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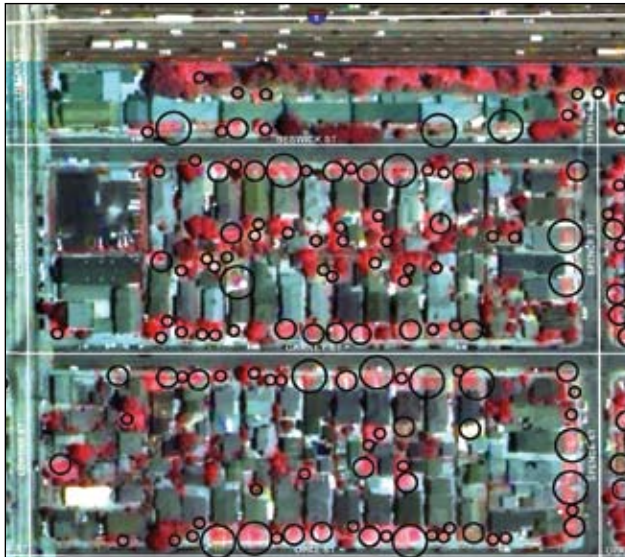
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# Los Angeles 1-Million Tree Canopy Cover Assessment

E. Gregory McPherson, James R. Simpson, Qingfu Xiao,  
Chunxia Wu



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## **Abstract**

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The Million Trees LA initiative intends to chart a course for sustainable growth through planting and stewardship of trees. The purpose of this study was to measure Los Angeles's existing tree canopy cover (TCC), determine if space exists for 1 million additional trees, and estimate future benefits from the planting. High-resolution QuickBird remote sensing data, aerial photographs, and geographic information systems were used to classify land cover types, measure TCC, and identify potential tree planting sites. Benefits were forecast for planting of 1 million trees between 2006 and 2010, and their growth and mortality were projected until 2040. Two scenarios reflected low (17 percent) and high (56 percent) mortality rates. Numerical models were used with geographic data and tree size information for coastal and inland climate zones to calculate annual benefits and their monetary value. Los Angeles's existing TCC was 21 percent, and ranged from 7 to 37 percent by council district. There is potential to add 2.5 million additional trees to the existing population of approximately 10.8 million, but only 1.3 million of the potential tree sites are deemed realistic to plant. Thus, there is space for planting 1 million new trees. Benefits for the 1-million-tree planting for the 35-year period were \$1.33 billion and \$1.95 billion for the high- and low-mortality scenarios, respectively. Average annual benefits were \$38 and \$56 per tree planted. Eighty-one percent of total benefits were aesthetic/other, 8 percent were stormwater runoff reduction, 6 percent energy savings, 4 percent air quality improvement, and less than 1 percent atmospheric carbon reduction. Recommendations included developing a decision-support tool for tree selection and tracking, as well as establishing a model parking lot greening program.

Keywords: Ecosystem services, urban forestry, Los Angeles, tree canopy cover, tree benefits.

## Executive Summary

Mayor Antonio Villaraigosa of the city of Los Angeles, California, has charted a course for sustainable growth, and the region's community forest is a critical component of that vision. On September 30, 2006, the mayor kicked off his plan to plant 1 million trees over the next several years. The Million Trees LA initiative demonstrates the relevance of community forestry to the environmental, social, and economic health of Los Angeles.

To assist the city of Los Angeles, the USDA Forest Service Center for Urban Forest Research has conducted the study presented here to (1) measure existing tree canopy cover (TCC), (2) characterize potential TCC to determine the feasibility of planting 1 million trees, and (3) estimate future benefits from planting 1 million new trees. The study area is the city of Los Angeles (473 mi<sup>2</sup>, population 3.7 million), excluding mountainous areas. Results are reported citywide and for the 15 council districts and 86 neighborhood councils.

High-resolution QuickBird remote sensing data, aerial photographs, geographic information systems (GIS), and image-processing software were used to classify land cover types, measure TCC, and identify potential tree planting sites. The accuracy assessment found that overall land cover classification accuracy was 88.6 percent based on a pixel-by-pixel comparison. The accuracy for classifying existing TCC was 74.3 percent.

One unique aspect of this study was "training" the computer to follow rules for locating potential planting sites, then drawing a circle for each small (15-ft crown diameter), medium (30 ft), and large (50 ft) tree site. Ground-truthing of 55 parcels led to calibration of the computer-generated estimates. Realistic TCC targets were determined for each council district with the goal of filling 50 percent of the available planting sites. This TCC target recognizes that each council district is unique because it has a different land use mix, as well as different existing and potential TCC that reflects historical patterns of development and tree stewardship. Each council district can do its "fair share" in helping the city meet its overall goal by filling 50 percent of its available tree planting sites. In so doing, council districts with the greatest number of empty planting sites will achieve the greatest relative increase in TCC, whereas those with higher stocking levels will obtain less enhancement.

Los Angeles's existing TCC is 21 percent, which compares favorably with 20 percent in Baltimore and 23 percent in New York City. This finding is surprising given Los Angeles's Mediterranean climate, which makes irrigation essential for establishment and growth of many tree species. Other plantable space, such as irrigated grass and dry grass/bare soil, accounts for 12 and 6 percent of the

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city, respectively. Impervious (e.g., paving, roofs) and other surfaces (i.e., water) comprise the remaining 61 percent of the city's land cover (excluding mountainous areas). Hence, one-third of Los Angeles's land cover is either existing TCC or grass/bare soil with potential to become TCC. The number of existing trees is estimated to be 10.8 million assuming an average tree crown diameter of 16.4 ft.

At the council district level, TCC ranged from lows of 7 to 9 percent in council districts 9 and 15 to a high of 37 percent in council district 5. Tree canopy cover was strongly related to land use. As expected, low-density residential land uses had the highest TCC citywide (31 percent), whereas industrial and commercial land uses had the lowest TCC (3 to 6 percent).

Existing TCC exceeded 40 percent in three neighborhood councils: Bel Air-Beverly Crest (53 percent), Arroyo Seco (46 percent), and Studio City (42 percent). Neighborhood councils with the lowest TCC were Downtown Los Angeles (3 percent), Wilmington (5 percent), and Historic Cultural and Macarthur (6 percent).

There is potential to add 2.5 million additional trees or 12.4 percent TCC. Thus, "technical" potential for Los Angeles is 33.2 percent TCC, or about 13.3 million trees. However, it is not realistic to think that every possible tree site will be planted. Assuming a realistic target of filling about 50 percent of the unplanted sites results in adding 1.3 million more trees equivalent to a 6.7-percent increase in TCC. Hence, "market" potential is 27.5 percent TCC, or 12.1 million trees. Planting 1 million trees is feasible and if accomplished as indicated above, would saturate 97 percent of the existing market potential.

Benefits are forecast for a scenario that gradually increases the rate of the planting of 1 million trees between 2006 and 2010 and tracks their growth and mortality until 2040. Tree growth over the 35-year period is based on intensive measurements of predominant street tree species in Santa Monica for coastal Los Angeles, and in Claremont, for inland Los Angeles. Representative small, medium, and large species were selected for each zone to model growth, with nearly one-half of the trees small, 42 percent medium, and 9 percent large at maturity. Low- and high-mortality scenarios reflect effects of loss rates on tree numbers and associated benefits. After 35 years, the number of surviving trees is 828,924 and 444,889 for the two scenarios, respectively. In both scenarios, planted trees are distributed among land uses such that 55 percent are in low-density residential, 17 percent in institutional, 14 percent in medium/high-density residential, 9 percent in commercial, and 5 percent in industrial use.

Numerical models were used with geographic data and tree size information for the coastal and inland climate zones to calculate annual benefits and their monetary value. Benefits calculated on an annual basis and summed for the 35-year

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**Benefits calculated on an annual basis and summed for the 35-year period are \$1.33 billion and \$1.95 billion for the high- and low-mortality scenarios, respectively.**

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**By improving air quality, the tree planting will enhance human health and environmental quality in Los Angeles. This benefit is valued at \$53 to \$83 million over the 35-year planning horizon. Interception of small particulate matter (PM<sub>10</sub>) and uptake of ozone (O<sub>3</sub>) and nitrogen dioxide (NO<sub>2</sub>) are especially valuable.**

period are \$1.33 billion and \$1.95 billion for the high- and low-mortality scenarios, respectively. These values translate into \$1,328 and \$1,951 per tree planted, or \$38 and \$56 per tree per year when divided by the 35-year period. For the low-mortality scenario, 81 percent of total benefits are aesthetic/other, 8 percent are stormwater runoff reduction, 6 percent energy savings, 4 percent air quality improvement, and less than 1 percent atmospheric carbon reduction.

The distribution of benefits among council districts is closely related to the climate zone and the number of trees planted. Benefits per tree are about 50 percent less (\$700 to \$1,000 instead of \$1,300 to \$2,400) in the coastal zone (council districts 11 and 15) than the inland zone because the growth curve data indicate that the trees are smaller, air pollutant concentrations are lower, and building heating and cooling loads are less owing to the milder climate.

**Aesthetic and other benefits.** Citywide, aesthetic and other benefits ranged from \$1.1 to \$1.6 billion, or \$1,100 to \$1,600 per tree over the 35-year period for the high- and low-mortality scenarios. This amount reflects the economic contribution of trees to property sales prices and retail sales, as well as other benefits such as beautification, privacy, wildlife habitat, sense of place, and psychological and spiritual well-being.

**Stormwater runoff reduction.** By intercepting rainfall in their crowns, trees reduce stormwater runoff and protect water quality. The average annual interception rate per tree ranges from a low of 102 gal to a high of 1,481 gal based on tree size, rainfall amounts, and foliage period. Over the 35-year span of the project, 1 million trees will reduce runoff by approximately 13.5 to 21.3 billion gallons (1,810 to 2,840 million cubic ft). The value of this benefit ranges from \$97.4 to \$153.1 million for the high- and low-mortality scenarios, respectively.

**Energy use reduction.** By shading residential buildings and lowering summertime air temperatures, the 1 million trees are projected to reduce electricity consumed for air conditioning by 718,671 to 1.1 million MWh or \$76 to \$119 million for the high- and low-mortality scenarios. However, this cooling savings is partially offset by increased heating costs from tree shade that obstructs winter sunlight. Tree shade is expected to increase natural gas required for heating by 101,000 to 154,000 MBtu, which is valued at \$674,000 to \$1 million. Despite this cost, a net energy savings of \$75.7 to \$117.4 million is projected for the high- and low-mortality scenarios.

**Atmospheric carbon dioxide reduction.** Over the 35-year planning horizon, the 1 million trees are projected to reduce atmospheric carbon dioxide (CO<sub>2</sub>) by 764,000 to 1.27 million tons, for the high- and low-mortality scenarios. Assuming this benefit is priced at \$6.68 per ton, the corresponding value is \$5.1 to \$8.5

million. Emission reductions at power plants associated with effects of the trees on building energy use (498,000 to 772,000 tons) are greater than biological sequestration of CO<sub>2</sub> by the trees themselves (389,000 to 598,000 tons). A relatively small amount of CO<sub>2</sub> is released during tree care and decomposition of dead biomass (101,000 to 123,000 tons). The CO<sub>2</sub> reduction benefit varies widely based on tree size. For example, in the inland zone for the low-mortality scenario, the small tree annually sequesters and reduces emissions by only 5 and 55 lb per tree on average, compared to 220 and 150 lb for the large tree.

**Air quality improvement.** By improving air quality, the tree planting will enhance human health and environmental quality in Los Angeles. This benefit is valued at \$53 to \$83 million over the 35-year planning horizon. Interception of small particulate matter (PM<sub>10</sub>) and uptake of ozone (O<sub>3</sub>) and nitrogen dioxide (NO<sub>2</sub>) are especially valuable. The 1-million-tree planting project is estimated to intercept and reduce power plant emissions of particulate matter by 1,846 to 2,886 tons over the 35-year period for the high- and low-mortality scenarios, respectively. The value of this benefit ranges from \$19 to \$29 million, or 35 percent of total air quality benefits.

The 1 million trees are projected to reduce O<sub>3</sub> by 2,430 to 3,813 tons, with average annual deposition rates ranging from 0.25 to 0.35 lb per medium tree in the low-mortality scenario for the coastal and inland zones, respectively. Ozone uptake is valued at \$17.9 to \$28.1 million over the project life for the high- and low-mortality scenarios, or 34 percent of total air quality benefits.

Uptake of NO<sub>2</sub>, an O<sub>3</sub> precursor, is estimated to range from 1,949 to 3,039 tons, with a value of \$14.6 to \$22.8 million for the high- and low-mortality scenarios over the 35-year period. This benefit accounts for 27 percent of the total air quality benefit. The small remaining benefit is reduced power plant emissions of volatile organic compounds from cooling energy savings.

We found that the benefit values reported here are reasonable when compared with previously reported findings from similar analyses for the same region. However, it is important to note limitations of this study and to identify sources of error. These limitations are discussed fully in the “Discussion” section of this report.

We conclude this study with a discussion of ways to successfully disseminate data, to implement the 1-million-trees program, and future research needs.

The Center for Urban Forest Research proposes a collaboration with other scientists in southern California to study the effects of trees on the social, economic, and environmental health of Los Angeles and its nearly 4 million residents. In particular, we need to better understand:

- Barriers to tree planting and incentives for different markets

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**As the second largest city in the United States, Los Angeles manages an extensive municipal forest. Its management should set the standard for the region and the country.**

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**Los Angeles is a vibrant city that will continue to grow. As it grows, it should also continue to invest in its tree canopy.**

- Effects of trees on the urban heat island and air quality
- Effects of drought stress on tree survival and ability to remove air pollutants
- Primary causes of tree mortality
- Best management practices to promote tree survival
- Citywide policy scenarios to promote urban tree canopy, neighborhood desirability, and economic development
- How to link TCC goals to other city goals: increasing community health, neighborhood quality of life, environmental literacy, and sustainability

As the second largest city in the United States, Los Angeles manages an extensive municipal forest. Its management should set the standard for the region and the country. Working cooperatively, the Center for Urban Forest Research and the city of Los Angeles could conduct a tree inventory and assessment that will establish a sound basis for future management aimed at increasing resource sustainability.

Los Angeles is a vibrant city that will continue to grow. As it grows, it should also continue to invest in its tree canopy. This is no easy task, given financial constraints and trends toward higher density development that may put space for trees at a premium. The challenge ahead is to better integrate the green infrastructure with the gray infrastructure by increasing tree planting, providing adequate space for trees, and designing plantings to maximize net benefits over the long term, thereby perpetuating a resource that is both functional and sustainable. The Center for Urban Forest Research looks forward to working with the city of Los Angeles and its many professionals to meet that challenge in the years ahead.

## Contents

|    |                                                            |
|----|------------------------------------------------------------|
| 1  | <b>Introduction</b>                                        |
| 1  | Million Trees LA Initiative                                |
| 2  | Tree Canopy Cover Assessments                              |
| 5  | <b>Objectives</b>                                          |
| 5  | <b>Methodology</b>                                         |
| 5  | Study Site                                                 |
| 6  | Data Sets                                                  |
| 7  | Measuring Existing Tree Canopy Cover                       |
| 9  | Characterizing Potential and Target Tree Canopy Cover      |
| 11 | Parking Lot Sampling                                       |
| 14 | Tree Canopy Cover Target                                   |
| 15 | The 1-Million-Tree Planting Scenario                       |
| 15 | Tree Data                                                  |
| 16 | Benefits                                                   |
| 20 | <b>Results</b>                                             |
| 20 | Existing Tree Canopy Cover                                 |
| 24 | Potential Tree Planting Sites and Target Tree Canopy Cover |
| 28 | Benefits From 1 Million Trees                              |
| 32 | Citywide Benefits by Benefits Type                         |
| 37 | <b>Discussion</b>                                          |
| 37 | Comparison of Results                                      |
| 39 | Uncertainty and Limitations                                |
| 43 | <b>Common and Scientific Names</b>                         |
| 44 | <b>Acknowledgments</b>                                     |
| 44 | <b>Metric Equivalents</b>                                  |
| 45 | <b>References</b>                                          |
| 50 | <b>Appendix</b>                                            |



## Introduction

Urbanization creates significant changes in land use and land cover, affecting the structure, pattern, and function of ecosystems. The public is increasingly concerned about how these changes influence daily life and affect the sustainability of “quality of life” for future generations. Improving air quality, alleviating water shortages, cooling urban heat islands, and reducing stormwater runoff are challenges facing Los Angeles. For example, between 627,800 and 1.48 million gastrointestinal illnesses are caused annually by swimming in contaminated beaches in southern California (Given et al. 2006). This public health impact corresponds to an economic loss of \$21 to \$51 million related to health care costs. Also, long-term effects of exposure to high air pollution levels in southern California have been associated with decreased respiratory health (Gauderman et al. 2004). Exposure to freeway-related pollutants has been found to impair children’s lungs and is associated with increased asthma (Gauderman et al. 2005). Rapid growth in Los Angeles, with a population of nearly 4 million, is accelerating these problems. The problems need solutions as the region tries to protect and restore environmental quality while enhancing economic opportunity.

