential building vintage distribution and combined vintage/saturation factors for heating and air conditioning.

Distributions of vintage or building type and trees	Single family residential[a] pre-1950	1950-1980	post-1980	Multi-family residential pre-1950	1950-1980	post-1980	Commercial/ Industrial Small	Large	Institutional/ Transportation
Vintage distribution	12%	52%	35%	12%	52%	35%	100%	100%	100%
Tree distribution	12.5%	23.6%	12.0%	6.7%	12.7%	6.5%	12.1%	10.5%	3.5%
Combined vintage, equipment saturation factors for cooling									
Cooling factor: shade	6.9%	18.2%	10.4%	1.1%	3.0%	1.7%	26.2%	0.0%	5.4%
Cooling factor: climate	7.2%	18.8%	10.7%	2.0%	5.3%	3.0%	30.1%	18.0%	6.2%
Combined vintage, equipment saturation factors for heating									
Heating factor: nat. gas	11%	18%	8%	1%	2%	1%	6%	0%	4.0%
Heating factor: electric	0.2%	0.8%	0.6%	0.0%	0.1%	0.1%	0.5%	0.0%	0.3%

[a]DOE/EIA 1999
Converts kBtu natural gas heat to kWh electricity used for heat based on HP and Elec Res saturation values, and AFUE and SEER by vintage. Factors here assume tree and building distribution are the same.

PCFs of 0.40, 0.25 and 0.20 were used for small C/I, large C/I and I/T, respectively. These values are based on estimates by Akbari and others (1990), who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

Electricity and Natural Gas Results. Electricity saved annually from both shading and climate effects totaled 1,250 MWh (**Table 8**), for a total retail savings of $150,000. Savings per tree for park trees were smaller than for street trees, averaging $3.23/tree compared to $5.21/tree for street trees, reflecting the fact that park trees provide only climate benefits, while street trees provide both shade and climate benefits.

Table 8. Electricity savings for all land uses.

	Street		Park		All Trees		
Species	MWh	$	MWh	$	Total $	$/tree	% of Total
Cedrus deodara	100	12,019	1.2	149	12,169	11.23	8.1%
Ficus microcarpa 'Nitida'+	227	27,214	6.9	829	28,043	8.10	18.7%
Pinus canariensis	63	7,535	3.0	358	7,893	8.72	5.3%
Eucalyptus ficifolia+	26	3,121	7.5	894	4,015	4.99	2.7%
Washingtonia palms	48	5,814	8.5	1,017	6,831	1.37	4.6%
Casuarina cunninghamiana	36	4,325	1.5	181	4,506	6.25	3.0%
Ceratonia siliqua	56	6,741	1.1	128	6,869	7.44	4.6%
Pittosporum undulatum	19	2,236	1.9	224	2,460	5.17	1.6%
Magnolia grandiflora	100	11,946	2.7	326	12,272	6.49	8.2%
Metrosideros excelsus	17	2,089	6.6	791	2,880	3.92	1.9%
Cinnamomum camphora	41	4,947	0.7	80	5,027	7.40	3.4%
Brachychiton populneus	46	5,496	0.4	45	5,541	9.86	3.7%
Phoenix palms	78	9,337	25.4	3,043	12,380	7.67	8.3%
All other trees	294	35,227	32.9	3,948	39,176	3.77	26.1%
Total	1,150	138,049	100	12,015	150,063	5.13	100%

Total increased cost for natural gas was nearly $2,500 (**Table 9**). This small increase in heating costs resulted from winter tree shade being somewhat larger than the savings from wind speed reduction (a climate effect). Note that park trees exhibited a net heating savings (**Table 9**). Only climate effects were attributed to them, and they did not provide shade in winter.

Table 9. Change in natural gas usage for all land uses.

	Street		Park		All Trees		
Species	MBtu	$	MBtu	$	Total $	$/tree	% of Total
Cedrus deodara	(47)	(383)	1.4	12	(371)	(0.34)	15.2%
Ficus microcarpa 'Nitida'+	12	95	8.0	65	160	0.05	-6.6%
Pinus canariensis	(77)	(626)	3.4	28	(599)	(0.66)	24.6%
Eucalyptus ficifolia+	(14)	(116)	10.2	83	(33)	(0.04)	1.3%
Washingtonia palms	(34)	(275)	9.7	79	(196)	(0.04)	8.0%
Casuarina cunninghamiana	(57)	(466)	1.7	14	(452)	(0.63)	18.6%
Ceratonia siliqua	(5)	(38)	1.2	9	(28)	(0.03)	1.2%
Pittosporum undulatum	(5)	(41)	2.1	17	(24)	(0.05)	1.0%
Magnolia grandiflora	(50)	(404)	2.5	20	(384)	(0.20)	15.7%
Metrosideros excelsus	(4)	(34)	7.5	61	27	0.04	-1.1%
Cinnamomum camphora	(3)	(26)	0.8	6	(20)	(0.03)	0.8%
Brachychiton populneus	(1)	(12)	0.4	3	(8)	(0.02)	0.3%
Phoenix palms	(32)	(264)	28.9	235	(28)	(0.02)	1.2%
All other trees	(96)	(782)	37.0	301	(481)	(0.05)	19.8%
Total	(415)	(3,371)	115	934	(2,437)	(0.08)	100%

Net Energy Savings. Net savings (**Table 10**) were primarily from reduced summer air conditioning. Heating benefits due to reduced wind speeds were approximately compensated for by heating increases due to winter shading. Total savings were 9,700 MBtu, valued at over $147,000. Average savings per tree were $5.05, and greater than $8/tree for larger varieties (e.g., Deodar cedar, laurel fig, bottle tree, pine).

Table 10. Net energy savings for all land uses.

	Street		Park		All Trees		
Species	MBtu	$	MBtu	$	Total $	$/tree	% of Total
Cedrus deodara	754	11,636	11	161	11,797	10.88	8.0%
Ficus microcarpa 'Nitida'+	1,826	27,309	63	894	28,203	8.15	19.1%
Pinus canariensis	425	6,909	27	385	7,295	8.06	4.9%
Eucalyptus ficifolia+	194	3,005	70	978	3,982	4.95	2.7%
Washingtonia palms	354	5,540	77	1,095	6,635	1.33	4.5%
Casuarina cunninghamiana	231	3,859	14	195	4,054	5.62	2.7%
Ceratonia siliqua	445	6,704	10	137	6,841	7.41	4.6%
Pittosporum undulatum	144	2,195	17	241	2,437	5.12	1.7%
Magnolia grandiflora	747	11,542	24	346	11,888	6.28	8.1%
Metrosideros excelsus	135	2,055	60	852	2,907	3.96	2.0%
Cinnamomum camphora	327	4,921	6	86	5,007	7.37	3.4%
Brachychiton populneus	365	5,484	3	49	5,533	9.84	3.7%
Phoenix palms	590	9,074	232	3,278	12,352	7.65	8.4%
All other trees	2,252	34,445	300	4,249	38,695	3.73	26.2%
Total	8,789	134,678	916	12,949	147,626	5.05	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, and 2) trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

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

Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential CO_2 emission reductions. Santa Monica's climate is moderated by the nearby Pacific Ocean, resulting in relatively small cooling and heating loads compared to inland California locations. An emission factor for electricity of 0.44 kg per kWh (0.98 lb CO_2/kWh) was used based on Southern California Edison's fuel mix (CEC 1994), nearly 30% greater than the California state average (0.34 kg/kWh).

Avoided Emissions Methodology: Reductions in building energy use result in reduced emissions of CO_2. Emissions were calculated as the product of energy use and CO_2 emission factors for electricity and heating. Heating fuel is largely natural gas and electricity in Santa Monica (**Table 6**); the fuel mix for electrical generation in Santa Monica is approximately 55% natural gas, 14% coal, 22% hydroelectric and nuclear and the remainder 9% (California Energy Commission 1994). CO_2 emissions factors for electrical generation (kg/tree) weighted by the appropriate fuel mix are given in **Table 11**. Value of CO_2 reductions (**Table 11**) are based on control costs recommended by the California Energy Commission (California Energy Commission 1994).

Table 11. Emissions factors and implied values for CO2 and criteria air pollutants (kg)

	Emission Factor[a]		Implied
	Electricity (kg/MWh)	Natural gas (kg/MBtu)	value ($/kg)
CO2	444	53.4	0.033[b]
NO2	0.589	0.0462	27.54[c]
SO2	1.729	0.0003	10.19[c]
PM10	0.090	0.0034	13.67[c]
VOC's	0.049	0.0024	4.23[c]

[a]U. S. Environmental Protection Agency 1998.
[b]California Energy Commission 1994.
[c] Cantor Fitzgerald Environmental Brokerage Services, 1999.

Avoided Emissions Result: Emission of about 179 metric tonnes (193 short tons) of CO_2 was avoided as a result of energy saved from reduced space heating and air conditioning (**Table 12**). This savings was valued at nearly $6,000, averaging $0.20 per tree, and as high as $0.43 per tree.

Sequestered and Released CO_2 Methodology. Sequestration, the net rate of CO_2 storage in above- and below-ground biomass over the course of one growing season, was calculated by species using tree growth data described in Chapter 2 and biomass equations from Pillsbury et al. (1998) and Frangi and Lugo (1985) for palms (see McPherson and Simpson [1999] for additional information). Urban-based biomass equations were used as available for the most commonly occurring species. Equations for the following species were used for remaining trees: London plane *(Platanus acerifolia)* for large deciduous, liquidambar *(Liquidambar styraciflua*) for medium deciduous and jacaranda *(Jacaranda mimosifolia)* for small deciduous trees, gum *(Eucalyptus ficifolia)* for large broadleaf evergreens, camphor (Cinnamomum camphora) for medium broadleaf evergreens, Brazilian pepper *(Schinus terebinthifolius)* for small broadleaf evergreens, deodar cedar *(Cedrus deodara)* for large conifers, and Japanese black pine *(Pinus thunbergii)* for small conifers.

Table 12. CO2 emissions avoided due to energy savings.

	Street		Park		All Trees		
Species	kg	$	kg	$	Total $	$/tree	% of Total
Cedrus deodara	13,755	455	214.8	7	462	0.43	7.8%
Ficus microcarpa 'Nitida'+	33,743	1,116	1,203.6	40	1,156	0.33	19.5%
Pinus canariensis	7,590	251	514.5	17	268	0.30	4.5%
Eucalyptus ficifolia+	4,044	134	1,617.7	53	187	0.23	3.2%
Washingtonia palms	6,449	213	1,461.9	48	262	0.05	4.4%
Casuarina cunninghamiana	4,056	134	260.7	9	143	0.20	2.4%
Ceratonia siliqua	8,191	271	183.1	6	277	0.30	4.7%
Pittosporum undulatum	2,634	87	322.2	11	98	0.21	1.7%
Magnolia grandiflora	13,699	453	458.1	15	468	0.25	7.9%
Metrosideros excelsus	2,473	82	1,137.5	38	119	0.16	2.0%
Cinnamomum camphora	6,005	199	115.2	4	202	0.30	3.4%
Brachychiton populneus	6,718	222	65.0	2	224	0.40	3.8%
Phoenix palms	10,842	359	4,375.1	145	503	0.31	8.5%
All other trees	41,165	1,361	5,667.8	187	1,549	0.15	26.2%
Total	161,364	5,336	17,597	582	5,918	0.20	100%

CO_2 released through decomposition of dead woody biomass varies with characteristics of the wood itself, fate of the wood (e.g., left standing, chipped, 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. We conservatively estimate 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 is based on annual removal data for the city of Santa Monica (**Table 13**).

Table 13. Tree removal information.

	Tree Dbh Class (cm)						
	0-15	15-30	30-46	46-61	61-76	>76	Total
% of total trees	15%	27%	28%	16%	7%	7%	100%
Removed in 3 yrs	9	235	14	11	99	20	388
Avg. annual loss %	0.07%	1.01%	0.06%	0.08%	1.5%	0.34%	0.44%

Finally, CO_2 released from tree maintenance is estimated to be 0.23 kg CO_2/cm dbh based on annual consumption of gasoline, diesel, and propane fuel over the course of a year by contractors and Community Forest Operations (personal communication, Walter Warriner, City of Santa Monica, December 19, 1999). After converting fuel consumption into CO_2 equivalent emissions, total annual release is 272,267 kg (300 tons).

Sequestered and Released CO_2 Result. Sequestration less releases due to decomposition and maintenance (net sequestration) resulted in total savings of 1,831 metric tonnes (2,018 short tons) of CO_2, with an implied value of over $60,000 (**Table 14)**. Average annual net sequestration per tree was 63 kg (140 lb) and this was valued at over $2.00 per tree. Eucalyptus accounted for 13% of total CO_2 sequestered by street trees. Annual CO_2 releases were equivalent to 13% of total CO_2 sequestered.

Net sequestration was over 10 times avoided CO_2. This result was largely due to the clean resource mix for electrical generation, the moderate climate and relatively rapid tree growth in Santa Monica. The resource contains a large proportion of natural gas (55%) and hydroelectric (19%) sources. The moderate climate results in small cooling and heating loads, and hence smaller possible absolute savings. Finally, the favorable growing season results in vigorous tree growth and carbon uptake.

Table 14. CO2 sequestered as biomass, less release from decomposition and maintenance.

	Street		Park			All Trees	
Species	kg	$	kg	$	Total $	$/tree	% of Total
Cedrus deodara	125,384	4,146	2,028	67	4,213	3.89	7.0%
Ficus microcarpa 'Nitida'+	200,063	6,616	7,386	244	6,860	1.98	11.3%
Pinus canariensis	58,045	1,919	6,097	202	2,121	2.34	3.5%
Eucalyptus ficifolia+	166,735	5,514	73,608	2,434	7,948	9.89	13.1%
Washingtonia palms	68,475	2,264	17,556	581	2,845	0.57	4.7%
Casuarina cunninghamiana	52,974	1,752	2,178	72	1,824	2.53	3.0%
Ceratonia siliqua	77,210	2,553	1,706	56	2,610	2.83	4.3%
Pittosporum undulatum	86,433	2,858	10,409	344	3,202	6.73	5.3%
Magnolia grandiflora	90,241	2,984	2,289	76	3,060	1.62	5.1%
Metrosideros excelsus	53,680	1,775	22,450	742	2,518	3.43	4.2%
Cinnamomum camphora	52,445	1,734	1,317	44	1,778	2.62	2.9%
Brachychiton populneus	61,413	2,031	644	21	2,052	3.65	3.4%
Phoenix palms	24,888	823	10,379	343	1,166	0.72	1.9%
All other trees	487,506	16,121	67,640	2,237	18,358	1.77	30.3%
Total	1,605,491	53,092	225,687	7,463	60,555	2.07	100%

Net Atmospheric CO_2 Reductions. Net CO_2 reduction, the sum of avoided and net sequestration, was 2,010 metric tonnes (2,215 short tons), with a value of over $66,000 (**Table 15**). This was an average benefit of $2.27 per tree, with a maximum of $10 per tree. Eucalyptus (12%), laurel fig (12%), and Deodar cedar (7%) were responsible for the largest percentages of net atmospheric CO_2 reductions.

Table 15. Net atmospheric CO2 reductions.

	Street		Park		All Trees		
Species	kg	$	kg	$	Total $	$/tree	% of Total
Cedrus deodara	139,139	4,601	2,243	74	4,675	4.31	7.0%
Ficus microcarpa 'Nitida'+	233,807	7,732	8,589	284	8,016	2.32	12.1%
Pinus canariensis	65,635	2,170	6,611	219	2,389	2.64	3.6%
Eucalyptus ficifolia+	170,779	5,647	75,226	2,488	8,135	10.12	12.2%
Washingtonia palms	74,923	2,478	19,017	629	3,107	0.62	4.7%
Casuarina cunninghamiana	57,030	1,886	2,439	81	1,967	2.73	3.0%
Ceratonia siliqua	85,401	2,824	1,889	62	2,887	3.13	4.3%
Pittosporum undulatum	89,067	2,945	10,731	355	3,300	6.93	5.0%
Magnolia grandiflora	103,941	3,437	2,747	91	3,528	1.86	5.3%
Metrosideros excelsus	56,153	1,857	23,587	780	2,637	3.59	4.0%
Cinnamomum camphora	58,450	1,933	1,433	47	1,980	2.92	3.0%
Brachychiton populneus	68,131	2,253	709	23	2,276	4.05	3.4%
Phoenix palms	35,730	1,182	14,754	488	1,669	1.03	2.5%
All other trees	528,671	17,483	73,308	2,424	19,907	1.92	29.9%
Total	1,766,855	58,428	243,284	8,045	66,473	2.27	100%

Air Quality Improvement

Urban trees provide air quality benefits by 1) absorbing gaseous pollutants (ozone, nitrogen oxides) through leaf surfaces, 2) intercepting particulate matter (e.g., dust, ash, pollen, smoke), 3) releasing oxygen through photosynthesis, and 4) and transpiring water and shading surfaces, which lowers local air temperatures, thereby reducing ozone levels. In the absence of the cooling effects of trees, higher air temperatures contribute to ozone formation. Most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can contribute to ozone formation. The ozone forming potential of different tree species varies considerably (Benjamin and Winer 1998). Two of the three dominant species in Santa Monica, eucalyptus and ficus, are high emitters of BVOCs.

Scott et al. (1998) found that the total value of annual air pollutant uptake produced by Sacramento County's six million trees was $28.7 million, nearly $5 per tree on average. The urban forest removed approximately 1,457 metric tons (1,606 short tons) of air pollutant annually. Trees were most effective at removing ozone and particulate matter (PM_{10}). Daily uptake of NO_2 and PM_{10} represented 1 to 2% of emission inventories for the county. Pollutant uptake rates were highest for residential and institutional land uses.

Trees in a Davis CA parking lot were found to benefit air quality by reducing air temperatures 0.5-1.5 °C (1-3°F) (Scott et al. 1999). By shading asphalt surfaces and parked vehicles the trees reduce hydrocarbon emissions from gasoline that evaporates out of leaky fuel tanks and worn hoses. These evaporative emissions are a principal component of smog, and parked vehicles are a primary source. Initial calculations indicate that planting trees in parking lots throughout the region could reduce hydrocarbon emissions comparable to the levels achieved through the local air quality district's currently funded programs (e.g., graphic arts, waste burning, vehicle scrappage).