Tree canopy is a valuable component of Los Angeles’s urban ecosystem (McBride and Jacobs 1986). Trees in urban settings are important to improving urban life, as well as human physical and emotional well-being. Research suggests that human beings have an innate affiliation to natural settings, a concept described as biophilia (Kellert and Wilson 1993). Numerous studies link access to living trees, outdoor air, and natural light to increased employee and student productivity, faster hospital recoveries, less crime, and an overall reduction in stress and anxiety. Thus, expanding the urban forest is part of the solution to Los Angeles’s social, environmental, and economic problems—it is integral to enhancing public health programs, increasing land values and local tax bases, providing job training and employment opportunities, reducing costs of city services, increasing public safety, improving air quality, offsetting carbon emissions, managing stormwater runoff, mitigating water shortages, and conserving energy.

## Million Trees LA Initiative

Mayor Antonio Villaraigosa of the city of Los Angeles, California, has charted a course for sustainable growth, and the region’s community forest is a critical component of that vision. On September 30, 2006, the mayor kicked off his plan to plant 1 million trees in the next several years. The Million Trees LA initiative demonstrates the relevance of community forestry to the environmental, social, and economic health of Los Angeles.

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**Long-term effects of exposure to high air pollution levels in southern California have been associated with decreased respiratory health.**

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**Expanding the urban forest is part of the solution to Los Angeles’s social, environmental, and economic problems.**

## Tree Canopy Cover Assessments

Tree canopy cover (TCC) is the percentage of a site covered by the canopies of trees. Many communities are adopting TCC goals to maintain and improve forest cover. Advances in remote sensing technology and geographic information systems (GIS) make it practical to measure TCC on a periodic basis (Price et al. 2002, Xiao and McPherson 2005, Xiao et al. 2004). Vegetation has unique spectral reflectance characteristics with strong absorption in red wavelengths and strong reflectance in near-infrared wavelengths that allow distinction of trees from other ground surface covers.

Tree canopy cover has become a popular metric for several reasons. It is relatively easy to measure with remote sensing technology and less costly than field sampling. It is comparable across a city and among cities. The size of the area measured does not matter. The TCC is a good performance measure because it can be applied to detect change across space and time. Finally, TCC is an easy-to-understand concept that is useful in communicating to the public (Poracsky and Lackner 2004).

It is important to recognize the limitations associated with using TCC as a metric. The TCC is two dimensional, only indicating the spread of canopy across land surfaces. It does not provide information on the vertical extent of tree canopy, species composition, age diversity, or health. To describe the structure, function, and value of urban forests fully, data obtained from field sampling are required as well. For example, many functional benefits have been linked to the leaf surface area of trees, which is difficult to estimate with accuracy using only TCC. Moreover, predicting future trends in urban forest structure, function, and management needs requires a richer data set than TCC alone provides.

Accurately classifying TCC is difficult owing to the complex spatial assemblages of disparate patches of land cover types in urban settings. Urban areas are a mosaic of many different land covers, land uses, and built structures, each of which has different spectral reflectance characteristics (Gong and Howarth 1990). Unlike trees in rural forests that tend to form continuous canopies, trees in urban settings are often isolated or in small groups. The influence of background, such as soil and shadow, makes the problem of characterizing trees by remote sensing even more difficult. In such cases, high-resolution remotely sensed data are important for accurate TCC mapping (Xiao et al. 2004).

Many studies have used remote sensing data and GIS to map TCC. American Forests has used satellite imagery and CITYgreen GIS software to map historical TCC change, as well as the value of annual benefits from urban forests for cities such as Atlanta, Georgia, Washington, D.C., and Roanoke, North Carolina

(American Forests 2002a, 2002b, 2002c). Irani and Galvin (2003) used IKONOS data (13-ft spatial resolution) to map TCC in Baltimore, Maryland. Goetz and others (2003) found the accuracy of tree cover estimates mapped with IKONOS imagery in the mid-Atlantic region to be comparable to manual aerial photointerpretation. Poracsky and Lackner (2004) compared Portland's tree canopy in 1972, 1991, and 2002 by using TM and multispectral scanner data (100-ft plus resolution). High-resolution infrared photography and light detection and ranging (LIDAR) data were used to map TCC in Vancouver, Washington (Kaler and Ray 2005). Urban cover was mapped with 82 percent accuracy for Syracuse, New York, using high-resolution digital color-infrared imagery (Myeong et al. 2001), and similar data were used to assess New York City's TCC (Grove et al. 2006). Xiao et al. (2004) used AVIRIS (airborne visible infrared imaging spectrometer) data to map urban tree species in Modesto, California, but developing spectral signatures for each species was time consuming.

Potential TCC (PTCC) is the percentage of area on the ground without TCC that could be covered by additional tree canopy. Traditionally, PTCC is the amount of residual pervious surface, including all grass and bare soil. It does not include tree cover that could be achieved by adding trees to impervious surfaces like paved parking lots and plazas.

We differentiate between two other terms related to TCC, technical potential and market potential (McPherson 1993). Technical potential is the total amount of planting space—existing TCC plus pervious surfaces that could have trees (TCC + PTCC)—whereas market potential is the amount of TCC plus the amount of PTCC that is plantable given physical or preferential barriers that preclude planting. Physical barriers include conflicts between trees and other higher priority existing or future uses, such as sports fields, vegetable gardens, and development. Another type of market barrier is personal preference to keep certain locations free of TCC. Whereas technical potential is easily measured, market potential is a complex sociocultural phenomenon that has not been well studied. The only study we are aware of is a survey of nonparticipants of the Sacramento Shade program (Sarkovich 2006). The two most common reasons customers chose not to accept a free shade tree were lack of space (34 percent), a physical constraint, and “Do Not Want Any More Trees” (25 percent), a personal preference. This finding applies primarily to low-density residential land uses and suggests that a substantial amount of PTCC is likely to remain tree-free because of market forces.

Communities set TCC targets as measurable goals that inform policies, ordinances, and specifications for land development, tree planting, and preservation. Targets should respond to the regional climate and local land use patterns. Climate

is important because cities in regions where the amount of rainfall favors tree growth tend to have the most TCC. For example, mean TCC was higher in cities in naturally forested areas (31 percent) than in grasslands (19 percent) and deserts (10 percent) (Nowak et al. 1996). Within a city, land use is the dominant factor influencing TCC because it affects the amount of space available for vegetation. Residential land uses tend to have the greatest TCC, and commercial/industrial land uses have the least (Sanders 1984).

American Forests has developed the most widely adopted TCC targets. Their TCC targets reflect constraints posed by regional climate and land use patterns. Based on studies throughout the United States, American Forests developed generic TCC targets for temperate and arid climate cities (Kollin 2006). For arid cities such as Los Angeles, they recommend an average citywide TCC of 25 percent, with values of 35 percent for suburban zones, 18 percent for urban residential zones, and 9 percent for commercial land uses. Suggested TCC targets are substantially higher for temperate cities. Communities such as Roanoke, Virginia (Urban Forestry Task Force 2003), and Montgomery County, Maryland (Montgomery County 2000), have adopted American Forests' TCC targets.

In New York City, where existing TCC was 23 percent and another 43 percent of PTCC was identified, the TCC target was set at 30 percent (Grove et al. 2006) (fig. 1). The 30-percent target corresponded to an air quality modeling scenario employed in a related study (Luley and Bond 2002). Above this TCC target, there were no additional air pollutant reductions. In Baltimore, existing TCC was 20 percent and there was potential for another 53 percent TCC (Galvin et al. 2006). A 46-percent target TCC was recommended, filling about one-half of the remaining PTCC (fig. 1). This target was related to results from a remote sensing study that detected increased levels of stream health associated with greater watershed tree cover, although impervious cover was the primary predictive variable (Geotz et al. 2003). City leaders adopted a 40 percent TCC target, thinking that doubling the overall TCC from 20 to 40 percent was an easily understood goal. Different TCC targets were set for each land use in both New York City and Baltimore.

The cities of Portland, Oregon (Poracsky and Lackner 2004), and Vancouver, Washington (Kaler and Ray 2005), set TCC targets by land use corresponding to the 75<sup>th</sup> percentile of TCC, a value that falls mid-way in the range of the upper-half of TCC for polygons in each land use class (fig. 1). They found that TCC values were not normally distributed within land uses and, therefore, the mean value is not very representative. They selected the 75<sup>th</sup> percentile value as a target because it is both attainable—that value had been achieved or surpassed in 25 percent of the data set—and high enough to result in a noticeable expansion of TCC. Citywide TCC targets were set at 46 percent in Portland and 28 percent in Vancouver.

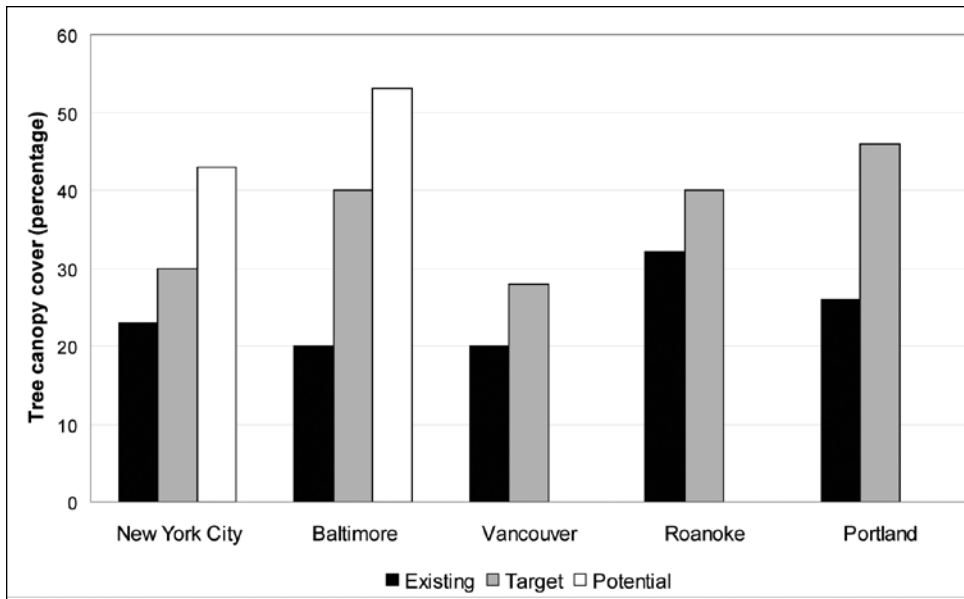


Figure 1—Existing, target, and potential tree canopy cover for five U.S. cities.

## Objectives

The objectives of this study were to (1) measure existing TCC, (2) characterize PTCC to determine the feasibility of planting 1 million trees, and (3) estimate future benefits from planting 1 million new trees.

## Methodology

### Study Site

The city of Los Angeles was founded by the Spanish in 1781 and served as a colonial capital before incorporation in 1850. City development began in the late 1800s after arrival of the railroads and the discovery of oil in the 1890s. Today, Los Angeles is one of the largest metropolitan areas in the United States and is a major shipping, manufacturing, communications, financial, and distribution center noted for its entertainment industry (fig. 2). Like many coastal California cities, it is undergoing a period of rapid population growth and expansion.

Los Angeles (latitude: 34°06' 36" N, longitude: 118°24' 40" W) has a land area of 473 mi<sup>2</sup> and a population of 3,694,820 (U.S. Census Bureau 2000). There are 15 council districts and 86 neighborhood councils. Topographic gradients are small in the coastal areas and inland valleys; however, within the city limits there are mountain ranges with steep slopes. Elevation changes from sea level to 5,063 ft at Mount Lukens in the northeast corner of the city.



Figure 2—The city of Los Angeles.

## Data Sets

## Remote sensing data—

Very high spatial resolution remote sensing data were required to accurately map vegetation coverage and available tree planting sites at the parcel scale. QuickBird<sup>1</sup> satellite imagery (DigitalGlobe, Longmont, Colorado) was used with pixel resolutions of 2.0 ft for panchromatic data and 7.9 ft for multispectral data.

<sup>1</sup> The use of trade names or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

**In this study, we demonstrate an important application of urban TCC mapping by combining remote sensing and GIS techniques.**

In this study, we demonstrate an important application of urban TCC mapping by combining remote sensing and GIS techniques. Coupling GIS to the analysis of remote sensing data improves the accuracy of the results. Incorporating spatial location is a standard method for registering images to base maps (Ambrosia et al. 1998, Lakshmi et al. 1998, Shao et al. 1998).

Three types of remotely sensed data and several GIS data layers were used in this study. The QuickBird data included 82 scenes that were collected from 2002 to 2005. Most of these data were collected when deciduous trees were in leaf, but several images were collected during the transition periods of late March and early November. Aerial imagery included year 2000 black-and-white images at 6-in resolution (city of Los Angeles, California) and 2005 natural color images at 3-ft resolution (USDA Forest Service), both taken when trees were in leaf. The image-processing system ENVI (Environment for Visualizing Images, Research Systems, Lafayette, Colorado) was used for image analysis.

**GIS data—**

The GIS data layers were provided by the Public Works, Bureau of Engineering of the city of Los Angeles. Data layers included the boundaries of the city, neighborhood councils, council districts, parcels, parks, streets, and land uses. ArcGIS (Environmental Systems Research Institute) was used for mapping and other spatial analysis. All vegetation and potential tree planting sites were in ArcGIS format. Nine original land use classes were aggregated into six classes (table 1).

**Measuring Existing Tree Canopy Cover**

Initial data processing involved reassembling remote sensing and GIS data layers. The key elements of this step included georegistering remote sensing data and projecting all data to the California State Plane. The multispectral QuickBird data

**Three types of remotely sensed data and several GIS data layers were used.**

**Table 1—Nine land use classes aggregated into six**

| Final land use class            | Original land use class                  |
|---------------------------------|------------------------------------------|
| Unknown                         | Unknown                                  |
| Low-density residential         | Low-density housing                      |
| Medium/high-density residential | Medium-density housing                   |
|                                 | High-density housing                     |
| Industrial                      | Heavy industry                           |
|                                 | Light industry                           |
| Commercial                      | Neighborhood commerce                    |
|                                 | Regional commerce                        |
| Institutional                   | Open space/public and quasi-public lands |

were pan-sharpened (resampled by using a principal-components bilinear interpolation of a coarser resolution image) to produce a more defined image at 60-cm spatial resolution.

#### **General classification processes—**

Classification is a statistical process that groups homogeneous pixels into areas of interest based on common spectral characteristics. Two commonly used classification techniques are supervised (human-assisted) and unsupervised (clustering). Each method serves a particular purpose, and both methods were used in this study. We selected four land cover mapping types based on the objectives of this project: tree (tree and shrub), grass (green grass and ground cover), dry grass/bare soil (dry grass and bare soil), and impervious surface (includes pervious pavement).

Supervised classification used spectral angle mapper because it is a physically based spectral classification. Pixels were classified by using radiance rather than reflectance. Unsupervised classification automatically clusters pixels into classes with similar spectral signatures based on statistics, without any user-defined training classes. We used K-means, which calculates class means evenly distributed in the data space, then iteratively clusters the pixels into the nearest class by using a minimum-distance technique (Tou and Gonzalez 1974).

#### **Data set masking—**

Masking techniques have been widely used in urban vegetation mapping (Xiao et al. 2004) to reduce the possibility of confusion among cover classes. Three masks were used in this study. The first mask separated green vegetation. The second mask separated nonvegetation (i.e., pavements, buildings, water, and bare soil) and dry vegetation (i.e., unirrigated grass). The third mask separated areas with dry vegetation, bare soil, and other pavements where spectral mixing occurs. These masks were created based on NDVI (normalized difference vegetation index), the ratio of the reflectance difference between near-infrared (NIR) and red and the sum of the reflectance at NIR and red. The NDVI's threshold values for these masks varied from image to image because the QuickBird images were from several years.

The naturally vegetated mountains (50,208 acres) were digitized and masked out from the study area. We masked mountains because their land cover, vegetation management, and topographic gradient are different from those of the urban areas. A small part of the study area was covered with cloud cover and masked out (8,202 acres). Color aerial images replaced the QuickBird data in these areas.

#### **Vegetation cover mapping—**

Vegetation cover mapping included mapping tree cover, green grass cover, and dry grass cover. In this study, shrubs were treated as trees. The NDVI was

used to distinguish vegetation and nonvegetation cover. We used unsupervised classification to separate mixed pixels containing vegetation and nonvegetation land cover types. In urban settings, most trees are planted in irrigated turf grass, where trees and the background cover have similar NDVI values. We used supervised classification to separate trees from irrigated grass.

#### **Vegetation mapping accuracy assessment—**

The accuracy of the classification models was assessed on a land cover type basis at pixel and parcel scales for a stratified random sample of 56 parcels based on land use (Nowak et al. 2003). Land cover types were digitized in each sample parcel from the Quickbird images as references for accuracy assessment. The pixel-scale analysis compared classified land cover types with digitized types by pixel. Over 1.5 million pixels were compared. The purpose of the parcel-scale analysis was to identify and eliminate problems caused by co-registration of different data layers. We compared the amount of each land cover area by parcel. The confusion matrix (Kohavi and Provost 1998, Xiao and McPherson 2005) was used to assess mapping accuracy.

#### **Existing TCC and tree number estimates—**

Existing TCC is presented at the citywide, council district, and neighborhood council levels. The number of existing trees is estimated assuming an average tree crown diameter of 16.4 ft, based on results from an intensive field study of trees throughout Sacramento, California (McPherson 1998).

### **Characterizing Potential and Target Tree Canopy Cover**

Previous studies characterized PTCC as the amount of existing pervious surface (i.e., grass and bare soil) that is not tree cover. Instead of characterizing PTCC as the residual pervious area, we identify potential tree planting sites for individual trees of small (15-ft crown diameter), medium (30-ft crown diameter), and large (50-ft crown diameter) mature sizes. Data on the numbers and ratios of small, medium, and large trees are used to project future benefits from the 1-million-tree planting for trees with these mature sizes.