Avoided Emissions Methodology. Reductions in building energy use also result in reduced emissions of criteria air pollutants from power plants and space heating equipment. We considered volatile organic hydrocarbons (VOC's) and nitrogen dioxide (NO_2), both precursors of ozone (O_3) formation, as well as particulate matter of <10 micron diameter (PM_{10}). Changes in average annual emissions and their offset values were calculated in the same way as for $CO_{2,}$, again using utility-specific emission factors for electricity and heating fuels, with the value of emissions savings (**Table 11**) based on control costs specific to the South Coast Air Quality Management District (Cantor Fitzgerald Environmental Brokerage Services, 1999).

Avoided Emissions Result. Avoided emissions of NO_2, PM_{10} and VOC's were small (**Table 16**), totaling 362 kg (0.4 short ton), valued at $8,700. This result was due to the relatively small effect trees have on energy use in Santa Monica, where the climate is mild year-round.

Deposition and Interception Methodology. Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of a deposition velocity $V_d = 1/(R_a+R_b+R_c)$, a pollutant concentration C, a canopy projection area CP, and a time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances R_a, R_b, and R_c estimated for each hour throughout a "base year" (1991) using formulations described by Scott et al. (1998). We assume a 9-month in-leaf season for all trees. Our interception results are conservative because evergreens will provide greater benefit than we estimate due to their year-round foliage. Hourly meteorological data for wind speed, solar radiation and precipitation from California Department of Water Resources monitoring sites located in Hawthorne and Long Beach are used as input data. Hourly concentrations for NO_2 , O_3, and PM_{10} were obtained for Hawthorne from the South Coast Air Quality Management District via the California Air Resources Board (personal communication, Klaus Scott, California Air Resources Board, November 11, 1999). This station monitors for air pollutant concentrations representative of areas of high population density, at spatial scales of up to 3 miles, and is located approximately 4 miles ESE of Los Angeles International Airport. See Scott et al. (1998) for details. We applied a 50% resuspension rate to PM_{10} deposition. We used control costs from **Table 11** to value emissions reductions; we used NO_2 control costs for ozone since ozone control measures are primarily aimed at NO_x reduction in coastal southern California.

Table 16. Avoided pollutants.

Species	NO2	PM10	Total kg VOC's	Total $	Avg. $/tree	% of Total $
Cedrus deodara	22	3.6	1.9	676	0.62	7.7%
Ficus microcarpa 'Nitida'+	56	8.6	4.7	1,679	0.49	19.2%
Pinus canariensis	13	2.2	1.2	398	0.44	4.6%
Eucalyptus ficifolia+	12	1.9	1.0	358	0.45	4.1%
Washingtonia palms	13	2.1	1.1	387	0.08	4.4%
Casuarina cunninghamiana	7	1.2	0.7	213	0.30	2.4%
Ceratonia siliqua	13	2.1	1.1	402	0.44	4.6%
Pittosporum undulatum	5	0.7	0.4	142	0.30	1.6%
Magnolia grandiflora	23	3.6	2.0	690	0.36	7.9%
Metrosideros excelsus	6	0.9	0.5	172	0.23	2.0%
Cinnamomum camphora	10	1.5	0.8	293	0.43	3.4%
Brachychiton populneus	11	1.7	0.9	325	0.58	3.7%
Phoenix palms	25	3.9	2.1	748	0.46	8.6%
All other trees	75	11.9	6.4	2,254	0.22	25.8%
Total	291	46	25	8,738	0.30	100%

Deposition and Interception Result. Pollutant uptake by tree foliage (pollutant deposition and particulate interception) was 14 metric tonnes (16 short tons) of combined uptake (**Table 17**). The total value of this benefit was over $276,000, or about $9 per tree. Ozone, PM_{10} and NO_2 uptake accounted for $133,000 (48%), $33,000 (12%) and $110,000 (40%) of the savings, respectively.

BVOC Emissions Methodology. Emission of biogenic volatile organic carbon (BVOCs, sometimes called biogenic hydrocarbons) associated with increased ozone formation were estimated for the tree canopy using methods described by McPherson et al. (1998). In this approach, the hourly emissions of carbon as isoprene and monoterpene are expressed as products of base emission factors, leaf biomass factors adjusted for sunlight and temperature (isoprene) or temperature (monoterpene). Hourly emissions were summed to get annual totals. We do not account for the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from anthropogenic and biogenic sources. This is a conservative approach, since simulation results from Los Angeles and Sacramento indicate that ozone reduction benefits of tree planting with "low-emitting" species exceed costs associated with their BVOC emissions (Taha 1996, McPherson et al. 1998). The cost of these emissions is priced at $4.23/kg (**Table 11**).

Table 17. Pollutant uptake.

Species	O3	NO2	Total kg PM10	Total $	Avg. $/tree	% of Total $
Cedrus deodara	586	144	936	**32,895**	30.35	11.9%
Ficus microcarpa 'Nitida'+	543	134	1,004	32,376	9.36	11.7%
Pinus canariensis	986	242	1,544	54,913	60.68	19.9%
Eucalyptus ficifolia+	252	62	395	14,038	17.46	5.1%
Washingtonia palms	184	45	305	10,459	2.09	3.8%
Casuarina cunninghamiana	162	40	292	9,533	13.22	3.5%
Ceratonia siliqua	195	48	326	11,128	12.06	4.0%
Pittosporum undulatum	76	19	131	4,387	9.22	1.6%
Magnolia grandiflora	161	40	319	9,870	5.22	3.6%
Metrosideros excelsus	23	6	48	1,440	1.96	0.5%
Cinnamomum camphora	121	30	203	6,925	10.20	2.5%
Brachychiton populneus	132	33	226	7,630	13.58	2.8%
Phoenix palms	610	150	897	33,183	20.55	12.0%
All other trees	814	200	1,428	47,449	4.57	17.2%
Total	4,843	1,190	8,054	276,226	9.45	100%

BVOC Emissions Result. Annual BVOC emissions totaled 3,793 kg, or 27% of total pollutant uptake (**Table 17a**). The estimated annual cost of BVOC emissions was $16,000, or $0.55/tree on average. Canary island pine (15%), laurel fig (15%), Southern magnolia (12%), date palms (8%), and eucalyptus (8%) were species responsible for the greatest BVOC emissions.

Table 17a. Biogenic Volatile Organic Compound emissions

Species	Total kg VOC's	Total $	Avg. $/tree	% of Total $
Cedrus deodara	(107)	(455)	(0.42)	2.8%
Ficus microcarpa 'Nitida'+	(559)	(2,367)	(0.68)	14.7%
Pinus canariensis	(573)	(2,426)	(2.68)	15.1%
Eucalyptus ficifolia+	(291)	(1,233)	(1.53)	7.7%
Washingtonia palms	(72)	(305)	(0.06)	1.9%
Casuarina cunninghamiana	(25)	(105)	(0.15)	0.7%
Ceratonia siliqua	(94)	(396)	(0.43)	2.5%
Pittosporum undulatum	(1)	(4)	(0.01)	0.0%
Magnolia grandiflora	(437)	(1,851)	(0.98)	11.5%
Metrosideros excelsus	(102)	(431)	(0.59)	2.7%
Cinnamomum camphora	(1)	(5)	(0.01)	0.0%
Brachychiton populneus	(99)	(419)	(0.74)	2.6%
Phoenix palms	(302)	(1,278)	(0.79)	8.0%
All other trees	(1,130)	(4,781)	(0.46)	29.8%
Total	(3,793)	(16,056)	(0.55)	100%

Net Air Quality Improvement. Net air quality savings (**Table 18**) were primarily due to pollutant uptake, since the amount of avoided pollutants and BVOC emissions were relatively small. Net savings of all pollutants taken together was approximately 10.7 metric tonnes (11.7 short tons), valued at nearly

$269,000. Savings averaged over $9 per tree, and were as large as $58 per tree for Canary Island pine.

Table 18. Net pollutant reduction.

Species	Total $	Avg. $/tree	% of Total $
Cedrus deodara	33,117	30.55	12.3%
Ficus microcarpa 'Nitida'+	31,689	9.16	11.8%
Pinus canariensis	52,885	58.44	19.7%
Eucalyptus ficifolia+	13,163	16.37	4.9%
Washingtonia palms	10,540	2.11	3.9%
Casuarina cunninghamiana	9,641	13.37	3.6%
Ceratonia siliqua	11,134	12.06	4.1%
Pittosporum undulatum	4,525	9.51	1.7%
Magnolia grandiflora	8,709	4.60	3.2%
Metrosideros excelsus	1,181	1.61	0.4%
Cinnamomum camphora	7,213	10.62	2.7%
Brachychiton populneus	7,537	13.41	2.8%
Phoenix palms	32,653	20.22	12.1%
All other trees	44,921	4.33	16.7%
Total	268,908	9.20	100%

Stormwater Runoff Reductions

Urban stormwater runoff is a major source of pollution entering local rivers and the Santa Monica Bay. A healthy urban forest can reduce the amount of runoff and pollutant loading in receiving waters. Trees intercept and store rainfall on leaves and branch surfaces, thereby reducing runoff volumes and delaying the onset of peak flows. Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow. Urban forest canopy cover reduces soil erosion by diminishing the impact of raindrops on barren surfaces, as well as runoff.

Studies that have simulated urban forest impacts on stormwater report annual runoff reductions of 2-7%. Annual interception of rainfall by Sacramento’s urban forest for the urbanized area was only about 2% due to the winter rainfall pattern and predominance of non-evergreen species (Xiao et al. 1998). However, average interception loss for the land with tree canopy cover ranged from 6 to 13% (150 gal per tree on average), close to values reported for rural forests. Trees are less effective for flood control than water quality protection because canopy storage is exceeded well before peak flows occur. Trees can delay the time of peak runoff because it often takes 10-20 minutes for the tree crown to become saturated and flow to begin from stems and trunk to the ground. By reducing runoff from small storms, which are responsible for most annual pollutant washoff, trees can protect water quality.

Urban forests can provide other hydrologic benefits. For example, irrigated tree plantations can be a safe and productive means of wastewater disposal. Reused wastewater can recharge aquifers, reduce stormwater treatment loads, and create income through sales of wood products. Recycling urban wastewater into greenspace areas can be an economical means of treatment and disposal, while at the same time providing other environmental benefits.

Methodology. A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 1998). The interception model accounts for water intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Once the leaf is saturated it drips from the leaf surface and flows down the stem surface to the ground, or evaporates. Tree canopy parameters include species, leaf area, shade coefficient (visual density of the crown), and tree height. Tree height data are used to estimate wind speed at different heights above the ground and resulting rates of evaporation. The volume of water stored in the tree crown is calculated from crown projection area (area under tree dripline), leaf area indexes (LAI, the ratio of leaf surface area to crown projection area), and water depth on the canopy surface. Species-specific shade coefficients influence the amount of projected throughfall. Hourly meteorological and rainfall data for 1996 from the Santa Monica California Irrigation Management Information System (CIMIS) are used for this simulation. Annual precipitation during 1996 was 22.4 inches (570 mm), somewhat greater than the mean annual precipitation amount of 17.8 inches (451 mm) for the region (U.S. Dept. of Commerce 1968). A more complete description of the interception model can be found in Xiao et al. (1998).

To estimate the implied value of rainfall intercepted we considered current expenditures for flood control and urban stormwater quality programs. During small rainfall events excess capacity in sanitary treatment plants can be used to treat stormwater. In the Los Angeles region it costs approximately $1.37 / Ccf ($0.00183 / gal) to treat sanitary waste (Condon and Moriarty 1999). We use this value to price stormwater quality benefits because the cost of treating stormwater in central facilities is likely to be close to the cost of treating an equal amount of sanitary waste. The treatment cost is multiplied by gallons of rainfall intercepted each year to calculate water quality benefit.

As part of the TreePeople's program called T.R.E.E.S. (Trans-agency Resources for Environmental and Economic Sustainability) it was determined that over $50 million ($500,000 / sq mile) is spent annually controlling floods in the Los Angeles area (Condon and Moriarty 1999). We assume that the impact of rainfall interception by tree crowns will be minimal during very large storms that result in catastrophic flooding of the Los Angeles River and its tributaries (133-year design storm). Although storm drains are designed to control 25-year events, localized flooding is a problem during these smaller events. Following the economic approach used in the T.R.E.E.S. cost-benefit analysis, we assume that $50 million is spent per year for local problem areas and the annual value of peak flow reduction is $500,000 per square mile for each percent decrease in 25-year peak flow (Jones & Stokes Associates, Inc. 1998). A 25-year winter event deposits 134 mm (5.3 inches) of rainfall during 57 hours. Approximately $1.44 / m^3 ($0.0054 / gal) is spent annually for controlling flooding caused by such an event. This price is multiplied by the amount of rainfall intercepted during a single 25-year event to estimate the annual flood control benefit. Water quality and flood control benefits are summed to calculate the total hydrology benefit.

Result. Santa Monica's street and park trees were estimated to reduce annual runoff by about 205,000 m^3 (73,000 Ccf) with an implied value of nearly $111,000 (**Table 19**). On average, each tree reduced stormwater runoff by 7 m^3 (1,856 gal) annually, and the value of this benefit was $3.79. Although park trees comprised 13% of the total tree population, they accounted for only 10% of this hydrologic benefit. This result was primarily due to their relatively smaller proportion of trees with evergreen foliage compared to street trees (41% vs. 63%). Broadleaf evergreens and conifers intercepted more rainfall than deciduous trees because of the winter rainfall pattern. Street tree species that produced the greatest annual benefits per tree were Canary Island pine ($14), Deodar cedar ($8), date palms ($6), and eucalyptus ($6).

The benefit of tree rainfall interception was from both flood management and runoff water quality improvement. Most of the annual stormwater runoff reduction benefit came from small storm events. Small rainfall events do not cause serious flood problems, but they can wash pollutants into watershed outlets or storm runoff treatment facilities. Canopy interception not only reduces the amount of runoff, but it also reduces the kinetic energy required to washoff pollutants and carry them to receiving water bodies.

Table 19. Stormwater runoff reductions.

	Street		Park			All Trees	
Species	m3	$	m3	$	Total $	$/tree	% of Total
Cedrus deodara	16,715	9,001	264	143	9,144	8.44	8.3%
Ficus microcarpa 'Nitida'+	31,796	16,505	1,142	595	17,100	4.94	15.4%
Pinus canariensis	19,615	12,641	908	525	13,165	14.55	11.9%
Eucalyptus ficifolia+	6,272	3,315	2,758	1,462	4,777	5.94	4.3%
Washingtonia palms	7,981	3,476	1,849	806	4,282	0.86	3.9%
Casuarina cunninghamiana	6,429	3,597	683	440	4,037	5.60	3.6%
Ceratonia siliqua	8,406	4,390	182	95	4,485	4.86	4.0%
Pittosporum undulatum	3,238	1,725	386	206	1,930	4.06	1.7%
Magnolia grandiflora	14,094	7,379	526	278	7,657	4.05	6.9%
Metrosideros excelsus	2,336	1,208	1,116	555	1,763	2.40	1.6%
Cinnamomum camphora	5,699	2,947	105	54	3,001	4.42	2.7%
Brachychiton populneus	6,195	3,192	56	29	3,221	5.73	2.9%
Phoenix palms	12,316	6,868	4,430	2,849	9,716	6.02	8.8%
All other trees	43,242	22,893	6,587	3,613	26,507	2.55	23.9%
Total	184,336	99,135	20,991	11,648	110,784	3.79	100%

The 25-year flood event (134.2 mm, 5.3 inches, February 19, 1996) accounted for 16% of the total annual stormwater runoff reduction benefit ($17,506, assume the runoff from this size storm bypasses the storm runoff treatment facilities). Rainfall interception by the public trees for this storm only accounted for 0.1% of total precipitation on the entire land area of the City. However, Santa Monica's street and park trees intercepted 12,158 m^3 (3.2 million gal) of rainwater, with implied savings of $17,506 in flood management costs. For this type and size storm, on average, each tree intercepted 0.4 m^3 (110 gal) of rainwater and the benefit was $0.60.

Property Values and Other Benefits

Trees provide a host of social, economic, and health benefits that should be described if not monetized in this benefit-cost analysis. Environmental benefits from trees not accounted for previously include noise abatement and wildlife habitat. Although these types of environmental benefits are more difficult to quantify than those previously described, they can be important. Another important benefit from street tree shade is money saved for repaving because shaded streets do not deteriorate as fast as unshaded streets.

Property Value Increases and Other Benefits

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 land forms or solid barriers can reduce highway noise by 6-15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Miller 1997).

Although urban forests contain less biological diversity than rural woodlands, numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Remnant coastal sage and riparian habitats within Santa Monica connect the City to its surrounding bioregion. Wetlands, greenways (linear parks), and other greenspace resources provide habitats that conserve biodiversity (Platt et al. 1994).

The social and psychological benefits provided by Santa Monica's urban forest improve human well-being. Research indicates that views of vegetation and nature bring relaxation and sharpen concentration.

Hospitalized patients with views of nature and time spent outdoors needed less medication, slept better, and were happier than patients without these connections to nature (Ulrich et al.1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful health effects from skin cancer and cataracts. Other research shows that humans derive substantial pleasure from trees, whether it be feelings of relaxation, connection to nature, or religious joy (Dwyer et al. 1992). Trees provide important settings for recreation in and near Santa Monica. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality. Just the act of planting trees has social value in that new bonds between people often result. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience.

Research comparing sales prices of residential properties with different tree resources suggests that people are willing to pay 3 -7% more for properties with ample tree resources versus few or no trees. One of the most comprehensive studies of the influence of trees on residential property values was based on actual sales prices for 844 single family homes in Athens, Georgia (Anderson and Cordell 1988). Using regression analysis, each large front-yard tree was found to be associated with about a 1% increase in sales price ($336 in 1985 dollars). This increase in property value resulted in an estimated increase of $100,000 (1978 dollars) in the city's property tax revenues. A much greater value of 9% ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988).

Methodology. Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place and well-being are products that are difficult to price. However, the value of some of these benefits may be captured in the property values for the land on which trees stand. To estimate the value of these "other" benefits we apply results of research that compares differences in sales prices of houses to statistically quantify the amount of difference associated with trees. The amount of difference in sales price should reflect the willingness of buyers to pay for the benefits and costs associated with the trees. This approach has the virtue of capturing what buyers perceive to be as both the benefits and costs of trees in the sales price. Some limitations to using this approach for the present study include the difficulty associated with 1) determining the value of individual trees on a property, 2) the need to extrapolate results from studies done years ago in the east and south to California, and 3) the need to extrapolate results from front yard trees on residential properties to trees in other locations (e.g., streets and parks).