#### **Decision rules for locating potential tree planting sites—**

Although circle-packing algorithms have been developed to place circles into an empty space, they are hard to implement in ArcGIS given the many irregularly shaped polygons that could contain tree sites. We therefore developed a computer program to iteratively search, test, and locate potential tree planting sites. The program begins by masking out a 2-ft buffer around impervious surfaces to avoid conflicts with tree trunks and roots that are too close to buildings and paving. In

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**Previous studies characterized PTCC as the amount of existing pervious surface that is not tree cover. Instead of characterizing PTCC as the residual pervious area, we identify potential tree planting sites for individual trees of small, medium, and large mature sizes.**

addition, restricted soil volumes in urban areas can limit tree survival and growth. The computer program therefore tests each potential planting site to ensure that each tree is allotted sufficient space to grow: 16 ft<sup>2</sup> of pervious surface for small trees, 36 ft<sup>2</sup> for medium trees, and 100 ft<sup>2</sup> for large trees. Because large trees produce proportionately greater benefits than small trees, the program starts by filling sites with large trees (50-ft crown diameters), then medium (30-ft crown diameter), and small (15-ft) trees. The program “draws” a 25-ft no-planting buffer around existing TCC to avoid overlapping crowns from potential trees with 50-ft crown diameters. It then “draws” the circular crowns of appropriately scaled 50-ft trees beginning in the center of each polygon. This procedure is repeated several times for 50-ft trees, with buffers redrawn each time to eliminate overlap with crowns of previously located planting sites for new 50-ft trees. The process is then repeated for 30-ft and 15-ft trees (fig. 3).

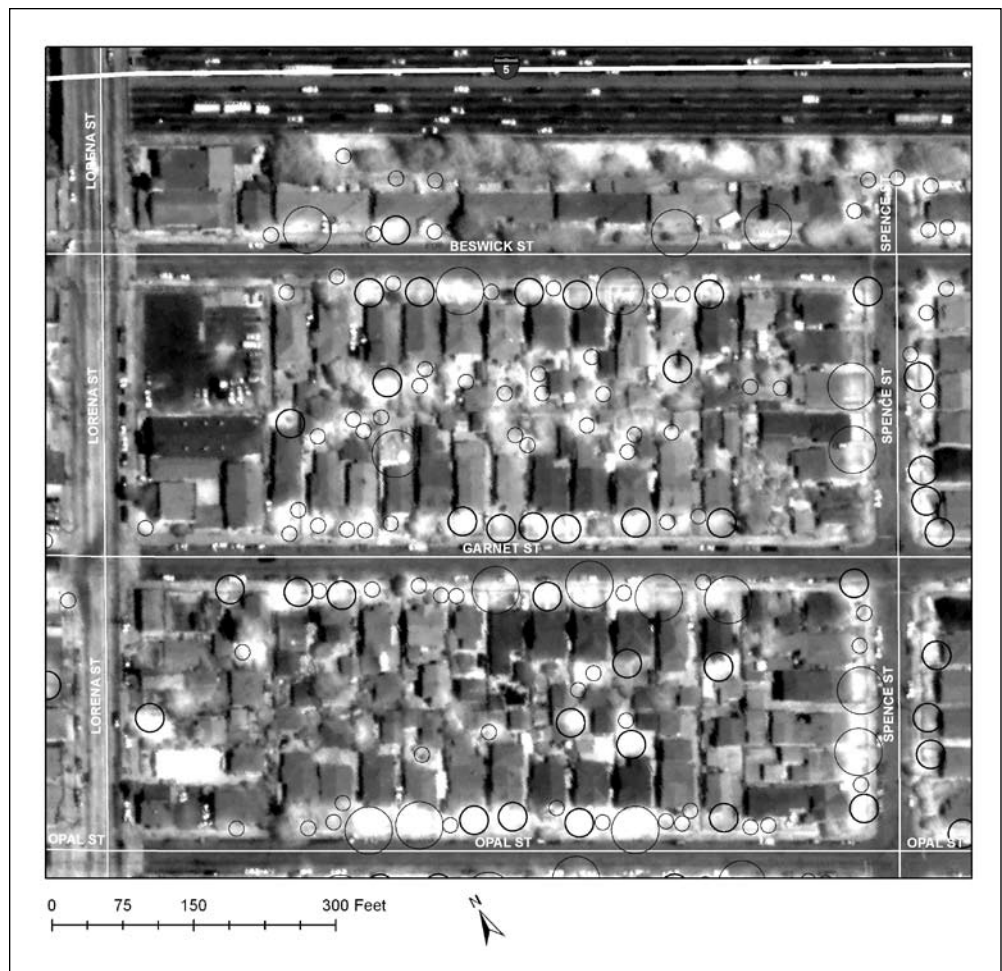


Figure 3—Potential tree planting sites in a Los Angeles neighborhood as identified by the tree-planting algorithm.

## Parking Lot Sampling

Parking lots cover a large area of Los Angeles and represent an important tree planting opportunity. However, distinguishing parking lots from other impervious surfaces (e.g., buildings and roads) is difficult because they are constructed from similar materials. Using remotely sensed data to identify parking lots and potential tree planting sites was not feasible given the resources at hand. Therefore, we decided to identify the amount of paved area that could be available for tree planting based on a sample of parking lots located throughout the city. We focused on large parking lots ( $>5,000 \text{ ft}^2$ ) in industrial, commercial, and institutional (called ICI land) land uses, as residential land uses contain relatively few lots, and these lots are usually small.

Sixteen sample boxes were randomly located across Los Angeles. The boxes were large and each contained a mix of land uses. The total area within these boxes was 70,784 acres, or approximately 28.3 percent of the city. The ICI land in the sample boxes equaled 23,742 acres, approximately 34 percent of the city's total ICI land (table 2).

Pan-sharpened QuickBird images were analyzed to separate asphalt surfaces from other impervious surfaces by using ENVI 4.2. Classification results from ENVI were exported to ArcGIS and reclassified into three categories: vegetation cover or no data, parking lot, and nonparking impervious area.

Further processing was required to separate streets from parking areas where trees could be planted. Streets were partitioned from the imagery by overlaying land use shapefiles. Segmentation resulted in delineation of paved parking lot areas, but contained many small polygons representing motor vehicles and other objects within paved parking lot areas. These segments were cleaned up in the ArcGIS environment.

For each council district, the total area of land use type  $i$  ( $Area\_CDLU_i$ , where  $i = 3$ , industrial, commercial, institutional), the sampled area ( $spArea$ ), and the total area of identified parking lots ( $sp\_PKArea$ ) were calculated for each land use. The total paved parking area for land use type  $i$  within a council district can be estimated as:

$$CD\_pkArea_i = \frac{sp\_PKArea_i}{spArea_i} \times Area\_CDLU_i$$

Then the total parking lot area for each council district can be calculated as:

$$CD\_pkArea = \sum_i \left( \frac{sp\_PKArea_i}{spArea_i} \times Area\_CDLU_i \right)$$

where  $i = 3, 4, 5$ .

**Table 2—Estimated paved parking lot area by land use and council district**

| Council district | Land use (ICI) <sup>a</sup> | Total ICI land area | Sampled ICI land area | Paved parking lot area within sampled area | Paved parking lot rate | Estimated paved parking lot area | Total est. paved parking lot area | Paved parking lot rate for ICI land |
|------------------|-----------------------------|---------------------|-----------------------|--------------------------------------------|------------------------|----------------------------------|-----------------------------------|-------------------------------------|
|                  |                             | <i>Acres</i>        | <i>Acres</i>          | <i>Acres</i>                               | <i>Percent</i>         | <i>Acres</i>                     | <i>Acres</i>                      | <i>Percent</i>                      |
| 1                | Ind.                        | 818                 | 575                   | 45                                         | 7.9                    | 65                               | 240                               | 7.6                                 |
|                  | Com.                        | 854                 | 692                   | 101                                        | 14.5                   | 124                              |                                   |                                     |
|                  | Instit.                     | 1,494               | 719                   | 25                                         | 3.4                    | 51                               |                                   |                                     |
| 2                | Ind.                        | 973                 | 251                   | 45                                         | 18.0                   | 175                              | 544                               | 13.7                                |
|                  | Com.                        | 940                 | 311                   | 93                                         | 30.0                   | 282                              |                                   |                                     |
|                  | Instit.                     | 2,049               | 590                   | 25                                         | 4.2                    | 86                               |                                   |                                     |
| 3                | Ind.                        | 731                 | 521                   | 104                                        | 20.1                   | 147                              | 669                               | 15.5                                |
|                  | Com.                        | 1,335               | 592                   | 175                                        | 29.5                   | 394                              |                                   |                                     |
|                  | Instit.                     | 2,240               | 367                   | 21                                         | 5.7                    | 128                              |                                   |                                     |
| 4                | Ind.                        | 402                 | 189                   | 25                                         | 13.2                   | 53                               | 409                               | 8.4                                 |
|                  | Com.                        | 997                 | 515                   | 82                                         | 15.9                   | 159                              |                                   |                                     |
|                  | Instit.                     | 3,496               | 411                   | 23                                         | 5.6                    | 197                              |                                   |                                     |
| 5                | Ind.                        | 167                 | 100                   | 12                                         | 11.6                   | 19                               | 220                               | 6.3                                 |
|                  | Com.                        | 1,077               | 265                   | 33                                         | 12.6                   | 136                              |                                   |                                     |
|                  | Instit.                     | 2,269               | 223                   | 6                                          | 2.8                    | 64                               |                                   |                                     |
| 6                | Ind.                        | 3,362               | 2,526                 | 302                                        | 12.0                   | 402                              | 793                               | 10.3                                |
|                  | Com.                        | 692                 | 512                   | 160                                        | 31.2                   | 216                              |                                   |                                     |
|                  | Instit.                     | 3,633               | 1,627                 | 78                                         | 4.8                    | 174                              |                                   |                                     |
| 7                | Ind.                        | 983                 | 335                   | 105                                        | 31.2                   | 307                              | 624                               | 13.2                                |
|                  | Com.                        | 667                 | 210                   | 71                                         | 33.9                   | 226                              |                                   |                                     |
|                  | Instit.                     | 3,080               | 624                   | 18                                         | 3.0                    | 91                               |                                   |                                     |
| 8                | Ind.                        | 179                 | 83                    | 14                                         | 16.8                   | 30                               | 261                               | 13.9                                |
|                  | Com.                        | 980                 | 266                   | 39                                         | 14.8                   | 145                              |                                   |                                     |
|                  | Instit.                     | 722                 | 178                   | 21                                         | 12.0                   | 87                               |                                   |                                     |
| 9                | Ind.                        | 1,748               | 461                   | 54                                         | 11.8                   | 207                              | 472                               | 12.8                                |
|                  | Com.                        | 1,043               | 648                   | 112                                        | 17.3                   | 180                              |                                   |                                     |
|                  | Instit.                     | 891                 | 521                   | 50                                         | 9.6                    | 85                               |                                   |                                     |
| 10               | Ind.                        | 328                 | 41                    | 2                                          | 3.9                    | 13                               | 179                               | 9.8                                 |
|                  | Com.                        | 896                 | 201                   | 26                                         | 12.7                   | 114                              |                                   |                                     |
|                  | Instit.                     | 601                 | 138                   | 12                                         | 8.7                    | 53                               |                                   |                                     |
| 11               | Ind.                        | 952                 | 499                   | 77                                         | 15.4                   | 147                              | 500                               | 8.6                                 |
|                  | Com.                        | 904                 | 319                   | 33                                         | 10.3                   | 93                               |                                   |                                     |
|                  | Instit.                     | 3,943               | 778                   | 51                                         | 6.6                    | 260                              |                                   |                                     |
| 12               | Ind.                        | 1,885               | 1,252                 | 224                                        | 17.9                   | 337                              | 1,061                             | 14.6                                |
|                  | Com.                        | 972                 | 198                   | 57                                         | 28.5                   | 277                              |                                   |                                     |
|                  | Instit.                     | 4,428               | 483                   | 49                                         | 10.1                   | 447                              |                                   |                                     |
| 13               | Ind.                        | 412                 | 213                   | 24                                         | 11.5                   | 47                               | 246                               | 9.9                                 |
|                  | Com.                        | 950                 | 413                   | 71                                         | 17.1                   | 163                              |                                   |                                     |
|                  | Instit.                     | 1,121               | 554                   | 18                                         | 3.2                    | 36                               |                                   |                                     |
| 14               | Ind.                        | 2,113               | 929                   | 58                                         | 6.2                    | 131                              | 325                               | 6.5                                 |
|                  | Com.                        | 708                 | 169                   | 21                                         | 12.3                   | 87                               |                                   |                                     |
|                  | Instit.                     | 2,173               | 641                   | 31                                         | 4.9                    | 107                              |                                   |                                     |
| 15               | Ind.                        | 6,815               | 1,149                 | 264                                        | 23.0                   | 1,565                            | 1,850                             | 17.5                                |
|                  | Com.                        | 743                 | 252                   | 48                                         | 18.9                   | 140                              |                                   |                                     |
|                  | Instit.                     | 3,017               | 1,199                 | 57                                         | 4.8                    | 145                              |                                   |                                     |
| Total            |                             | 70,784              | 23,742                | 2,962                                      |                        | 8,393                            |                                   |                                     |

<sup>a</sup> ICI = industrial (Ind.), commercial (Com.), and institutional (Instit.).

The total parking lot area in a council district is estimated based on the ratio of parking lot area to total area of the same type of land use in the samples summed over land use types. This approach assumes that ratios of parking lot area to land use area found in each council district sample are representative of actual ratios throughout the council district.

To estimate technical PTCC in paved parking areas, the number of potential tree planting sites was assumed to cover 50 percent of the paved area, based on municipal tree shade ordinances that specify 50 percent shade within 10 to 15 years of planting (McPherson 2001). To calculate the number of trees needed to shade 50 percent of the paved area, we assume that all have the 30-ft crown diameter of the medium-stature tree.

#### **Ground-truthing and calibration of PTCC—**

The accuracy of potential planting site estimates depends on the accuracy of the initial land cover classification, as well as errors associated with the computer-based tree site selection process. A simple ground-truthing method was applied to estimate the accuracy of identifying potential tree planting sites and to calibrate our findings accordingly.

A stratified random sample of 100 parcels was located across Los Angeles by using the UFORE random plot selection tool (Nowak et al. 2003). The number of sample plots was proportional to area by land use. Personnel from TreePeople visited 55 of the sites to assess the accuracy of computer-generated maps showing potential planting sites for large, medium, and small trees. Sampled parcels were distributed by land use as follows: 44 percent low-density housing, 18 percent medium- to high-density housing, 16 percent industrial, 13 percent commercial, and 9 percent public/open space. Field crews had three maps for each site: aerial photograph (2000, 3-ft resolution, black and white) and two Quickbird pan-sharpened images (2-ft resolution), one showing existing tree cover, the other showing potential tree sites. After locating the property and obtaining permission to conduct the analysis, the crews crossed out potential planting sites that did not exist and drew circles locating sites not identified by the computer program. In some cases, the sizes of trees and their placement were changed in the field by using the same rules that the program applied.

Computer-based estimates of potential tree sites were adjusted by using ratio estimators for each tree size and land use (table 3). Ratio estimators express the ratio of ground-truthed tree sites to computer-generated sites by land use. For example, the value 1.67 for medium trees in the low-density residential land use indicates that the number of plantable sites found from ground truthing was 1.67 times the number generated by the computer.

Overall, the number of ground-truthed potential tree sites was 32 percent less than computer-generated sites, but the overall potential canopy increase was similar (difference is less than 1 percent). This result is explained by the fact that the ground-truthed sites contained relatively more sites for large and medium stature trees than were generated by the computer.

**Table 3—Ratio estimators used to correct the number of computer-generated potential tree planting sites based on ground-truthing**

| Land use                        | Tree size |      |        |      |       |      |
|---------------------------------|-----------|------|--------|------|-------|------|
|                                 | Small     |      | Medium |      | Large |      |
|                                 | Ratio     | SE   | Ratio  | SE   | Ratio | SE   |
| Low density residential         | 0.73      | 0.72 | 1.67   | 1.65 | 1     | 1.54 |
| Medium/high-density residential | 0.88      | 0.46 | 1      | 0.63 | 1     | 0    |
| Industrial                      | 0.28      | 0.48 | 0.5    | 0.8  | 1.04  | 0.23 |
| Commercial                      | 0.8       | 0.49 | 1.18   | 0.67 | 1.62  | 1.43 |
| Institutional                   | 0.61      | 0.07 | 1      | 0.24 | 2.2   | 0.15 |

SE = standard error.

The computer program generated 877 potential tree planting sites (73 large, 170 medium, and 634 small) that increased TCC by 8.6 acres for the 55 parcels. Our ground-truth results indicated potential for 599 trees (106 large, 158 medium, and 335 small) that increased TCC by 8.7 acres. Overall, the number of ground-truthed potential tree sites was 32 percent less than computer-generated sites, but the overall potential canopy increase was similar (difference is less than 1 percent). This result is explained by the fact that the ground-truthed sites contained relatively more sites for large and medium stature trees than were generated by the computer. After applying the ratio estimators to our computer-generated estimates, the total number of potential sites was reduced.

### Tree Canopy Cover Target

The primary purpose behind setting a realistic TCC target for Los Angeles was to determine if the 1-million-tree planting goal was feasible. In the event that our TCC target exceeded the 1-million-tree goal, it would confirm feasibility of the goal and provide impetus for planting in excess of the goal. If our TCC target was less than the goal, it would indicate need to reevaluate the goal.