Anderson and Cordell (1988) surveyed 844 single family residences and found that each large front-yard tree was associated with a $336 increase in sales price or nearly 1% of the average sales price of $38,100 (in 1978 dollars). We use this 1% of sales price as an indicator of the additional value a Santa Monica resident would gain from sale of residential property with a large tree. The sales price of residential properties varies by location within the city. In 1998 the median home price in Santa Monica was $450,000 (California Association of Realtors 1999). The value of a large tree that adds 0.9% to the sales price of such a home is $3,969. Based on growth data for a 40-year old camphor tree, such a tree is 11.1-m (36 ft) tall, with a 12.3m (40-ft) crown diameter, 59-cm (23 in) trunk diameter, and 250 m^2 (2,675 ft^2) of leaf surface area.

A land-use adjustment was made to account for the fact that the aesthetic benefit of residential street trees may be greater than for comparable street trees in commercial or multi-family land uses. This adjustment used data from a sample of aerial photographs to estimate the distribution of street trees among land uses in Santa Monica. An average weighted reduction factor was calculated by multiplying these proportions (single-family residential 45%, multi-family residential 28%, commercial 24%, other 3%) by land-use reduction terms. The reduction terms were arbitrarily determined after discussion with local real estate agents and they reflect the observation that trees contribute more to the value of single-family homes than to apartment properties and retail properties. The reduction terms were 75% for multi-family residential land uses, 66% for commercial land uses, and 50% for other land uses. The average weighted reduction factor was 82% and the annual aesthetic benefit for a street tree in Santa Monica was $13.21/$m^2$ ($1.23/$ft^2$) of leaf surface area. To estimate annual benefits, this value is multiplied by the amount of leaf surface area added to the tree during one year of growth.

Although the impact of parks on real estate values has been reported (Hammer et al. 1974; Schroeder 1982; Tyrvainen 1999), to our knowledge the on-site and external benefits of park trees alone have not been isolated (More et al. 1988). After reviewing the literature and recognizing an absence of data, we assume that park trees have 50% of the impact on property sales prices as street trees. Given these assumptions, the typical park tree is estimated to increase property values by $7.93/m^2 ($0.74/ft^2) of leaf surface area.

Result. The estimated total annual benefit associated with property value increase and other less tangible benefits was nearly $1.9 million, or $64/tree on average (**Table 20**). Street trees were responsible for 92% of this benefit because they were assumed to have greater impact on property values than park trees. Tree species adding the largest amount of leaf area over the course of a year tended to produce the highest average annual benefit: Deodar cedar ($273), eucalyptus ($164), casuarina ($157), and Canary Island pine ($136).

Table 20. Property value and other benefits.

	Street	Park	All Trees		
Species	$	$	Total $	$/tree	% of Total
Cedrus deodara	293,519	2,493	296,011	273.07	15.6%
Ficus microcarpa 'Nitida'+	180,404	3,804	184,208	53.24	9.7%
Pinus canariensis	114,458	8,251	122,709	135.59	6.5%
Eucalyptus ficifolia+	104,363	27,189	131,553	163.62	6.9%
Washingtonia palms	103,118	17,181	120,299	24.09	6.3%
Casuarina cunninghamiana	110,613	2,586	113,199	157.00	6.0%
Ceratonia siliqua	64,922	855	65,777	71.26	3.5%
Pittosporum undulatum	71,572	5,132	76,704	161.14	4.0%
Magnolia grandiflora	51,774	726	52,500	27.75	2.8%
Metrosideros excelsus	57,542	15,548	73,090	99.44	3.9%
Cinnamomum camphora	49,934	1,215	51,149	75.33	2.7%
Brachychiton populneus	47,292	343	47,635	84.76	2.5%
Phoenix palms	3,664	4,501	8,166	5.06	0.4%
All other trees	490,874	60,885	551,759	53.16	29.1%
Total	1,744,050	150,708	1,894,758	64.82	100%

Total Benefits

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

Santa Monica residents can obtain additional economic benefits from street and park trees depending on tree location and condition. For example, street trees can provide air conditioning savings by shading buildings and pavement. This benefit can extend to the neighborhood, as the aggregate effect of many street trees is to reduce air temperatures and lower cooling costs. Neighborhood property values can be influenced by the extent of tree canopy cover on streets and in nearby parks. The community benefits from cleaner air and water and reduced local flooding. Reductions in atmospheric CO_2 concentrations due to trees can have global benefits.

Methodology

To capture the value of all annual benefits B we sum each type of benefit as follows:

$$B = E + AQ + CO_2 + H + PV$$

where

E = price of net annual energy savings (cooling and heating)

AQ = price of annual air quality improvement (pollutant uptake+avoided power plant emissions)

CO_2 = price of annual carbon dioxide reductions

H = price of annual stormwater runoff reductions

PV = price of annual property value and other benefits

Result

Total benefits produced during 1999 by Santa Monica's street and park trees were estimated to have a value of $2.49 million (**Table 21**), about $27/resident. The average annual benefit was $85/tree. Street trees produced benefits valued at $2.27 million, while park tree benefits were valued at $214,385 and represented 9% of total benefits. Urban forest effects on property values and other intangible benefits accounted for 76% of total benefits ($65/tree). Air quality benefits were second in importance (11% of total benefits, $9/tree). Benefits associated with energy savings represented 6% ($5/tree) of total benefits. Stormwater runoff reductions and atmospheric CO_2 reductions accounted for 5% ($4/tree) and 3% ($2/tree) of estimated total annual benefits, respectively.

Table 21. The value of annual benefits from the urban forest.

Benefit Category	Total $	% of Total Benefit	Average $/tree
Environmental			
Energy	147,626	5.9%	5.05
CO2	66,473	2.7%	2.27
Air Quality	268,908	10.8%	9.20
Stormwater	110,784	4.5%	3.79
Environmental subtotal	593,791	23.9%	20.32
Property/Other	1,894,758	76.1%	64.82
Total Benefits	2,488,550	100.0%	85.14

Average annual benefits per tree increased from $50 for small trees to $200 for large trees (**Fig. 3**). Property Value/Other benefits were most important for young trees because the result was influenced by growth rate. Air quality benefits were greatest for older trees because leaf area and crown diameter influenced pollutant uptake.

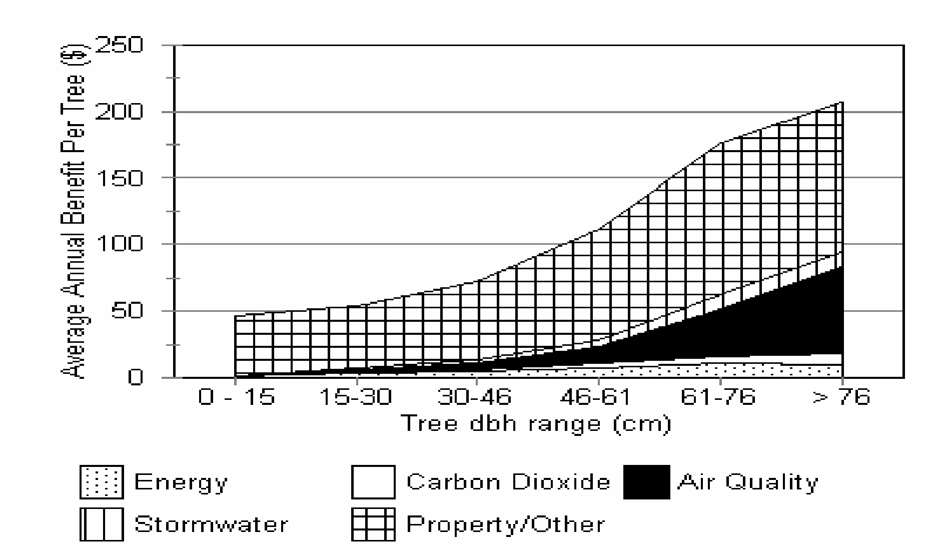

Figure 3. Average annual benefits per tree by dbh size classes.

Table 22 shows the distribution of annual benefits by species and size class. Deodar cedar, which made up 4% of all trees and 9% of all leaf area, accounted for 14% of all benefits by virtue of their size and numbers. Laurel fig (11%), Canary Island pine (8%), and eucalyptus (7%) were also important producers of benefits (**Fig. 4**).

Annual benefits from small, young trees (< 15 cm dbh, 6") averaged $46/tree and accounted for 8% of total benefits, although the trees made up 15% of the population. Nearly 10% of these benefits were from Deodar cedar (4% of small trees), 7% from carrotwood (7% of small trees), and 6% from yew pine (10% of small trees). Other broadleaf evergreen small trees comprised 13% of this size class and 17% of total benefits.

Annual benefits from maturing trees (15-30 cm dbh, 6-12") were more evenly distributed among species and averaged $54/tree. Deodar cedar, beefwood (*Casuarina cunninghamiana*), Victorian box, Southern magnolia, and New Zealand Christmas tree each accounted for 6% of total benefits from this size class.