We examined the distribution of TCC by land use polygons and found that, in most cases, they were not normally distributed. However, determining the appropriate percentile targets for different land uses seemed arbitrary and nonuniform. Therefore, TCC targets for this study were designed to fill 50 percent of the available planting sites in each land use and council district. The exception is for large paved parking lot surfaces ( $>5,000 \text{ ft}^2$ ) for commercial and institutional land uses, where we assume that the TCC target is 50 percent of the paved area based on the fact that many municipal parking lot tree shade ordinances have adopted this 50 percent target. However, for industrial land uses we reduced the target to 25 percent TCC because a substantial amount of paved area is used by trucks, as temporary

storage, and for loading and unloading. The goal of filling 50 percent of all potential tree planting sites acknowledges that:

- Each council district is unique because it has a different land use mix, as well as different existing and PTCC that reflects historical patterns of development and tree stewardship.
- Every council district can do its “fair share” by filling 50 percent of its available tree planting sites, thus contributing to a shared citywide goal.
- Council districts with the most empty planting sites will achieve the greatest relative increase in TCC, whereas those with higher stocking levels will obtain less enhancement.

## The 1-Million-Tree Planting Scenario

The 1-million-tree planting scenario was developed by using the TCC targets and a reduction factor applied uniformly across all council districts and land uses. The reduction factor, 76.5 percent, was the ratio of program trees (1 million) to target trees (1.31 million).

We used existing data on tree benefits for coastal (McPherson et al. 2000) and inland southern California (McPherson et al. 2001) to project future annual benefits from 1 million new trees. Our analysis incorporated a range of mortality rates for typical small, medium, and large growing trees over a 35-year period (2006–2040). Results are reported in terms of annual value per tree planted and cumulative value for the 35-year period. This accounting approach “grows” trees in different locations and uses computer simulation to directly calculate the annual flow of benefits as trees mature and die (McPherson 1992).

## Tree Data

Based on discussions with program planners, we assume that 1 million trees are planted during the first 5 years of the program at an increasing rate to allow the program to ramp up as resources and capacity grow:

- 2006–50,000 trees
- 2007–160,000 trees
- 2008–230,000 trees
- 2009–270,000 trees
- 2010–290,000 trees

Low- and high-mortality rates provide realistic bounds for uncertainty regarding survival of transplants. Respective annual mortality rates for establishment (the first 5 years after planting) are 1 percent (low) and 5 percent (high), and thereafter

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**To account for differences in the growth patterns and benefits of trees of different sizes, we made use of growth curves for small, medium, and large tree species in each climate zone developed from street trees in Santa Monica and Claremont. For the coastal zone, growth curves for the yew, jacaranda, and camphor were used. For the inland zone, growth curves for crapemyrtle, jacaranda, and evergreen ash were used.**

rates are 0.5 and 2 percent. Over a 35-year period, these annual mortality rates translate into total low and high rates of about 17 and 56 percent. The average mortality rate is 36.5 percent.

Los Angeles has a variety of climate zones because of its proximity to the Pacific Ocean and the nearby mountain ranges. We have classified each council district as coastal zone or inland zone based on an aggregation of Sunset climate zones (Brenzel 2001). Council districts 11 and 15 are coastal, and the remaining 13 are inland.

To account for differences in the growth patterns and benefits of trees of different sizes, we made use of growth curves for small, medium, and large tree species in each climate zone developed from street trees in Santa Monica and Claremont (McPherson et al. 2000, 2001). For the coastal zone, growth curves for the yew (see “Common and Scientific Names” section), jacaranda, and camphor were used. For the inland zone, growth curves for crapemyrtle, jacaranda, and evergreen ash were used. The mature crown diameters of these species roughly correspond with the 15-, 30-, and 50-ft sizes used in determining potential planting sites. The selection of these species was based on data availability and is not intended to endorse their use in large numbers. In fact, the camphor has a poor form for a street tree and in certain areas crapemyrtle is overused. In addition, relying on too few species can increase the likelihood of catastrophic loss owing to pests, disease, or other threats.

## Benefits

Benefits are calculated with numerical models and data for trees in each land use, using methods previously described (McPherson et al. 2000, 2001). Projected energy savings reflect differences in cooling and heating loads associated with coastal and inland zone climates. Similarly, air pollutant uptake calculations use air pollutant concentrations measured at monitoring stations in each zone. Costs of preventing or repairing damage from pollution, flooding, or other environmental risks are used to estimate society’s willingness to pay for clean air and water (Wang and Santini 1995). For example, the value of stormwater runoff reduction owing to rainfall interception by trees is estimated by using marginal control costs. If a community or developer is willing to pay an average of \$0.01 per gallon of treated and controlled runoff to meet minimum standards, then the stormwater runoff mitigation value of a tree that intercepts 1,000 gal of rain, eliminating the need for control, should be \$10.

## Energy savings—

Effects of tree shade and urban heat island mitigation on building energy use are applied to trees planted in residential areas only. Energy effects were based on

computer simulations that incorporated building, climate, and shading effects (McPherson and Simpson 1999). Tree distribution with respect to residential buildings was determined by classifying 130 potential planting sites in 34 ground-truthed low-density housing parcels by azimuth and distance class from the building (table 4). We lack sufficient data on nonresidential building stock and tree location effects to simulate energy savings for these buildings.

Typical meteorological year weather data for Los Angeles International Airport (coastal) and Riverside (inland), as well as local building characteristics were used. The dollar values of electrical energy (\$0.10634 per kWh) and natural gas (\$0.0067 per kBtu) were based on retail residential electricity and natural gas prices obtained from the Los Angeles Department of Water and Power (LADWP).

#### Atmospheric carbon dioxide reductions—

Sequestration, the net rate of carbon dioxide (CO<sub>2</sub>) storage in above- and below-ground biomass over the course of one growing season, was calculated by using Santa Monica (coastal) and Claremont (inland) tree growth data and biomass equations for urban trees (Pillsbury et al. 1998). The CO<sub>2</sub> released through decomposition of dead woody biomass was based on annual tree removal rates. The CO<sub>2</sub> released during tree maintenance activities was estimated based on annual consumption of gasoline and diesel fuel as 0.635 lb per in of diameter at breast height (d.b.h.), the average of values previously used (McPherson et al. 2000, 2001).

Reductions in building energy use result in reduced emissions of CO<sub>2</sub>. Emission reductions were calculated as the product of energy savings and CO<sub>2</sub> emission factors for electricity and heating. Heating fuel was natural gas, and the fuel mix for electrical generation was 52 percent coal, 6 percent hydro, 26 percent natural gas, 11 percent nuclear, and 5 percent other. The value of CO<sub>2</sub> reductions was \$6.68 per ton of CO<sub>2</sub> (Pearce 2003).

#### Air quality benefits—

The hourly pollutant dry deposition per tree was expressed as the product of deposition velocity  $V_d = 1/(R_a + R_b + R_c)$  (where  $R_a$ ,  $R_b$ , and  $R_c$  are aerodynamic, boundary layer, and stomatal resistances), pollutant concentration  $C$ , canopy projection area (CPA), and a time step. Hourly deposition velocities for ozone (O<sub>3</sub>), nitrogen dioxide

**Table 4—Distribution of potential tree planting sites around homes based on ground-truthing**

| Distance classes   | North          | Northeast | East | Southeast | South | Southwest | West | Northwest |
|--------------------|----------------|-----------|------|-----------|-------|-----------|------|-----------|
|                    | <i>Percent</i> |           |      |           |       |           |      |           |
| Adjacent (<20 ft)  | 10.8           | 1.5       | 10.0 | 2.3       | 10.0  | 3.8       | 6.2  | 2.3       |
| Near (21 to 40 ft) | 7.7            | 2.3       | 12.3 | 4.6       | 6.2   | 3.8       | 3.8  | 1.5       |
| Far (41 to 60 ft)  | 1.5            | 0.0       | 3.8  | 1.5       | 1.5   | 0.8       | 0.8  | 0.8       |

(NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), and particulate matter of <10-micron diameter (PM<sub>10</sub>) were calculated by using estimates for the resistances  $R_a$ ,  $R_b$ , and  $R_c$  for each hour throughout a “base year” (Scott et al. 1998). Hourly meteorological data and pollutant concentrations were obtained from monitoring stations in Hawthorne (coastal) and Azusa (inland) when pollutant concentrations were near average.

Energy savings result in reduced emissions of criteria air pollutants (volatile organic hydrocarbons [VOCs], NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub>) from power plants and space-heating equipment. These avoided emissions were calculated by using LADWP emission factors for electricity and heating fuels.

Emissions of biogenic volatile organic compounds (BVOCs) from trees affect O<sub>3</sub> formation. The hourly emission rates of the four tree species used in this analysis are minimal (Benjamin and Winer 1998). In reality, a large-scale tree planting like this is likely to include some species with emission rates higher than reported here. Although our approach may understate BVOC emissions from new trees, it also understates the air quality benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from anthropogenic and biogenic sources.

The monetary value of tree effects on air quality should reflect the value that society places on clean air, as indicated by willingness to pay for pollutant reductions. Lacking specific data for Los Angeles, air quality benefits were monetized as damage values (table 5) by using regression relationships among emission values, pollutant concentrations, and population numbers (Wang and Santini 1995). This regression provides estimates of the costs of damages to human health resulting from air pollution.

#### **Stormwater runoff reductions—**

A numerical interception model accounted for the amount of annual rainfall intercepted by trees, as well as throughfall and stem flow (Xiao et al. 2000). The volume of water stored in tree crowns was calculated from tree crown leaf and stem surface areas and water depth on these surfaces. Hourly meteorological and rainfall data for

**Table 5—Values of air pollutant reduction for coastal and inland zones**

| <b>Pollutant</b>           | <b>Coastal</b>           | <b>Inland</b> |
|----------------------------|--------------------------|---------------|
|                            | <i>Dollars per pound</i> |               |
| Nitrogen dioxide           | 2.26                     | 3.95          |
| Sulfur dioxide             | 2.50                     | 2.50          |
| Small particulate matter   | 5.44                     | 4.95          |
| Volatile organic compounds | 1.06                     | 1.98          |
| Ozone                      | 2.26                     | 3.95          |

1996 from California Irrigation Management Information System stations in Santa Monica and Claremont were used because total rainfall in that year was close to the average annual amount.

Stormwater runoff reduction benefits were priced by estimating costs of controlling stormwater runoff and treating sanitary waste in Los Angeles. During small rainfall events, excess capacity in sanitary treatment plants can be used to treat stormwater. In the Los Angeles region, it costs approximately \$0.0018 per gal to treat sanitary waste (Condon and Moriarty 1999). We used this price to value the water quality benefit of rainfall interception by trees 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.

To calculate water quality benefit, the treatment cost is multiplied by gallons of rainfall intercepted after the first 0.1 in has fallen for each event (24 hours without rain) during the year. The first 0.1 in of rainfall seldom results in runoff, and thus, interception is not a benefit until precipitation exceeds this amount. Over \$50 million (\$500,000 per square mile) is spent annually controlling floods in the Los Angeles area (Condon and Moriarty 1999). We assume that rainfall interception by tree crowns will have minimal effect during very large storms that result in catastrophic flooding of the Los Angeles River and its tributaries (133-year storm).

Although storm drains are designed to control 25-year events, localized flooding is a problem during smaller events. 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 25-year peak flow event (Jones & Stokes Associates, Inc. 1998). A 25-year winter event deposits 6.7 in of rainfall during 67 hours. Approximately \$0.0054 per gal is spent annually for controlling flooding caused by such an event. Water quality and flood control benefits are summed to calculate the total hydrology benefit of \$0.0072 per gal. This price is multiplied by the amount of rainfall intercepted annually, after excluding events less than 0.1 in.

#### **Aesthetics and other benefits—**

Many benefits attributed to urban trees are difficult to price (e.g., beautification, privacy, wildlife habitat, sense of place, well-being). However, the value of some of these benefits can be captured in the differences in sales prices of properties with and without trees. Anderson and Cordell (1988) found that each large front-yard tree in Athens, Georgia, was associated with a 0.88-percent increase in sales price. In this analysis, aesthetic (*A*) benefits (dollars per tree per year) are expressed for a single tree as:

$$A = L \times P$$

where *L* is the annual increase in tree leaf area (LA) and *P* is the adjusted price

(dollars per square foot of LA) :

$$P = (T \times C) / M$$

where

$T$  = Large tree contribution to home sales price = 0.88 percent  $\times$  median sales price

$C$  = Tree location factor (percent) that discounts the benefit for trees outside of low-density residential areas

$M$  = Large tree LA

The median sales price for single-family homes in Los Angeles in December 2006 was \$530,000 (California Association of Realtors 2006). The values for  $C$  were 100 percent for low-density residential, 70 percent for medium/high-density residential, and 40 percent for other land uses (Gonzales 2004, McPherson 2001). The values for  $M$  were 2,691 and 3,591 ft<sup>2</sup> for coastal and inland zones, respectively.

## Results

### Existing Tree Canopy Cover

The TCC in the city of Los Angeles is 21 percent (52,493 acres) (table 6). Irrigated grass and dry grass/bare soil account for 12 percent (31,206 acres) and 6 percent (13,790 acres) of the city, respectively (fig. 4). Impervious (e.g., paving, roofs) and

**Table 6—Land cover distribution by council district (excludes mountains) for Los Angeles**

| Council district | Land area    | Tree canopy cover |                | Irrigated grass cover |                | Dry grass /bare soil |                | Impervious/other |                | Mountain     |
|------------------|--------------|-------------------|----------------|-----------------------|----------------|----------------------|----------------|------------------|----------------|--------------|
|                  | <i>Acres</i> | <i>Acres</i>      | <i>Percent</i> | <i>Acres</i>          | <i>Percent</i> | <i>Acres</i>         | <i>Percent</i> | <i>Acres</i>     | <i>Percent</i> | <i>Acres</i> |
| 1                | 7,949        | 1,266             | 15.9           | 474                   | 6.00           | 395                  | 5.00           | 5,814            | 73.0           | 873          |
| 2                | 20,295       | 5,395             | 26.6           | 1,987                 | 9.80           | 1,310                | 6.50           | 11,603           | 57.0           | 11,489       |
| 3                | 24,359       | 6,345             | 26.0           | 3,443                 | 14.10          | 1,458                | 6.00           | 13,114           | 54.0           | 2,076        |
| 4                | 15,403       | 4,429             | 28.8           | 1,954                 | 12.70          | 679                  | 4.40           | 8,341            | 54.0           | 4,069        |
| 5                | 24,317       | 9,047             | 37.2           | 2,798                 | 11.50          | 737                  | 3.00           | 11,735           | 48.0           | 5,842        |
| 6                | 17,047       | 2,550             | 15.0           | 1,808                 | 10.60          | 945                  | 5.50           | 11,744           | 69.0           | -            |
| 7                | 15,789       | 2,572             | 16.3           | 1,513                 | 9.60           | 2,334                | 14.80          | 9,371            | 59.0           | 2,540        |
| 8                | 11,174       | 1,192             | 10.7           | 2,175                 | 19.50          | 414                  | 3.70           | 7,393            | 66.0           | -            |
| 9                | 9,564        | 719               | 7.5            | 838                   | 8.80           | 254                  | 2.70           | 7,753            | 81.0           | -            |
| 10               | 8,541        | 1,018             | 11.9           | 812                   | 9.50           | 415                  | 4.90           | 6,296            | 74.0           | -            |
| 11               | 25,922       | 6,094             | 23.5           | 4,467                 | 17.20          | 642                  | 2.50           | 14,719           | 57.0           | 15,259       |
| 12               | 29,232       | 5,796             | 19.8           | 4,751                 | 16.30          | 2,258                | 7.70           | 16,426           | 56.0           | 7,060        |
| 13               | 7,845        | 1,072             | 13.7           | 889                   | 11.30          | 323                  | 4.10           | 5,560            | 71.0           | 72           |
| 14               | 13,972       | 3,126             | 22.4           | 673                   | 4.80           | 704                  | 5.00           | 9,470            | 68.0           | 928          |
| 15               | 20,976       | 1,871             | 8.9            | 2,625                 | 12.50          | 923                  | 4.40           | 15,557           | 74.0           | -            |
| Total            | 252,384      | 52,493            | 20.8           | 31,206                | 12.40          | 13,790               | 5.50           | 154,895          | 61.0           | 50,208       |