Mature trees, those between 30-61 cm dbh (12-24"), made up 44% of the tree population and were responsible for 45% of total benefits. The annual benefit averaged $86/tree. The magnitude of future benefits depend on the extent to which these trees grow older and larger. Laurel figs accounted for 21% of these trees and produced 21% of mature tree benefits. Mexican fan palms represented 30% of the trees in this class and 11% of total benefits. Deodar cedar were only 3% of the tree count, but responsible for 10% of total benefits.

Table 22. Total annual benefits by tree DBH class in dollars ($).

	All trees DBH (cm)							
Species	0 - 15	15-30	30-46	46-61	61-76	> 76	Total	% Total
Cedrus deodara	19,050	26,627	42,801	63,484	98,186	104,599	354,745	14.3%
Ficus microcarpa 'Nitida'	1,120	11,837	63,269	166,493	25,300	1,197	269,216	10.8%
Pinus canariensis	4,593	10,111	19,365	40,314	83,876	40,184	198,443	8.0%
Eucalyptus ficifolia	941	8,569	24,220	24,156	28,585	75,140	161,610	6.5%
Washingtonia robusta	1,846	13,606	90,930	36,222	1,440	819	144,863	5.8%
Casuarina cunninghamiana	656	25,928	69,024	24,209	10,527	2,553	132,897	5.3%
Ceratonia siliqua	2,004	12,269	24,458	29,899	19,043	3,451	91,124	3.7%
Pittosporum undulatum	3,485	25,358	29,566	19,473	9,352	1,662	88,896	3.6%
Magnolia grandiflora	9,091	26,845	33,503	11,388	2,597	857	84,282	3.4%
Metrosideros excelsus	5,994	24,593	33,081	16,684	18	1,209	81,577	3.3%
Cinnamomum camphora	9,226	20,510	14,177	12,893	8,555	2,990	68,351	2.7%
Brachychiton populneus	1,370	11,226	20,117	20,279	12,387	823	66,202	2.7%
Phoenix canariensis	4,097	4,097	1,534	1,578	19,416	33,834	64,556	2.6%
All other trees	138,320	196,594	115,245	62,958	62,852	105,820	681,788	27.4%
Total	201,791	418,170	581,290	530,029	382,133	375,137	2,488,550	100.0%
% Total	8.1%	16.8%	23.4%	21.3%	15.4%	15.1%	100.0%	
Avg. $/tree	46	54	71	111	175	191	85	

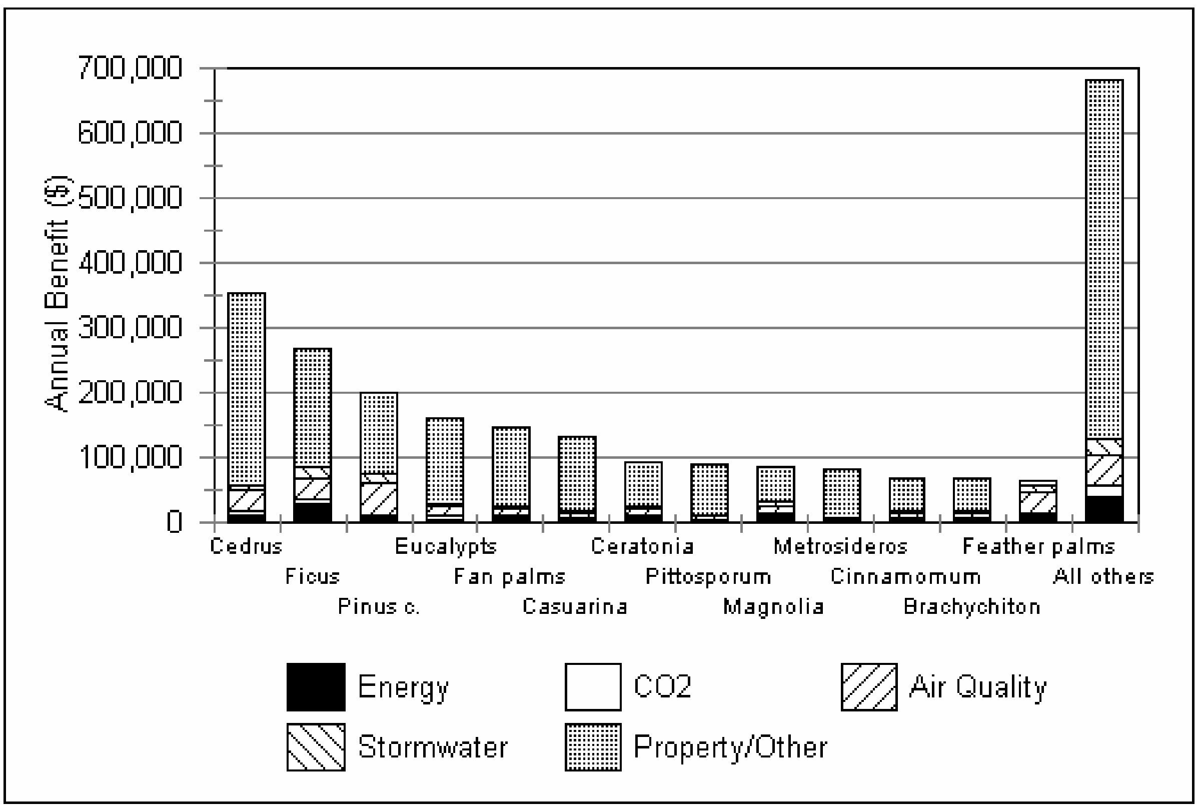

Figure 4. Deodar cedar accounted for 4% of the street tree population and produced 14% of total benefits. Because of their relatively rapid growth and good health, they made a substantial contribution to property value/other benefits.

Large old trees, those greater than 61 cm (24") dbh, were 14% of the population but produced 30% of all benefits ($757,000) (**Fig. 5**). Their average annual benefit was $182/tree. Deodar cedar alone accounted for 27% of total annual benefits from old trees, while comprising only 9% of the total population in this size class. Canary Island pine and eucalyptus contributed 16% and 14%, respectively, while accounting for 12% and 7% of the population. Most of the remaining benefits were spread among other large-stature broadleaf evergreens (16%), as well as the date palms (7%).

Relying on these few species for such a large portion of total benefits is risky. Commonly, relatively few species come to dominate urban forests by virtue of their ability to survive the tests of time. Critical to the benefit-cost equation is the suitability of the dominant species. Canary Island pine is more suitable than dominant species in other cities such as Fremont poplar (*Populus fremontii*) and Siberian elm (*Ulmuspumila*) in Albuquerque NM and silver maple (*Acer saccharinum*) in many Midwestern cities (McPherson and Rowntree 1989).

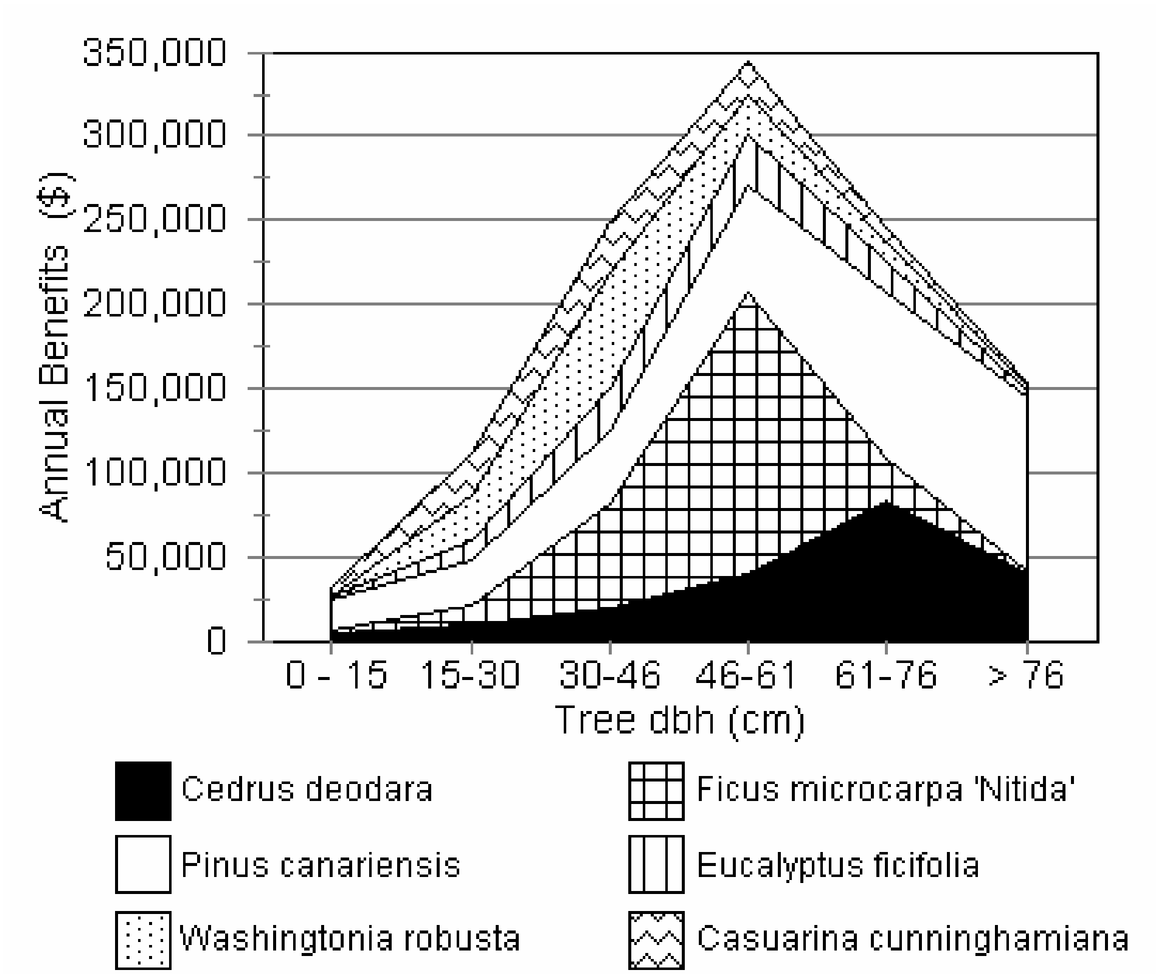

Figure 5. The magnitude of benefits from six species that produced the greatest benefits change due to the number and size of trees in each size class. Benefits from Deodar cedar and Canary Island pine were predominately from older, large trees. Benefits from laurel fig were largely from mid-sized trees. Benefits from eucalyptus, fan palms, and beefwood were more evenly distributed among size classes.