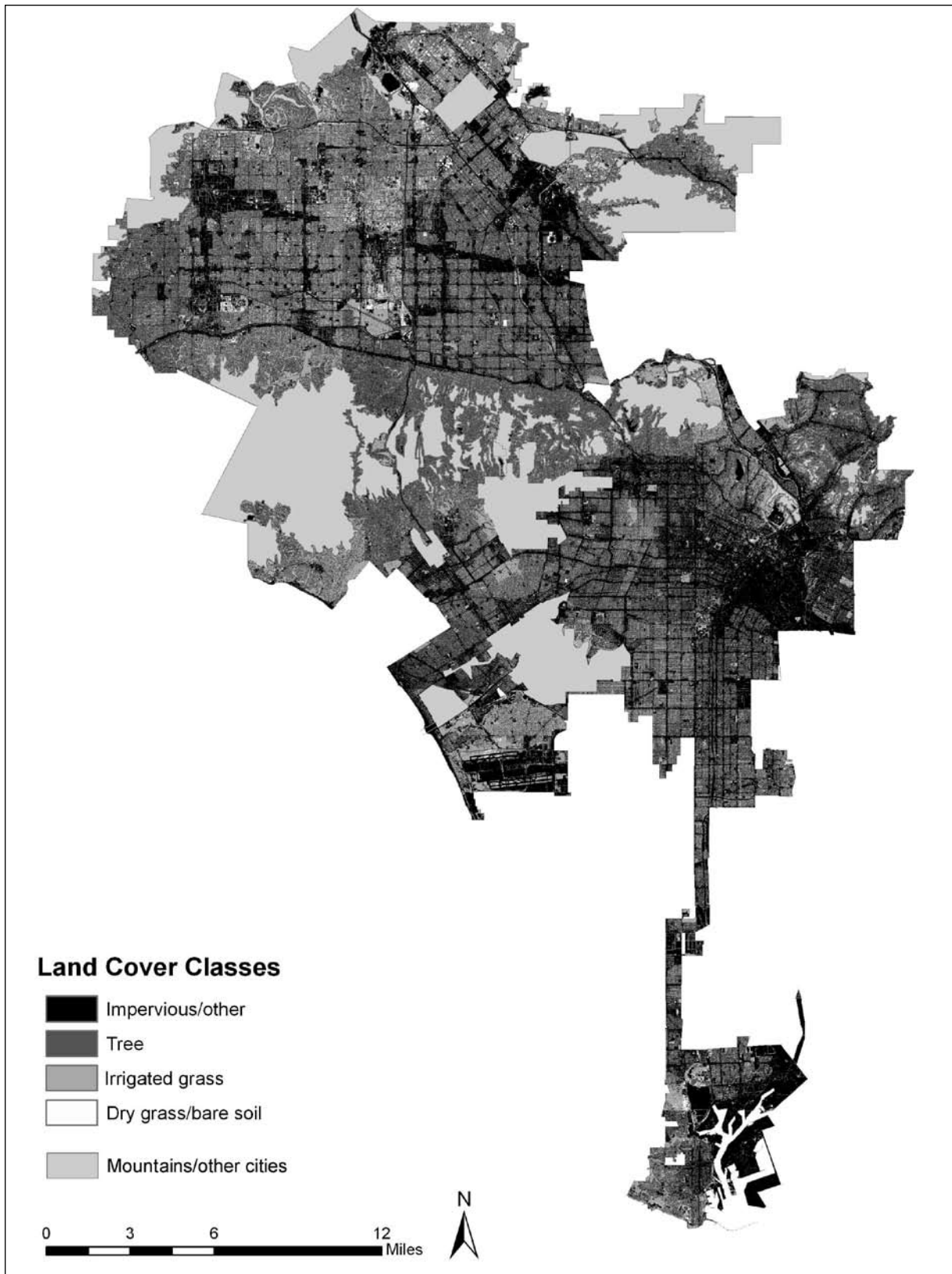


Figure 4—Spatial distribution of land cover classes.

**One-third of Los Angeles's land cover is existing TCC and grass/bare soil with potential to become TCC. The number of existing trees is estimated to be 10.8 million assuming an average tree crown diameter of 16.4 ft.**

other surfaces (i.e., water) make up the remaining 61 percent (154,895 acres) of the city's land cover (excluding mountainous areas). Hence, one-third of Los Angeles's land cover is existing TCC and grass/bare soil with potential to become TCC. The number of existing trees is estimated to be 10.8 million assuming an average tree crown diameter of 16.4 ft.

**By council district—**

At the council district level, TCC ranged from lows of 7 to 9 percent in council districts 9 and 15 to a high of 37 percent in council district 5 (table 6). The TCC was strongly related to land use. As expected, low-density residential land uses had the highest TCC citywide (31 percent), whereas industrial and commercial land uses had the lowest TCC (3 and 6 percent) (table 7). Tree canopy cover tended to be higher in areas near mountains compared to areas closer to downtown Los Angeles.

Relations between TCC and land use are evident in council districts 5 and 9. Council district 5 (37 percent TCC) is dominated by low-density housing (70 percent) and has 49 percent tree/grass/soil cover. In contrast, low-density housing covered only 4 percent of council district 9 (7 percent TCC), whereas industrial and commercial land uses covered 42 percent of the land (table 8).

There are approximately 10.8 million trees (43 trees per acre) in Los Angeles. Council districts estimated to have the highest tree densities are 5 (37 percent), 4 (29 percent), 2 (27 percent), and 3 (26 percent) (fig. 5). These council districts contain approximately 77, 59, 55, and 53 trees per acre, respectively. Council districts with the lowest estimated tree densities are 9 (8 percent), 15 (9 percent), 8 (11 percent), and 10 (12 percent).

**By neighborhood council—**

The TCC and area are presented for each of the 86 neighborhood councils in the appendix. Existing TCC exceeded 40 percent in three neighborhood councils: Bel Air-Beverly Crest (53 percent), Arroyo Seco (46 percent), and Studio City (42

**Table 7—Land cover distribution by land use**

| Land use                        | Total area   | Tree cover   |                | Grass cover  |                | Dry grass /bare soil |                |
|---------------------------------|--------------|--------------|----------------|--------------|----------------|----------------------|----------------|
|                                 | <i>Acres</i> | <i>Acres</i> | <i>Percent</i> | <i>Acres</i> | <i>Percent</i> | <i>Acres</i>         | <i>Percent</i> |
| Low-density residential         | 120,151      | 36,615       | 30.5           | 18,182       | 15.1           | 8,601                | 7.2            |
| Medium/high-density residential | 43,803       | 6,351        | 14.5           | 4,377        | 10.0           | 1,881                | 4.3            |
| Industrial                      | 25,693       | 901          | 3.5            | 649          | 2.5            | 493                  | 1.9            |
| Commercial                      | 20,130       | 1,121        | 5.6            | 622          | 3.1            | 352                  | 1.7            |
| Institutional                   | 39,093       | 7,174        | 18.3           | 6,809        | 17.4           | 2,356                | 6.0            |
| Unknown                         | 3,514        | 331          | 9.4            | 566          | 16.2           | 107                  | 3.1            |
| Total                           | 252,384      | 52,493       | 20.8           | 31,206       | 12.4           | 13,790               | 5.5            |

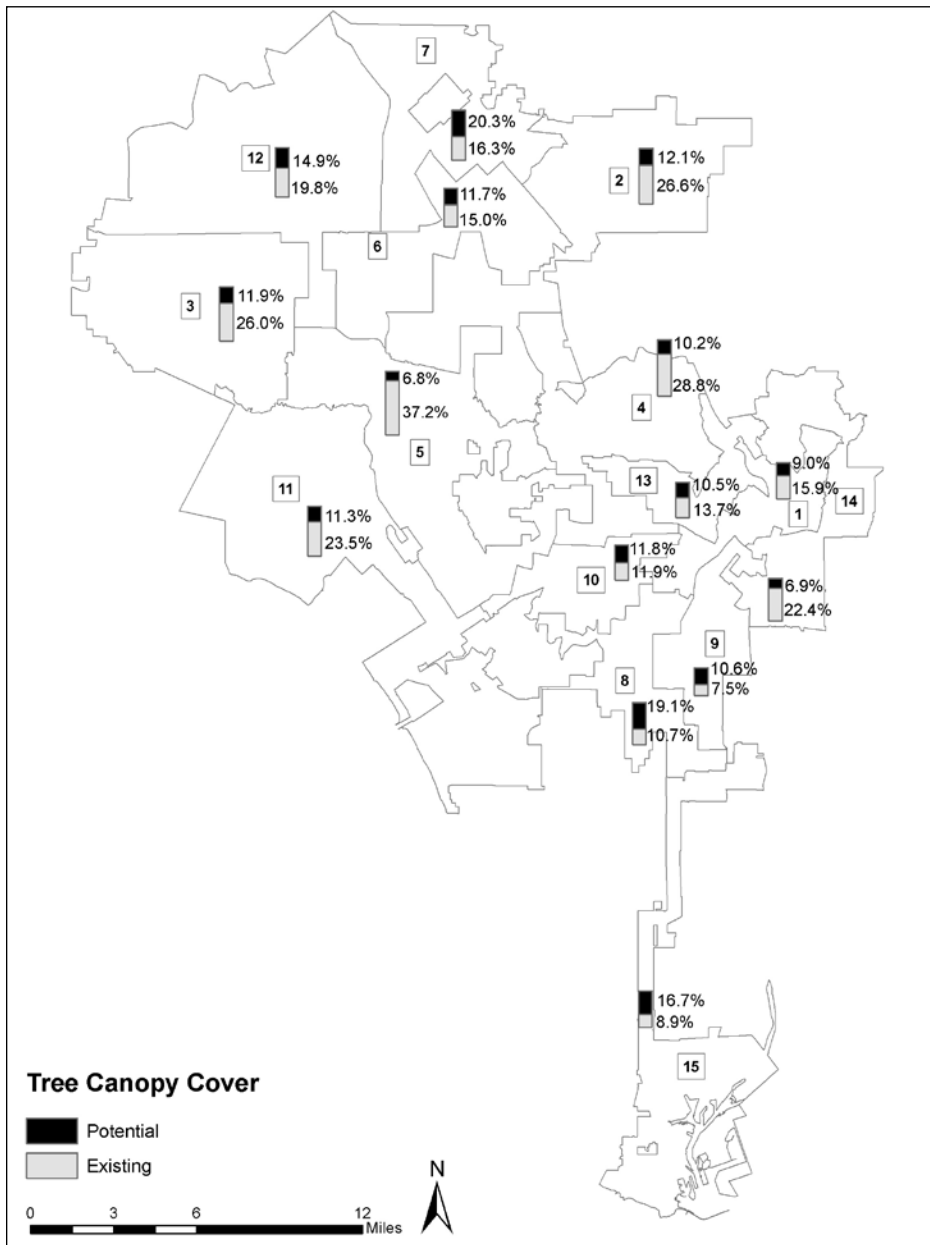


Figure 5—Existing and potential tree canopy cover by council district.

percent). Neighborhood councils with the lowest TCC were Downtown Los Angeles (3 percent), Wilmington (5 percent), and Historic Cultural and Macarthur (6 percent). The mean TCC was 17.7 percent and standard deviation was 9.8 percent.

#### Accuracy assessment—

Overall classification accuracy was 88.6 percent based on the pixel-by-pixel comparison. The accuracy for classifying existing TCC was 74.3 percent (table 9). Not surprisingly, TCC was most often misclassified as irrigated grass (13 percent),

**We estimate that there are approximately 2.47 million potential tree planting sites. If all potential tree sites were filled and the canopy matured, TCC would increase to 33 percent from 21 percent.**

and vice versa (17 percent). In the parcel-scale analysis, impervious surface was underestimated by 3.5 percent and TCC was overestimated by 5.0 percent. Factors that affected mapping accuracy included the treatment of the shadowed area and minimum mapping units during digitizing.

## Potential Tree Planting Sites and Target Tree Canopy Cover

### Potential tree planting sites—

After calibrating computer-estimated potential tree sites with ground-truthed data, we estimate that there are approximately 2.47 million potential tree planting

**Table 8—Land use distribution by council district**

| Council District | Total area | Land use                |                |                                 |                |              |                |              |                |               |                |              |                |
|------------------|------------|-------------------------|----------------|---------------------------------|----------------|--------------|----------------|--------------|----------------|---------------|----------------|--------------|----------------|
|                  |            | Low-density residential |                | Medium/high-density residential |                | Industrial   |                | Commercial   |                | Institutional |                | Unknown      |                |
|                  |            | <i>Acres</i>            | <i>Percent</i> | <i>Acres</i>                    | <i>Percent</i> | <i>Acres</i> | <i>Percent</i> | <i>Acres</i> | <i>Percent</i> | <i>Acres</i>  | <i>Percent</i> | <i>Acres</i> | <i>Percent</i> |
| 1                | 7,949      | 1,117                   | 14.1           | 2,751                           | 34.6           | 1,017        | 12.8           | 1,299        | 16.3           | 1,763         | 22.2           |              |                |
| 2                | 20,295     | 12,760                  | 62.9           | 2,798                           | 13.8           | 1,113        | 5.5            | 1,323        | 6.5            | 2,294         | 11.3           | 8            | 0.04           |
| 3                | 24,359     | 17,486                  | 71.8           | 1,736                           | 7.1            | 846          | 3.5            | 1,754        | 7.2            | 2,537         | 10.4           |              |                |
| 4                | 15,403     | 6,374                   | 41.4           | 3,378                           | 21.9           | 482          | 3.1            | 1,460        | 9.5            | 3,709         | 24.1           |              |                |
| 5                | 24,317     | 17,094                  | 70.3           | 2,878                           | 11.8           | 215          | 0.9            | 1,638        | 6.7            | 2,488         | 10.2           | 4            | 0.02           |
| 6                | 17,047     | 6,723                   | 39.4           | 1,616                           | 9.5            | 3,776        | 22.2           | 934          | 5.5            | 3,997         | 23.4           | 1            | 0.01           |
| 7                | 15,789     | 8,550                   | 54.2           | 1,907                           | 12.1           | 1,121        | 7.1            | 879          | 5.6            | 3,332         | 21.1           |              |                |
| 8                | 11,174     | 4,750                   | 42.5           | 3,725                           | 33.3           | 235          | 2.1            | 1,604        | 14.4           | 860           | 7.7            |              |                |
| 9                | 9,564      | 339                     | 3.5            | 4,084                           | 42.7           | 2,389        | 25.0           | 1,639        | 17.1           | 1,113         | 11.6           |              |                |
| 10               | 8,541      | 1,841                   | 21.6           | 4,142                           | 48.5           | 465          | 5.4            | 1,361        | 15.9           | 731           | 8.6            |              |                |
| 11               | 25,922     | 12,004                  | 46.3           | 3,502                           | 13.5           | 1,170        | 4.5            | 1,377        | 5.3            | 4,373         | 16.9           | 3,496        | 13.49          |
| 12               | 29,232     | 19,595                  | 67.0           | 1,422                           | 4.9            | 2,177        | 7.4            | 1,224        | 4.2            | 4,813         | 16.5           | 1            | 0.01           |
| 13               | 7,845      | 1,110                   | 14.2           | 3,526                           | 44.9           | 504          | 6.4            | 1,439        | 18.3           | 1,265         | 16.1           | 1            | 0.01           |
| 14               | 13,972     | 5,053                   | 36.2           | 2,711                           | 19.4           | 2,635        | 18.9           | 1,090        | 7.8            | 2,483         | 17.8           |              |                |
| 15               | 20,976     | 5,356                   | 25.5           | 3,627                           | 17.3           | 7,547        | 36.0           | 1,109        | 5.3            | 3,335         | 15.9           | 2            | 0.01           |
| Total            | 252,384    | 120,151                 | 47.6           | 43,803                          | 17.4           | 25,693       | 10.2           | 20,130       | 8.0            | 39,093        | 15.5           | 3,514        | 1.39           |

**Table 9—Land cover classification error matrix (number and percentage of pixels correctly identified) for four classes<sup>a</sup>**

|          |       | Classification   |               |              |                  |           |             |             |             |             |  |
|----------|-------|------------------|---------------|--------------|------------------|-----------|-------------|-------------|-------------|-------------|--|
|          |       | Number of pixels |               |              |                  |           | Percent     |             |             |             |  |
|          |       | TCC              | IG            | S            | IP               | Total     | TCC         | IG          | S           | IP          |  |
| Base map | TCC   | <b>145,335</b>   | 25,451        | 2,871        | 21,905           | 195,562   | <b>74.3</b> | 13          | 1.5         | 11.2        |  |
|          | IG    | 17,290           | <b>65,188</b> | 5,989        | 11,369           | 99,836    | 17.3        | <b>65.3</b> | 6           | 11.4        |  |
|          | S     | 1,402            | 1,435         | <b>2,717</b> | 4,795            | 10,349    | 13.5        | 13.9        | <b>26.3</b> | 46.3        |  |
|          | IP    | 41,290           | 17,737        | 21,258       | <b>1,134,016</b> | 1,214,301 | 3.4         | 1.5         | 1.8         | <b>93.4</b> |  |
|          | Total | 205,317          | 109,811       | 32,835       | 1,172,085        | 1,520,048 | 13.5        | 7.2         | 2.2         | 77.1        |  |

TC = tree cover, IG = irrigated grass, S = soil, IP=impervious.

<sup>a</sup> Rows show the distribution of the class in the base map, columns show the distribution in quickbird pixels. The overall accuracy for all classes is 88.6 percent.

**Table 10—Existing and target tree canopy cover (TCC) and potential and additional tree numbers and TCC by council district and mature tree size class**

| Council district | Area    | Existing TCC |         | Potential trees |         |         |           | Additional trees |       |         |         | Additional TCC |           | Target TCC |       |                  |
|------------------|---------|--------------|---------|-----------------|---------|---------|-----------|------------------|-------|---------|---------|----------------|-----------|------------|-------|------------------|
|                  |         | Acres        | Percent | Small           | Medium  | Large   | Total     | Potential TCC    | Acres | Percent | Small   | Medium         | Large     |            | Total |                  |
|                  |         |              |         |                 |         |         |           |                  |       |         |         |                |           |            |       | -----Number----- |
| 1                | 7,949   | 1,266        | 15.9    | 23,821          | 18,320  | 7,087   | 49,228    | 713              | 9.0   | 11,910  | 11,856  | 3,543          | 27,310    | 400        | 5.0   | 21.0             |
| 2                | 20,295  | 5,395        | 26.6    | 109,200         | 78,161  | 16,590  | 203,950   | 2,459            | 12.1  | 54,600  | 44,750  | 8,295          | 107,645   | 1,322      | 6.5   | 33.1             |
| 3                | 24,359  | 6,345        | 26.0    | 144,751         | 89,421  | 18,905  | 253,078   | 2,890            | 11.9  | 72,376  | 52,755  | 9,453          | 134,583   | 1,576      | 6.5   | 32.5             |
| 4                | 15,403  | 4,429        | 28.8    | 70,179          | 45,282  | 12,265  | 127,726   | 1,572            | 10.2  | 35,090  | 28,126  | 6,133          | 69,348    | 875        | 5.7   | 34.4             |
| 5                | 24,317  | 9,047        | 37.2    | 107,119         | 52,056  | 8,465   | 167,640   | 1,661            | 6.8   | 53,560  | 29,120  | 4,232          | 86,912    | 881        | 3.6   | 40.8             |
| 6                | 17,047  | 2,550        | 15.0    | 66,538          | 64,545  | 15,175  | 146,258   | 2,001            | 11.7  | 33,269  | 38,289  | 7,587          | 79,145    | 1,098      | 6.4   | 21.4             |
| 7                | 15,789  | 2,572        | 16.3    | 116,529         | 86,463  | 29,355  | 232,347   | 3,199            | 20.3  | 58,264  | 48,120  | 14,678         | 121,062   | 1,679      | 10.6  | 26.9             |
| 8                | 11,174  | 1,192        | 10.7    | 84,116          | 61,943  | 17,577  | 163,637   | 2,139            | 19.1  | 42,058  | 34,534  | 8,788          | 85,380    | 1,127      | 10.1  | 20.8             |
| 9                | 9,564   | 719          | 7.5     | 40,970          | 31,665  | 7,481   | 80,115    | 1,017            | 10.6  | 20,485  | 19,925  | 3,740          | 44,150    | 575        | 6.0   | 13.5             |
| 10               | 8,541   | 1,018        | 11.9    | 47,971          | 27,641  | 8,037   | 83,649    | 1,005            | 11.8  | 23,986  | 16,389  | 4,018          | 44,393    | 544        | 6.4   | 18.3             |
| 11               | 25,922  | 6,094        | 23.5    | 132,350         | 84,742  | 22,527  | 239,619   | 2,927            | 11.3  | 66,175  | 47,814  | 11,264         | 125,253   | 1,552      | 6.0   | 29.5             |
| 12               | 29,232  | 5,796        | 19.8    | 180,791         | 127,648 | 34,104  | 342,543   | 4,342            | 14.9  | 90,396  | 74,985  | 17,052         | 182,433   | 2,352      | 8.0   | 27.9             |
| 13               | 7,845   | 1,072        | 13.7    | 37,459          | 24,539  | 6,150   | 68,148    | 827              | 10.5  | 18,730  | 15,331  | 3,075          | 37,135    | 463        | 5.9   | 19.6             |
| 14               | 13,972  | 3,126        | 22.4    | 39,821          | 29,272  | 7,244   | 76,337    | 963              | 6.9   | 19,911  | 17,627  | 3,622          | 41,159    | 530        | 3.8   | 26.2             |
| 15               | 20,976  | 1,871        | 8.9     | 90,963          | 116,363 | 27,585  | 234,912   | 3,501            | 16.7  | 45,482  | 62,570  | 13,793         | 121,844   | 1,822      | 8.7   | 17.6             |
| Total            | 252,384 | 52,493       | 20.8    | 1,292,578       | 938,062 | 238,546 | 2,469,186 | 31,219           | 12.4  | 646,289 | 542,192 | 119,273        | 1,307,754 | 16,797     | 6.7   | 27.5             |

sites in Los Angeles (table 10). This potential for new trees covers 31,219 acres, or 12 percent of the city. Hence, if all potential tree sites were filled and the canopy matured as noted above, TCC would increase to 33 percent from 21 percent. Fifty-two percent of these potential sites are for small trees (15-ft crown diameter at maturity), 38 percent for medium trees (30-ft at maturity), and 10 percent for large trees (50 ft). All potential parking lot tree sites, which are estimated to equal 258,642 (10.5 percent), are assumed to be for medium trees, although in reality there will be a mix of tree sizes.

The distribution of potential tree sites differs by land use. Low-density residential areas contain the largest number of potential sites (1.4 million, 58 percent), followed by institutional (377,574, 15 percent) and medium/high-density residential (360,382, 15 percent). Industrial and commercial land uses each contain about 6 percent (about 140,000) of the total potential tree planting sites.

Six council districts (2, 3, 7, 11, 12, and 15) have potential for over 200,000 new trees, with these trees adding an additional 11 to 20 percent TCC when mature and assuming no mortality (table 10). Five council districts (1, 9, 10, 13, and 14) have space for fewer than 100,000 trees, with potential to increase TCC by 7 to 12 percent (fig. 5).

#### **Target tree canopy cover–**

The target TCC for Los Angeles accounts for the fact that only about 50 percent of the potential sites are suitable for planting owing to residents' desire for no additional trees and conflicts with higher priority uses. Thus, it is realistic for Los Angeles to strive to increase its TCC by 6.7 percent (16,797 acres), which equates to 1.3 million tree sites (table 10). If all additional tree sites were filled and the canopy matured as noted above, TCC would increase to 28 percent from 21 percent. This finding indicates that the goal of planting 1 million trees is feasible.

The distribution of additional tree sites among size classes and land uses is similar to the distribution of potential sites described above. Most sites are for small and medium trees (49 percent and 42 percent). Over 70 percent of the target tree sites are located in low-density residential and institutional land uses. About 16 percent (202,482) of the sites are in large parking lots.

Filling additional tree sites in council districts with the least TCC would increase relative TCC the most (table 10). For example, TCC would increase by 9 to 10 percent in council districts 8 (from 10.7 to 20.8 percent) and 15 (from 8.9 to 17.6 percent) (fig. 6). Similarly, the relative increase would be least in council districts with the greatest TCC, for example, a 3.5-percent increase in council district 5 (from 37.2 to 40.8 percent). If the targeted TCC were filled with 1.3 million trees, TCC would range from 13 to 40 percent across council districts, instead of the current 8 to 37 percent.

In summary, the existing TCC of Los Angeles is 20.8 percent, comprising approximately 10.8 million trees (table 11). There is potential to add 2.5 million additional trees or 12.4 percent TCC. Thus, technical potential for Los Angeles is 33.2 percent TCC or about 13.3 million trees. However, it is not realistic to think that every possible tree site will be planted. Assuming that about 50 percent of

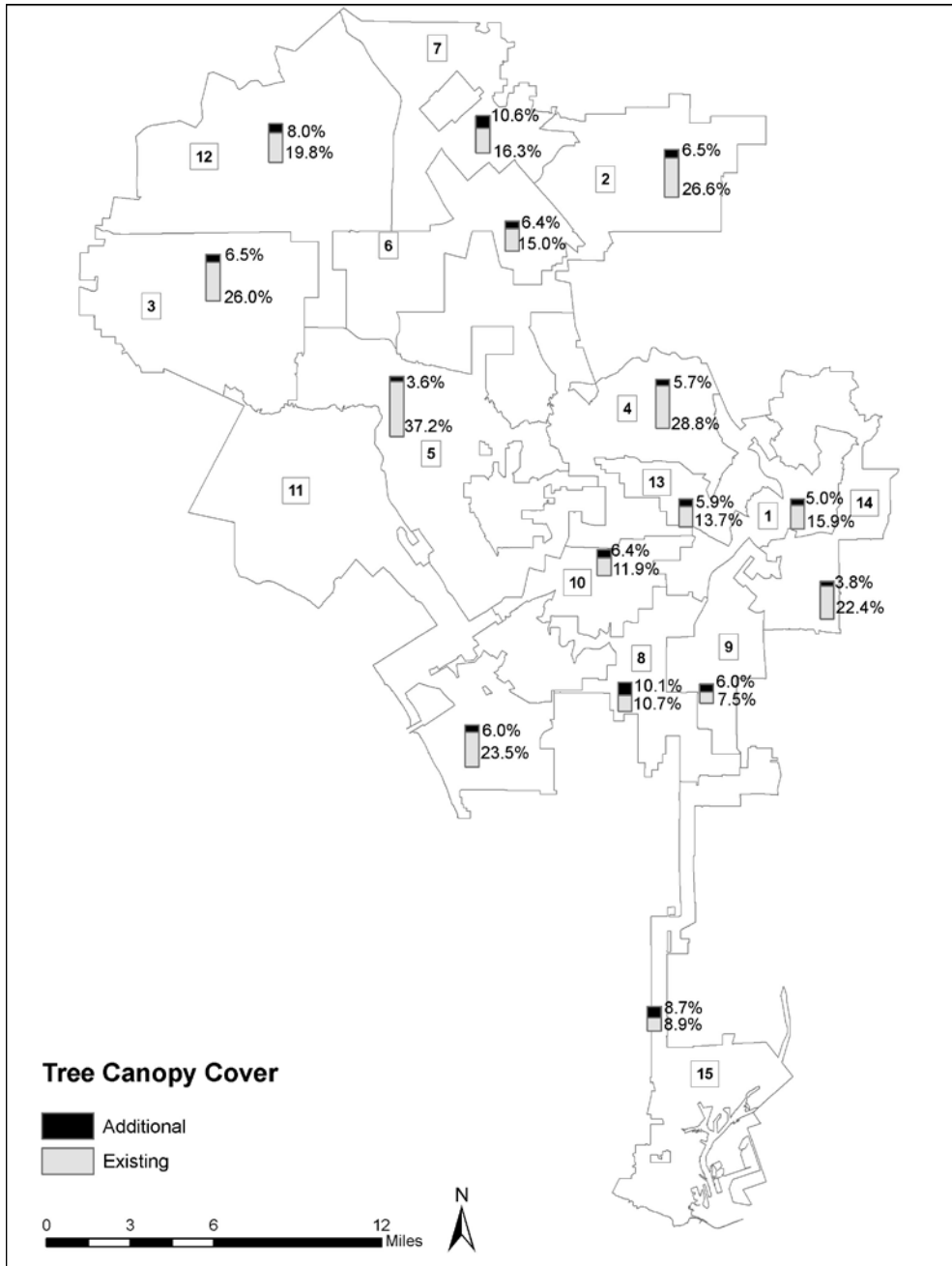


Figure 6—Existing and target tree canopy cover by council district.

the unplanted sites are feasible to plant results in adding 1.3 million more trees equivalent to a 6.7 percent increase in TCC. Hence, market potential (target TCC) is 27.5 percent of TCC or 12.1 million trees. Planting 1 million trees is feasible, and, if accomplished as indicated above, would saturate 97 percent of the existing market potential.

**Table 11—Summary of tree canopy cover and tree number estimates for Los Angeles**

|                             | Existing   | Potential | Tech potential | Additional | Target     |
|-----------------------------|------------|-----------|----------------|------------|------------|
| Tree canopy cover (percent) | 20.8       | 12.4      | 33.2           | 6.7        | 27.5       |
| Tree numbers                | 10,824,628 | 2,469,186 | 13,293,814     | 1,307,754  | 12,132,382 |

**Benefits From 1 Million Trees**

Benefits forecast from the planting of 1 million trees in Los Angeles depend on tree mortality, as well as climate zone, land use, and tree species. Our planting scenarios reflect effects of low (17 percent) and high (56 percent) mortality rates on tree numbers and associated benefits. After 35 years (2040), the number of surviving trees equals 828,924 and 444,889 for the low- and high-mortality scenarios, respectively. In both scenarios, the 1-million planted trees are distributed among council districts (fig. 7) and land uses such that 55 percent are in low-density residential, 17 percent in institutional, 14 percent in medium/high-density residential, 9 percent in commercial, and 5 percent in industrial. Nearly one-half of the trees are small (49 percent), 42 percent are medium, and 9 percent are large at maturity.

**Citywide benefits—**

Benefits calculated annually and totaled for the 35-year period are \$1.33 and \$1.95 billion for the high- and low-mortality scenarios, respectively (tables 12 and 13). These values translate into \$1,328 and \$1,951 per tree planted, or \$38 and \$56 per tree per year when divided by the 35-year period.

Eighty-one percent of total benefits are aesthetic/other, 8 percent are stormwater runoff reduction, 6 percent energy savings, 4 percent air quality improvement, and less than 1 percent atmospheric carbon reduction (fig. 8).

**Benefits by land use and council district—**

The distribution of benefits among council districts is closely related to the climate zone and the number of trees. Benefits per tree are about 50 percent less (\$700 to 1,000 instead of \$1,300 to 2,400) in the coastal zone (council districts 11 and

**Another factor influencing the distribution of benefits among council districts is the mix of land uses. Districts with relatively less land for housing and relatively more land for commercial, industrial, and institutional use have lower benefits per tree planted.**

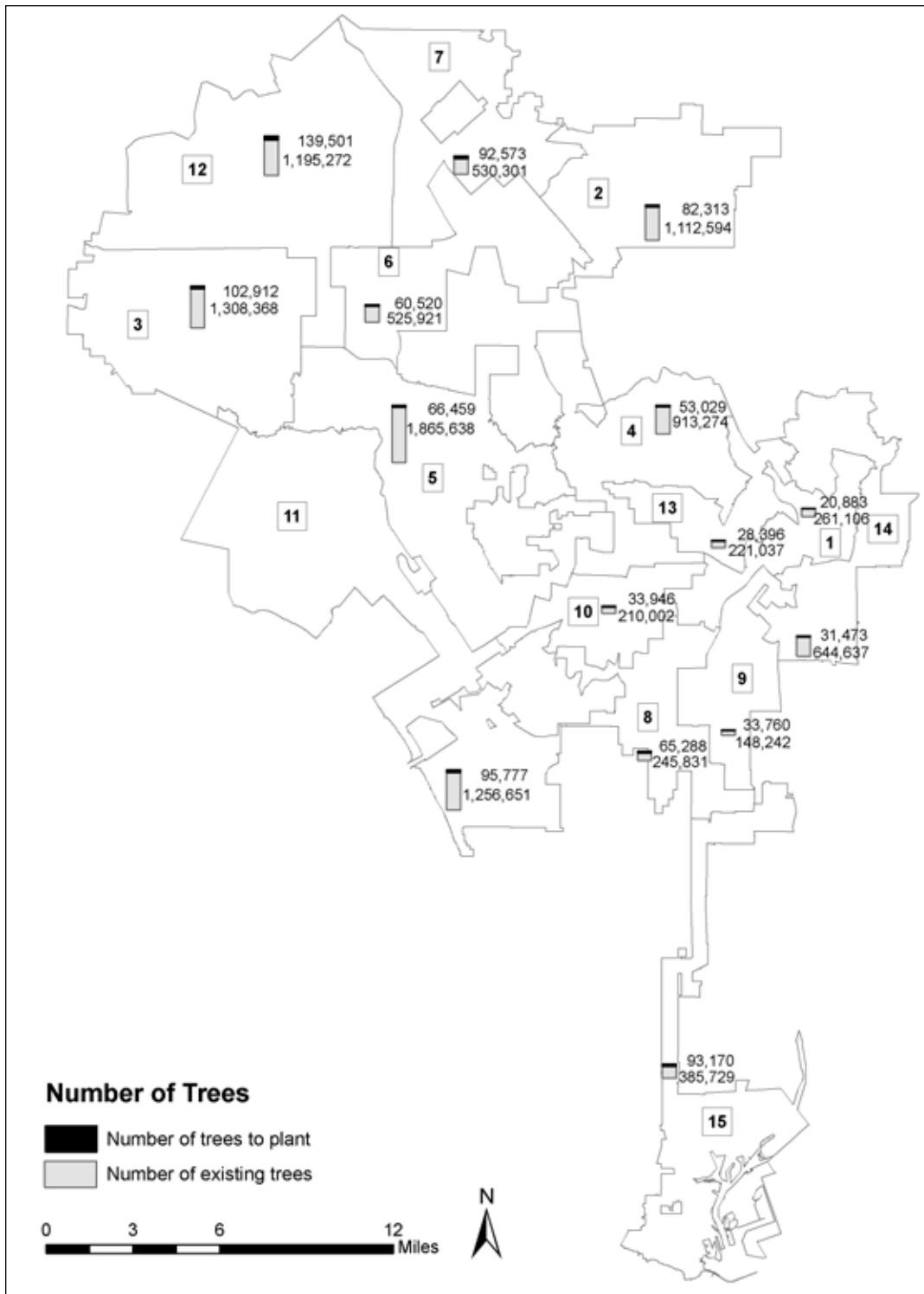


Figure 7—Number of existing trees and trees to plant (1 million total) by council district.