However, eucalyptus and Deodar cedar are less suitable. Some eucalypts are susceptible to the lerp psyllid, limb breakage, and other problems that afflict older trees. Aphids are a serious problem with the Deodar cedar due to the sticky honeydew that drips on objects below. Carefully timed releases of lady bugs that prey on aphids is reducing the problem. Intensive inspection and maintenance are necessary to insure that these problems do not jeopardize tree health, public safety, and the sizable benefits that large trees produce.

Net Benefits and Benefit-Cost Ratio

Total fiscal benefits of $2,488,550, less net expenditures of $1,544,000 resulted in a net annual benefit of $944,550 (**Table 23**). Average annual net benefits per resident and per tree were $10 and $32, respectively. The benefit-cost ratio was 1:1.61, meaning that for each $1 in net expenditures for urban forest management, benefits valued at $1.61 were returned to the residents of Santa Monica.

Table 23. Benefit-Cost summary.

Benefits		$	Expenditures	$
Environmental				
	Energy	147,626	Program Costs	
	CO2	66,473	Tree Establishment	22,900
	Air Quality	268,908	Mature Tree Care	986,644
	Stormwater	110,784	Administration	102,404
Environmental subtotal		593,791	Program subtotal	1,111,948
Property/Other		1,894,758	External Costs	432,052
			Revenue	0
Total Benefits		2,488,550	Total Costs	1,544,000
Net Benefits (Total Benefits - Costs) =			$944,550	
Benefit-Cost Ratio (Benefits / Costs) =			1.61	

We have greater certainty in our estimates of expenditures than benefits. Our uncertainty was greatest in estimating the amount of air pollutant uptake by trees, the value of stormwater runoff reductions, and property value/other benefits. Although our estimates of air pollutant uptake were in good agreement with results from urban forestry studies for Chicago, Sacramento, and Modesto, it should be noted that our ability to accurately estimate the extent to which shade trees produce air quality benefits was impaired by uncertainties regarding rates of pollutant deposition. We used canopy resistance values for rural forests because data are lacking for urban trees. We expect urban trees might have lower canopy resistance values than trees in rural forests due to lower levels of water stress and higher gas exchange rates. If this is the case, pollutant uptake rates will be greater than we estimated here. Although we have used the best information currently available, application of new research results or different modeling techniques could alter these findings. Net benefits will be sensitive to assumptions regarding pollutant uptake rates because air pollution improvement benefits represent 11% of total benefits.

Most of the stormwater benefit is associated with water quality benefits and we valued this benefit using sanitary treatment costs. Because most stormwater does not receive sanitary treatment in Santa Monica it could be argued that this is an inaccurate estimate and no benefits were realized. If this is the case, total benefits were reduced $3.38 million, net benefits dropped to $833,766, and the BCR was 1.54.

We also have a poor understanding of the effects of climate modification on energy savings compared to shading effects. A more liberal interpretation of the relevant literature would lead to a doubling of air temperature reductions, which are conservatively based on reductions of 0.1°C (0.2 °F), for each percentage increase in canopy cover. Such an interpretation would increase electricity savings from $148,000 to about to $300,000. This, plus increased savings from ancillary affects on avoided CO_2 and other pollutant emissions from power plants would increase the BCR from 1:1.61 to 1:1.64.

Estimating the property value/other benefits associated with public trees is open to debate because little research has examined this question and data for California was nonexistent. Given that the total property value and other benefits from park trees was only $151,000 of the $1.9 million, reducing or increasing the park tree reduction factor from 0.5 would not substantially alter results of this analysis. However, further research is needed to better understand relations between trees and these benefits in California communities.

We have elected to include benefits associated with trees removed over the course of the year because we have included expenditures for their removal and replacement. If all 128 trees were removed at the beginning of the year, total leaf surface area would be reduced by around 0.4%. Assuming a corresponding reduction in benefits, then total benefits dropped by about $11,000 and the BCR was 1:1.53. Our assumption regarding tree mortality does not have a marked influence on the outcome of this analysis.

Chapter V. Conclusions

"We forget that we owe our existence to the presence of trees and as far as forest cover goes, we have never been in such a vulnerable position as we are today. The only answer is to plant more trees, to plant for our lives."
--- Dr. Richard St. Barbe Baker, *Man of the Trees*

Santa Monica's municipal 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 40 years ago and at the same time constantly changing as new trees are planted and others mature. Although this study provides a "snapshot" in time of Santa Monica's urban forest, it also serves as an opportunity to speculate about the future. Given the current status of Santa Monica's street and park tree population, what future trends are likely and what management challenges will need to be met?

Santa Monica's existing urban forest is extensive. Private and public trees create a canopy over about 15% of the City. In Fiscal Year 1999-2000 (FY 1999) there were approximately 29,229 street and park trees, or one tree for every three residents. This ratio was substantially greater than the statewide average. The street tree stocking level was 96%, indicating that there were few vacant planting sites along Santa Monica streets. We estimated that street and park tree canopy covered 6% of the City and shaded 25% of all street surfaces. The asset value of Santa Monica's existing municipal forest was estimated to be $75.5 million ($2,582/tree, $815/resident). Replacing Santa Monica's trees would cost approximately this amount should a catastrophe occur.

Although over 215 different species of trees have been planted along streets and in parks, Laurel fig planted 30-60 years ago was the dominant tree. It accounted for 12% of all public trees, but was responsible for 26% of the total asset value and 11% of all annual benefits. Deodar cedar and Canary Island pine were other important tree species, accounting for 4% and 3% of all trees, but producing 14% and 8% of all benefits, respectively. The Santa Monica tree population had a relatively even age structure, indicating fewer than "ideal" young, replacement trees and more than "ideal" old, overmature trees. Given this age structure it was not surprising that expenditures for mature tree care comprised 89% of Community Forest Operation's program expenditures. Substantial funds were spent addressing other mature tree-related issues such as sidewalk repair and leaf clean-up. When considering total expenditures, Santa Monica spent $1.5 million annually for urban forestry ($17/resident, $53/tree). Survey results suggest that annual expenditures by Community Forest Operations were about twice the statewide average. Keeping old trees healthy, perpetuating the forest through planting, and providing a safe, healthful, and attractive environment for the public comes with a price.

We estimated that total annual benefits from Santa Monica's urban forest were $2.5 million ($27/resident, $85/tree). Net benefits (total benefits less costs) for FY 1999 were $944,550 million ($10/resident, $32/tree). For each $1 invested in urban forest management, benefits valued at $1.61 were returned to the residents of Santa Monica.

In FY 1999 Santa Monica's municipal trees provided substantial benefits. As trees grew they increased the value of nearby properties, enhanced scenic beauty, and produced other benefits with an estimated annual value of $1.9 million ($65/tree). The net annual air pollutant benefit was 10.7 metric tonnes (0.8 lb/tree) with an implied value of $269,000 ($9/tree). This finding indicated that the City's trees were providing important health benefits to residents. Building shade and cooler summertime temperatures attributed to street and park trees saved 9,700 MBtu, valued at $148,000 (5 MBtu/tree, $5/tree). Smaller benefits resulted from reductions in stormwater runoff (205,000 m^3 or 1,856 gal/tree, $111,000 or $4/tree) and atmospheric carbon dioxide (2,000 metric tonnes or 151 lb/tree, $66,000 or $2/tree).

The City's investment in urban forestry provided significant benefits to property owners in terms of increased sales prices. Increased property values benefited the City through increased property tax revenues. Public trees produced tangible air quality, flood control, energy conservation, and CO_2 reduction benefits. Those who benefit from these “environmental services” are potential new partners in urban forest management. The local air quality and stormwater management districts, electric utility, and industries interested in offsetting carbon dioxide emissions could view Santa Monica’s urban forest as an asset to their programs. As air pollution trading markets develop there is potential for the City to claim credits for these benefits. Urban forestry credits could be applied against municipal emissions or sold to local emitters. Money obtained from the sale of credits could help finance the tree program. Pollution trading markets exist for several criteria pollutants (PM_{10}, NO_2, VOCs), and have been proposed for CO_2.