**Table 12—Cumulative benefits (2006–2040) and average benefit per tree planted by council district for the low-mortality scenario**

| Council district | Trees planted | Trees alive in 2040 | Energy      |                  | Air quality |                  | Carbon dioxide |                  | Runoff      |                  | Aesthetic/other |                  | Total benefits |                  |
|------------------|---------------|---------------------|-------------|------------------|-------------|------------------|----------------|------------------|-------------|------------------|-----------------|------------------|----------------|------------------|
|                  |               |                     | Dollars     | Dollars per tree | Dollars     | Dollars per tree | Dollars        | Dollars per tree | Dollars     | Dollars per tree | Dollars         | Dollars per tree | Dollars        | Dollars per tree |
| 1                | 20,883        | 17,311              | 1,415,847   | 68               | 1,762,961   | 84               | 162,689        | 8                | 3,950,229   | 189              | 31,278,375      | 1,498            | 38,570,101     | 1,847            |
| 2                | 82,313        | 68,231              | 12,974,614  | 158              | 7,850,324   | 95               | 859,878        | 10               | 14,621,169  | 178              | 156,354,878     | 1,900            | 192,660,864    | 2,341            |
| 3                | 102,912       | 85,306              | 15,351,113  | 149              | 9,400,287   | 91               | 1,013,258      | 10               | 17,362,590  | 169              | 181,878,208     | 1,767            | 225,005,456    | 2,186            |
| 4                | 53,029        | 43,957              | 5,549,222   | 105              | 4,536,519   | 86               | 443,172        | 8                | 9,291,042   | 175              | 82,645,520      | 1,559            | 102,465,473    | 1,932            |
| 5                | 66,459        | 55,090              | 10,213,205  | 154              | 5,708,874   | 86               | 622,241        | 9                | 9,757,767   | 147              | 109,185,934     | 1,643            | 135,488,021    | 2,039            |
| 6                | 60,520        | 50,167              | 6,845,792   | 113              | 5,679,725   | 94               | 553,869        | 9                | 12,293,102  | 203              | 105,723,228     | 1,747            | 131,095,715    | 2,166            |
| 7                | 92,573        | 76,736              | 13,470,678  | 146              | 8,848,116   | 96               | 1,007,167      | 11               | 16,254,404  | 176              | 177,691,502     | 1,919            | 217,271,868    | 2,347            |
| 8                | 65,288        | 54,119              | 10,358,233  | 159              | 6,331,353   | 97               | 721,359        | 11               | 11,505,944  | 176              | 131,054,146     | 2,007            | 159,971,035    | 2,450            |
| 9                | 33,760        | 27,984              | 2,330,587   | 69               | 2,768,387   | 82               | 231,661        | 7                | 6,439,504   | 191              | 47,375,894      | 1,403            | 59,146,034     | 1,752            |
| 10               | 33,946        | 28,139              | 4,063,135   | 120              | 2,911,931   | 86               | 303,757        | 9                | 5,524,913   | 163              | 55,755,710      | 1,642            | 68,559,446     | 2,020            |
| 11               | 95,777        | 79,392              | 4,494,173   | 47               | 4,561,895   | 48               | 319,986        | 3                | 5,135,221   | 54               | 77,801,510      | 812              | 92,312,785     | 964              |
| 12               | 139,501       | 115,635             | 20,486,019  | 147              | 13,172,516  | 94               | 1,442,660      | 10               | 24,774,501  | 178              | 259,540,968     | 1,860            | 319,416,665    | 2,290            |
| 13               | 28,396        | 23,538              | 2,530,265   | 89               | 2,347,087   | 83               | 214,871        | 8                | 5,031,419   | 177              | 42,054,322      | 1,481            | 52,177,964     | 1,837            |
| 14               | 31,473        | 26,089              | 3,444,288   | 109              | 2,774,938   | 88               | 271,603        | 9                | 5,761,254   | 183              | 51,541,911      | 1,638            | 63,793,994     | 2,027            |
| 15               | 93,170        | 77,231              | 3,895,333   | 42               | 4,755,920   | 51               | 309,052        | 3                | 5,382,414   | 58               | 78,262,865      | 840              | 92,605,585     | 994              |
| Total            | 1,000,000     | 828,924             | 117,422,505 | 117              | 83,410,834  | 83               | 8,477,224      | 8                | 153,085,472 | 153              | 1,588,144,972   | 1,588            | 1,950,541,007  | 1,951            |

Table 13—Cumulative benefits (2006–2040) and average benefit per tree planted by council district for the high-mortality scenario

| Council district | Trees planted | Trees alive in 2040 | Energy     |                  | Air quality |                  | Carbon dioxide |                  | Runoff     |                  | Aesthetic/other |                  | Total benefits |                  |
|------------------|---------------|---------------------|------------|------------------|-------------|------------------|----------------|------------------|------------|------------------|-----------------|------------------|----------------|------------------|
|                  |               |                     | Dollars    | Dollars per tree | Dollars     | Dollars per tree | Dollars        | Dollars per tree | Dollars    | Dollars per tree | Dollars         | Dollars per tree | Dollars        | Dollars per tree |
| 1                | 20,883        | 9,291               | 912,296    | 44               | 1,121,764   | 54               | 94,218         | 4.51             | 2,511,415  | 120.26           | 21,507,152      | 1,030            | 26,146,845     | 1,252            |
| 2                | 82,313        | 36,620              | 8,367,563  | 102              | 5,008,384   | 61               | 522,874        | 6.35             | 9,295,655  | 112.93           | 107,544,314     | 1,307            | 130,738,789    | 1,588            |
| 3                | 102,912       | 45,784              | 9,900,006  | 96               | 5,996,296   | 58               | 616,283        | 5.99             | 11,037,937 | 107.26           | 124,949,646     | 1,214            | 152,500,169    | 1,482            |
| 4                | 53,029        | 23,592              | 3,578,062  | 67               | 2,890,179   | 55               | 264,175        | 4.98             | 5,906,717  | 111.39           | 56,805,841      | 1,071            | 69,444,974     | 1,310            |
| 5                | 66,459        | 29,567              | 6,586,022  | 99               | 3,642,382   | 55               | 381,817        | 5.75             | 6,202,337  | 93.33            | 74,881,653      | 1,127            | 91,694,211     | 1,380            |
| 6                | 60,520        | 26,925              | 4,415,479  | 73               | 3,619,609   | 60               | 329,891        | 5.45             | 7,816,601  | 129.16           | 72,874,493      | 1,204            | 89,056,074     | 1,472            |
| 7                | 92,573        | 41,185              | 8,687,081  | 94               | 5,642,314   | 61               | 605,258        | 6.54             | 10,333,083 | 111.62           | 122,123,766     | 1,319            | 147,391,503    | 1,592            |
| 8                | 65,288        | 29,046              | 6,678,559  | 102              | 4,038,655   | 62               | 436,477        | 6.69             | 7,314,704  | 112.04           | 90,137,473      | 1,381            | 108,605,867    | 1,663            |
| 9                | 33,760        | 15,019              | 1,500,722  | 44               | 1,761,633   | 52               | 135,277        | 4.01             | 4,094,339  | 121.28           | 32,600,171      | 966              | 40,092,141     | 1,188            |
| 10               | 33,946        | 15,102              | 2,618,321  | 77               | 1,855,579   | 55               | 182,259        | 5.37             | 3,512,055  | 103.46           | 38,273,115      | 1,127            | 46,441,329     | 1,368            |
| 11               | 95,777        | 42,610              | 2,921,106  | 30               | 2,966,367   | 31               | 190,585        | 1.99             | 3,320,115  | 34.67            | 55,843,968      | 583              | 65,242,141     | 681              |
| 12               | 139,501       | 62,062              | 13,211,419 | 95               | 8,401,166   | 60               | 871,748        | 6.25             | 15,750,370 | 112.91           | 178,387,854     | 1,279            | 216,622,557    | 1,553            |
| 13               | 28,396        | 12,633              | 1,630,553  | 57               | 1,494,522   | 53               | 127,237        | 4.48             | 3,198,768  | 112.65           | 28,920,459      | 1,018            | 35,371,539     | 1,246            |
| 14               | 31,473        | 14,002              | 2,220,566  | 71               | 1,768,095   | 56               | 162,091        | 5.15             | 3,662,890  | 116.38           | 35,447,144      | 1,126            | 43,260,785     | 1,375            |
| 15               | 93,170        | 41,451              | 2,521,639  | 27               | 3,091,410   | 33               | 181,931        | 1.95             | 3,477,891  | 37.33            | 55,895,029      | 600              | 65,167,901     | 699              |
| Total            | 1,000,000     | 444,889             | 75,749,392 | 76               | 53,298,356  | 53               | 5,102,121      | 5.10             | 97,434,876 | 97.43            | 1,096,192,081   | 1,096            | 1,327,776,826  | 1,328            |

15) than the inland zone because the growth curve data indicate that the trees are smaller, air pollutant concentrations are lower, and building heating and cooling loads are less because of the milder climate (figs. 9 and 10).

Another factor influencing the distribution of benefits among council districts is the mix of land uses (fig. 11). Districts with relatively less land for housing and relatively more land for commercial, industrial, and institutional use have lower benefits per tree planted. Energy savings are less because our model did not estimate benefits for heating and cooling effects in nonresidential buildings. Our model did not incorporate effects of trees on cooling and heating of nonresidential buildings. For example, residential land uses occupied only 35 to 37 percent of the land in council districts 1 and 9, and average benefits were among the lowest per tree (about \$1,800 and \$1,200 for low- and high-mortality scenarios) for all inland council districts. On the other hand, in council districts 2, 7, and 8, residential land uses exceeded 52 percent of total land, and average benefits were the highest (greater than \$2,300 per tree for the low-mortality scenario).

## Citywide Benefits by Benefit Type

### **Aesthetic and other benefits—**

Citywide, aesthetic/other benefits ranged from \$1.1 to \$1.6 billion, or \$1,100 to \$1,600 per tree over the 35-year period for the high- and low-mortality scenarios. This amount reflects the economic contribution of trees to property sales prices and retail sales, as well as other benefits such as beautification, privacy, wildlife habitat, sense of place, psychological and spiritual well-being.

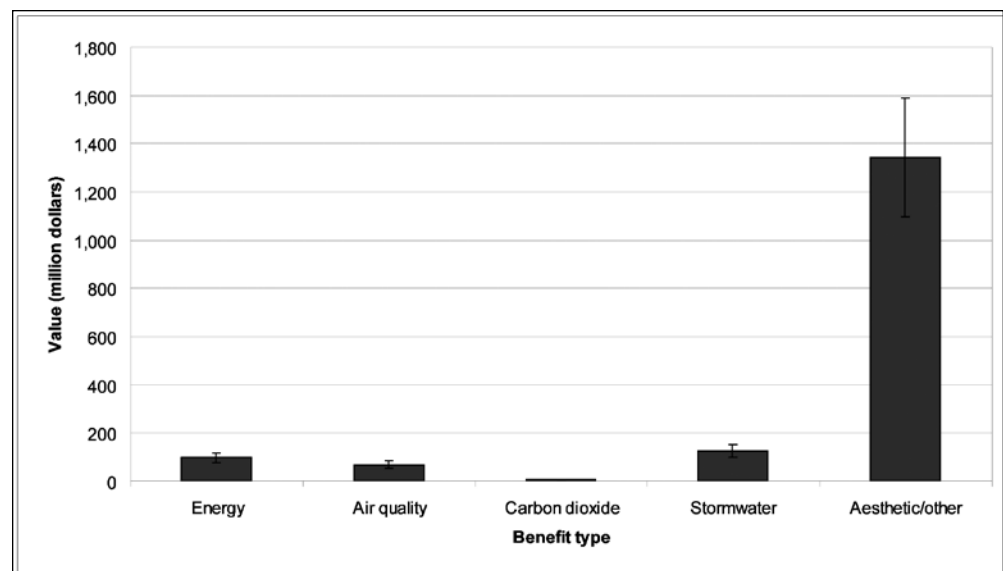


Figure 8—Total average value of benefits over the 35-year period by benefit type. Error bars show values for the low- and high-mortality scenarios.

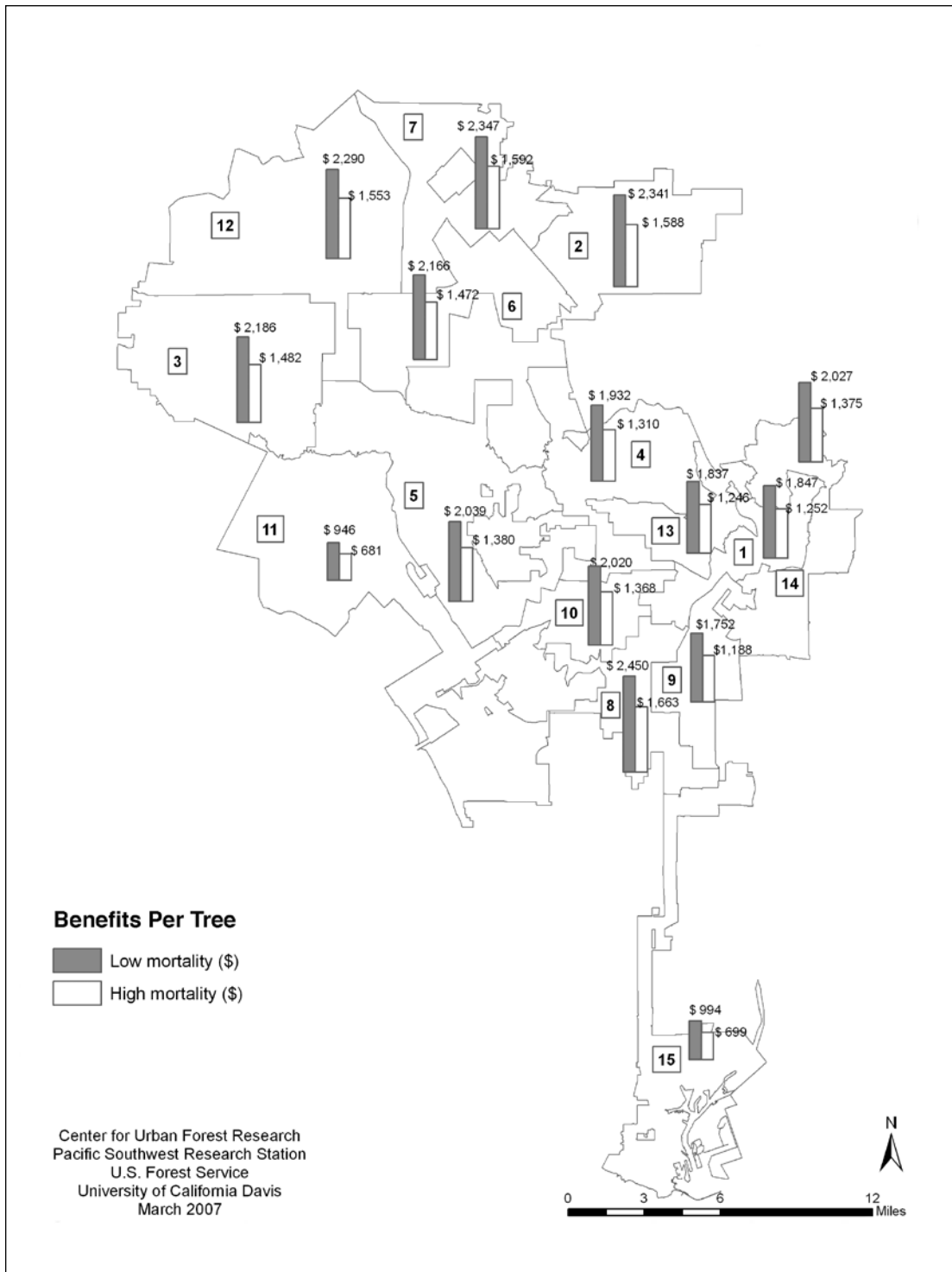


Figure 9— Average benefit per tree over the 35-year period for the low- and high-mortality scenarios.

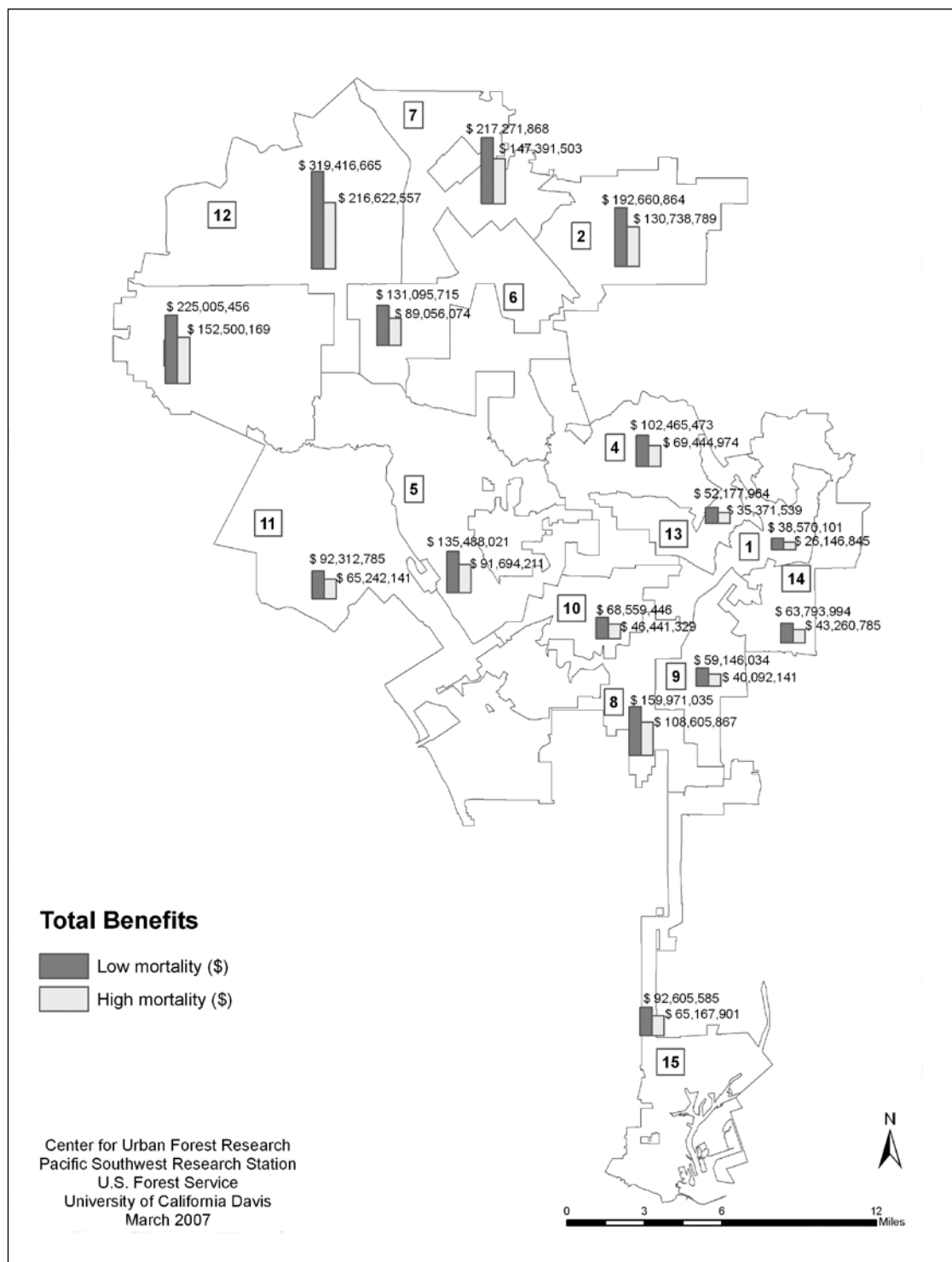


Figure 10— Total value of benefits over the 35-year period for the low- and high-mortality scenarios.