At the outset of this report we stated our primary question: *Do the accrued benefits from Santa Monica’s urban forest justify an annual municipal budget of $1.5 million?* Our results indicate that the benefits residents obtained from Santa Monica’s urban forest did exceed management costs by a factor of 1.61. Over the years Santa Monica has invested millions in its municipal forest. Citizens are now receiving a relatively large return on that investment. Continued investment in management is critical to insuring that residents continue to receive a healthy return on investment. Furthermore, because of the existing forest’s even-aged structure and reliance on benefits from older trees such as the laurel fig, Deodar cedar, and Canary Island pine, spending less on management at this time could jeopardize the future stream of net benefits.

Appearances can be deceiving. Although Santa Monica’s municipal forest is well maintained and appears to be as permanent as the City’s streets and homes, it is a rather fragile resource. Without the intensive maintenance that is needed to keep many older trees healthy and safe, these trees would produce fewer benefits and create greater costs. Already predisposed to health problems because of their age, future stress from disease, pests, drought, and repeated root pruning could decimate many old trees. Combating health problems, removing dead trees, and replanting could require an enormous expenditure by the City. Moreover, large-scale tree canopy cover reduction translates into substantial loss of benefits. This scenario has played out in other U.S. communities that lost large numbers of American elms (*Ulmus americana*) to disease within a few years. Although Deodar cedar and laurel fig are not as dominant in Santa Monica as American elm was in many Midwestern communities, the peril is evident. From our perspective, it seems prudent to continue investing in intensive management that will create a more stable forest over the next 20 years, rather than risking a catastrophic loss in tree cover and large emergency expenditures to obtain short-term budget savings.

Looking toward the future, it may not be possible to maintain the high level of net benefits produced today by Santa Monica’s municipal forest while at the same time increasing its stability. Creating a more stable forest may be a more appropriate goal than maximizing net benefits if it reduces the risk of catastrophic loss and lowers management costs on a per tree basis. Achieving a more stable forest will challenge management because of the forest’s current structure. At least three factors are significant:

• Deodar cedar and laurel fig were responsible for 25% of all tree benefits, but many of these trees will be more costly to maintain in the future. Deodar cedar that are stressed due to root pruning, over-watering, and trunk damage from string-trimmers grow increasingly susceptible with age to the deadly disease phytophthora. Aging laurel fig along streets are responsible for sidewalk damage that becomes increasingly expensive to repair as the trees grow larger. Keeping the best trees healthy and repairing their damage to sidewalks, while at the same time removing and replacing trees that are least valuable will require increased funding in the short-term. Gradual replacement of these large trees during the next 10 years will result in a short-term reduction of canopy cover and associated benefits. However, this loss is offset by the promise of increased net benefits in the long-term associated with more stable canopy cover.

• Many of the mature street trees planted 20-40 years ago that will be moving into the old tree class and replacing benefits lost by removal of Deodar cedar, laurel fig and other large, old trees will become more expensive to maintain due to conflicts between roots and sidewalks, curbs, and sewer lines. The predominant species in this age class (beefwood, Southern magnolia, eucalyptus, in addition to laurel fig, fan palm, Deodar cedar, and Canary Island pine) appear to have relatively shallow rooting patterns. Trees located in front lawns will fare better than those in narrow planting strips.

• Forest benefits that our children's children will realize depend on the survival and growth of young trees planted within the last 20 years. About one-third of these are small-statured trees. Smaller trees can be less expensive to maintain than larger trees, but also produce fewer benefits. The implication here is that the future forest will consist of relatively fewer large-statured trees. The key to maximizing net benefits lies in selecting trees that are well-matched to site conditions and insuring that they become vigorous growing, established trees. Community Forest Operations is taking advantage of the opportunity it has to create a more stable urban forest by planting trees better-suited to their sites. For example, Deodar cedar are being replaced with Atlas cedar (*Cedrus atlantica*), which is more disease resistant and compact. Filling vacant planting sites is an opportunity to create a more balanced and stable forest by increasing the number of young trees that are suitable to local growing conditions.

Several recommendations to maximize future benefits while controlling management costs follow:

• Front yard planting sites provide more space for tree roots to expand without conflict than narrow strips between curbs and sidewalks. Plant larger-statured trees in front yards where feasible. Where planting strips are narrow, consider moving sidewalks next to the curb or further from the sidewalk after trees are replaced to provide more space for roots.

• Continue experimenting with strategies to reduce root-hardscape conflicts and reduce repair costs. Meandering sidewalks around trees, resurfacing with rubberized "flexible" paving, and other means of preserving healthy trees and their roots is necessary. In new design, structural soils should be evaluated as a long-term solution. Because of predominantly sandy soils, irrigation patterns influence rooting patterns, especially during establishment. Planting details and follow-up care that promote delivery of water deep into the soil may be an effective measure to reduce shallow roots and hardscape damage in cut-outs and other space-restricted sites.

• Discontinue extensive pruning of all trees to increase their growth, leaf area, and associated benefits. In general, trees in Santa Monica are smaller and have less leaf area than similar aged trees in other cities we studied. Heavy pruning of young trees reduces their vigor and growth. Lifting of older trees to 5 m or higher reduces crown size. Although extensive trimming may be necessary in certain situations (e.g., light penetration through laurel figs or traffic sign visibility) it should not be standard practice. For example, lifting of street trees in residential areas should respond to the progressive growth of the crown over the sidewalk and street. Reducing pruning frequency and intensity will promote healthier trees that provide greater benefits at less cost to the City.

• Diversify species composition by identifying 5-10% of new plantings as "experimental." Plant and monitor species that have proven successful in nearby cities but have not been fully evaluated in Santa Monica (e.g., ginkgo). Consider planting new introductions that merit evaluation because of deep rooting patterns, compact form, pest/disease resistance, or other attributes.

Santa Monica's urban forest is in an era of transition. Planning and managing the transition from a relatively fragile and unstable forest to one that is more diverse and stable will require careful thinking and new analysis tools. We look forward to continuing our association with the City of Santa Monica to both advance urban forest science and provide information that will assist decision-making.

VI. Acknowledgments and References

"Isolation is a blind alley...Nothing on the planet grows except by convergence."
--- Pierre Teilhard de Chardin, Priest and author

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VII. Appendix

"They took all the trees
And put them in a tree museum...
And they charged all the people
A dollar and a half just to see 'em...
Don't it always seem to go
That you don't know what you've got...
Till it's gone
They've paved paradise
And put up a parking lot."
--- Joni Mitchell

Table A-1. Tree numbers in FY 1999-2000 by size class for all street and park trees.

	DBH (cm)	0 - 15.2	15.2 - 30.5	30.5 - 45.7	45.7 - 61.0	61.0 - 76.2	> 76.2		
Species	DBH (in)	(0 - 6)	(6 - 12)	(12 - 18)	(18 - 24)	(24 - 30)	(> 30)	Total	%Total
Platanus acerifolia+		31	41	17	7	2	3	101	0.35
Other (15 sp.)		14	5	7	5	3	4	38	0.13
Liquidambar styraciflua		153	341	210	74	3	0	781	2.67
Other (7 sp.)		52	25	5	0	0	0	82	0.28
Jacaranda mimosifolia		126	359	170	16	0	0	671	2.30
Other (20 sp.)		125	50	9	3	0	0	187	0.64
Eucalyptus ficifolia+		35	126	207	129	113	194	804	2.75
Other (16 sp.)		45	87	82	92	106	197	609	2.08
Podocarpus gracilior		132	211	189	40	1	0	573	1.96
Grevillea robusta		0	0	15	69	64	12	160	0.55
Ficus microcarpa 'Nitida'+		27	238	958	1,779	445	13	3,460	11.84
Magnolia grandiflora		297	664	722	176	28	5	1,892	6.47
Ceratonia siliqua		53	195	271	237	120	47	923	3.16
Metrosideros excelsus		206	305	178	45	0	1	735	2.51
Melaleuca quinquenervia		181	319	160	44	4	0	708	2.42
Cinnamomum camphora		140	234	129	94	50	32	679	2.32
Brachychiton populneus		20	128	183	149	73	9	562	1.92
Pittosporum undulatum		64	187	136	63	23	3	476	1.63
Other (15 sp.)		97	43	27	10	3	2	182	0.62
Podocarpus macrophyllus		429	920	46	0	0	0	1,395	4.77
Other (46 sp.)		568	356	34	7	1	2	968	3.31
Cupaniopsis anacardioides		310	395	175	13	0	0	893	3.06
Callistemon citrinus		199	542	18	1	0	0	760	2.60
Tristania conferta+		220	302	41	0	0	1	564	1.93
Schinus terebinthifolius		23	118	193	133	19	5	491	1.68
Nerium oleander		175	255	12	1	0	0	443	1.52
Prunus caroliniana		22	133	73	6	0	1	235	0.80
Cedrus deodara		185	170	183	193	204	149	1,084	3.71
Pinus canariensis		39	75	115	185	266	225	905	3.10
Casuarina cunninghamiana		5	173	386	107	36	14	721	2.47
Pinus halepensis+		73	104	74	23	21	51	346	1.18
Other (11 sp.)		40	30	16	3	9	4	102	0.35
Other (7 sp.)		23	51	13	3	1	0	91	0.31
Palm		57	49	25	43	527	914	1,615	5.53
Palm		205	536	3,069	1,041	67	75	4,993	17.08
Total		4,371	7,767	8,148	4,791	2,189	1,963	29,229	
% Total		14.95	26.57	27.88	16.39	7.49	6.72		