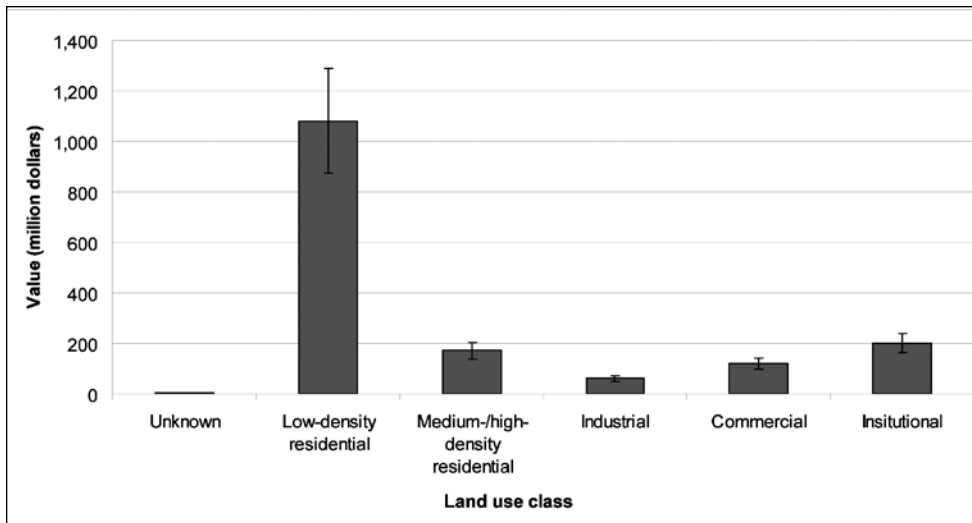


Figure 11—Total average value of benefits by land use class. Error bars show values for the low- and high-mortality scenarios.

### Stormwater runoff reduction—

By intercepting rainfall in their crowns, trees reduce stormwater runoff and thereby protect water quality. Over the 35-year span of the project, 1 million trees will reduce runoff by approximately 17.4 billion gal (2.3 billion cubic feet; fig. 12). The value of this benefit is \$125.3 million. The average annual interception rate per tree ranges from a low of 102 gal for the crapemyrtle (representative of small trees in the inland zone) to a high of 1,481 gal for the jacaranda (representative of medium trees in the inland zone). The difference is related to tree size and foliage period. The crapemyrtle is small at maturity and is deciduous during the rainy winter season, whereas the jacaranda develops a broad spreading crown and is in-leaf during the rainy season.

### Energy-use reduction—

By shading residential buildings and lowering summertime air temperatures, the 1 million trees are projected to reduce electricity consumed for air conditioning by 917,000 MWh or \$97 million (fig. 13). However, this cooling savings is partially offset by increased heating costs from tree shade that obstructs winter sunlight. Tree shade is expected to increase natural gas required for heating by 127,331 MBtu, which is valued at \$851,000. Despite this cost, a net energy savings of \$96 million is projected. The adverse effects of winter tree shade can be limited by strategically locating trees and selecting solar-friendly species for locations where solar access is a concern (McPherson et al. 2000, 2001).

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**Over its 35-year planning horizon, the 1-million-tree planting is projected to reduce atmospheric CO<sub>2</sub> by 1.02 million tons. Assuming this benefit is priced at \$6.68 per ton, the corresponding value is \$7.5 million.**

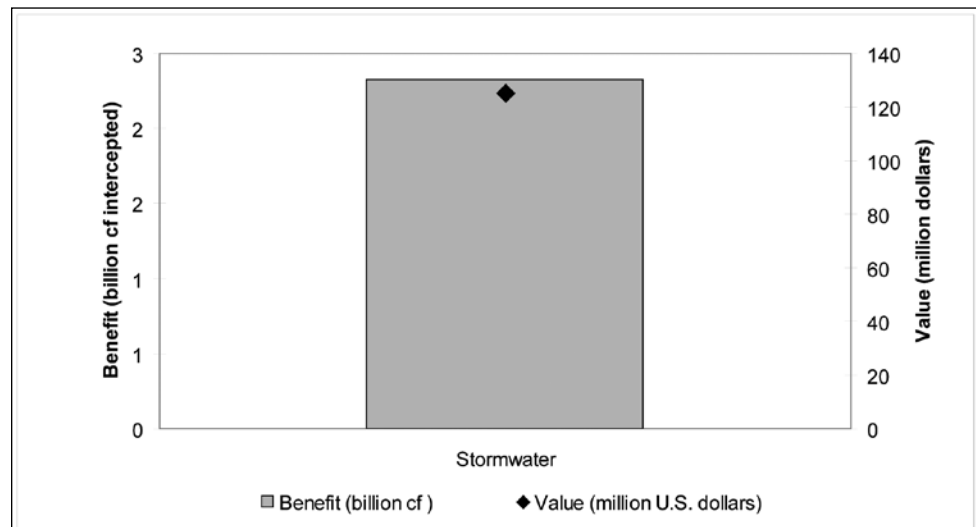


Figure 12—Total average value of stormwater runoff reduction benefits for the 35-year period.

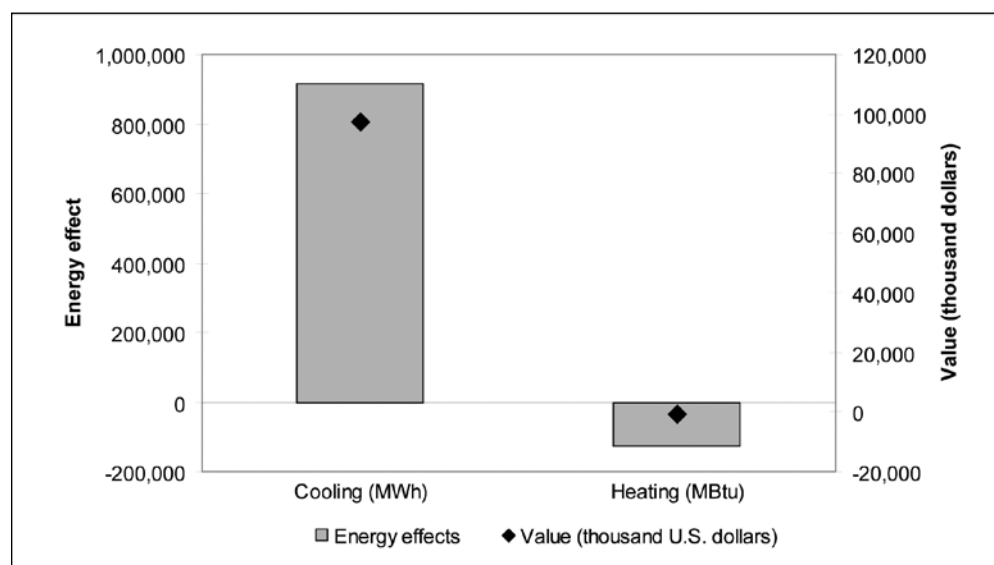


Figure 13—Total average value of tree effects on residential cooling (electricity, MWh) and heating (natural gas, MBtu) energy use for the 35-year period.

#### Atmospheric carbon dioxide reduction—

Over its 35-year planning horizon, the 1-million-tree planting is projected to reduce atmospheric CO<sub>2</sub> by 1.02 million tons (fig. 14). Assuming this benefit is priced at \$6.68 per ton, the corresponding value is \$7.5 million. Emission reductions at power plants associated with effects of the trees on building energy use (498,000 to 772,000 tons) are greater than biological sequestration of CO<sub>2</sub> by the trees

themselves (389,000 to 598,000 tons). A relatively small amount of CO<sub>2</sub> is released during tree care and decomposition of dead biomass (101,000 to 123,000 tons). The CO<sub>2</sub> reduction benefit varies widely based on tree size. For example, in the inland zone for the low-mortality scenario, the small crapemyrtle annually sequesters and reduces emissions by only 5 and 55 lb per tree on average, compared to 220 and 150 lb for the large evergreen ash. Where space permits, strategically locating large trees to reduce home cooling costs will result in substantial benefits to mitigate climate change.

#### **Air quality improvement—**

By improving air quality, the tree planting will enhance human health and environmental quality in Los Angeles. This benefit is valued at \$68 million over the 35-year planning horizon (fig. 15). Interception of PM<sub>10</sub> and uptake of O<sub>3</sub> and NO<sub>2</sub> are especially valuable. The 1-million-tree planting project is estimated to intercept and reduce power plant emissions of PM<sub>10</sub> by 2,365 tons over the 35-year period. The value of this benefit is \$24 million, or 35 percent of total air quality benefits. For the low-mortality example, annual deposition rates average 0.14 to 0.19 lb per tree for the medium tree in coastal and inland zones, while corresponding emission reductions range from 0.04 to 0.12 lb.

The 1 million trees are projected to reduce O<sub>3</sub> by 3,121 tons, with average annual deposition rates ranging from 0.25 to 0.35 lb per medium tree in the low-mortality scenario for the coastal and inland zones, respectively. Ozone uptake is valued at \$23 million over the project life, or 34 percent of total air quality benefits. Uptake of NO<sub>2</sub>, an ozone precursor, is estimated at 2,494 tons, with a value of \$18.7 million over the 35-year period. This benefit accounts for 27 percent of the total air quality benefit. A small amount of VOC emissions from power plants will be reduced because of energy savings. However, this analysis does not incorporate costs associated with biogenic VOCs, because all five species are low emitters.

## **Discussion**

### **Comparison of Results**

In Los Angeles, the existing TCC is 20.8 percent, which is close to the 20 percent TCC in Baltimore and 23 percent in New York City (table 14). This is surprising given Los Angeles's Mediterranean climate, which makes irrigation essential for establishment and growth of many tree species. However, the technical potential (existing TCC plus potential TCC) is much less in Los Angeles than reported for the other two cities. In Los Angeles, the technical potential (33 percent) represents only a 12-percent increase in TCC above the existing 21 percent. Hence, the PTCC is 57 percent of existing TCC. In New York City and Baltimore, the PTCC is 187

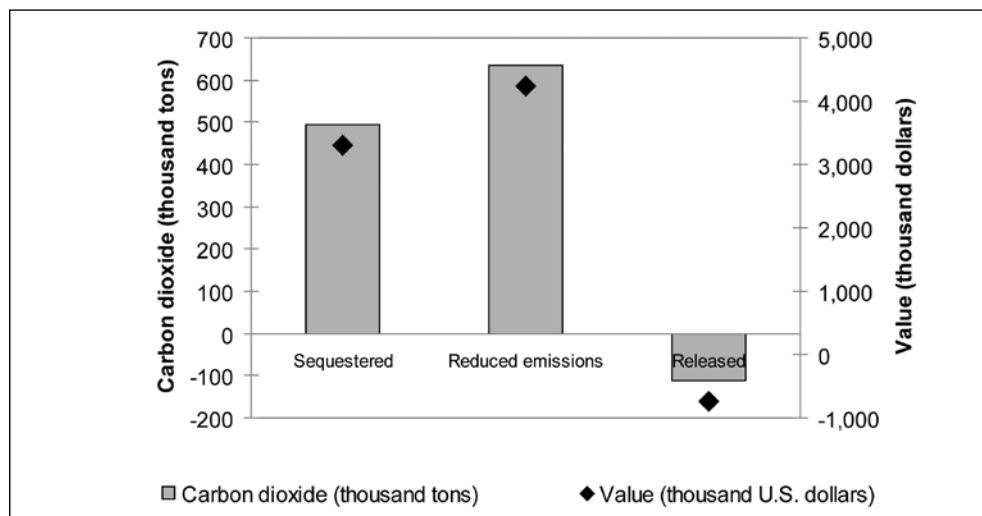


Figure 14—Total average value of carbon dioxide sequestration, emission reductions associated with energy effects, and release owing to tree care activities and decomposition of dead wood (1 short ton = 2,000 lb).

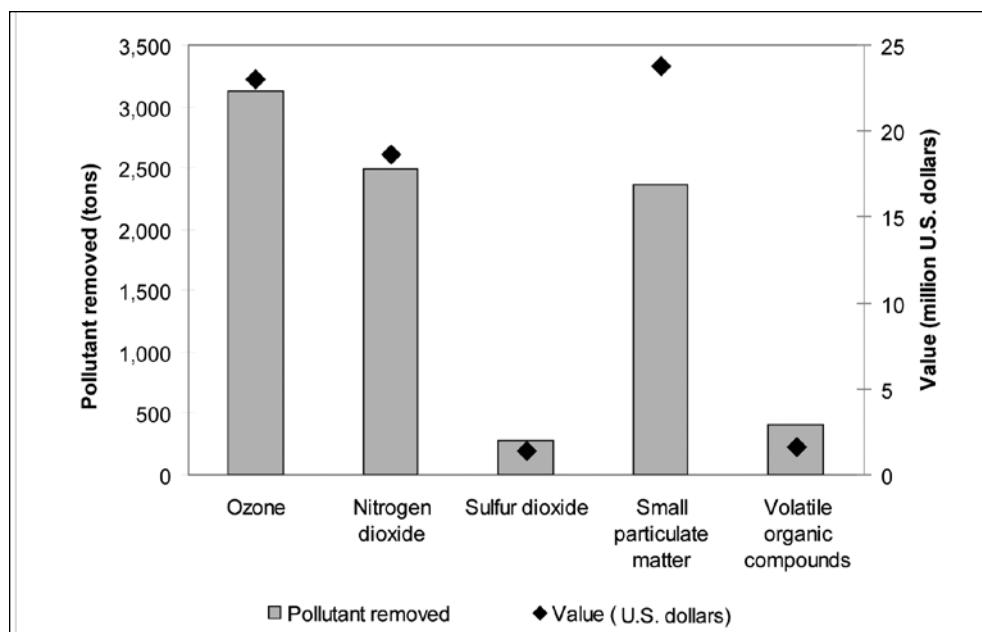


Figure 15—Total average value of tree effects on ozone, nitrogen dioxide, sulfur dioxide, particulate matter and volatile organic compounds. These values account for deposition to the tree canopy and emission reductions associated with energy effects.

**Table 14—Tree canopy cover (percentage) results for three U.S. cities**

| City          | Existing | Potential | Technical potential | Market potential |
|---------------|----------|-----------|---------------------|------------------|
|               |          |           | Percent             |                  |
| Los Angeles   | 21       | 12        | 33                  | 28               |
| New York City | 23       | 43        | 66                  | 30               |
| Baltimore     | 20       | 53        | 73                  | 40               |

percent and 265 percent times the existing TCC. This finding suggests that there is much less available growing space for trees in Los Angeles than in the other cities. Although we do not have a definitive explanation for this result, one reason may be the masking of mountain areas from our study site, which eliminated many potential tree planting sites.

In Los Angeles and Baltimore, the target TCC equals the existing TCC plus about one-half the difference between existing and technical PTCC. In New York City, the target is a much smaller percentage of the technical TCC. The lower target in New York City may reflect the fact that a larger proportion of PTCC is in open spaces where new plantings would conflict with existing uses such as ball fields and prairie landscapes.

We compared results of the benefits assessment with previous benefit-cost analyses in our tree guides for coastal southern California and Inland Empire communities (McPherson et al. 2000, 2001). We expected differences in results because the simulations for this study used more recent air quality data and median home sales prices, and different benefit prices and tree mortality rates. Nevertheless, the dollar values of average annual benefits compared well. In the coastal southern California tree guide, average annual benefits for the representative small and medium street trees were \$22 and \$48, compared to \$38 for this study (low-mortality scenario). In the Inland Empire tree guide, the average annual benefit was \$15 and \$61 for the small and medium trees. In this study, the corresponding value was \$56 (assumes 50 percent small, 41 percent medium, 9 percent large). Hence, benefit values reported here are reasonable when compared with previously reported findings from similar analyses for the same region.

## Uncertainty and Limitations

There are several sources of error associated with these benefit projections. One source of error pertains to land cover classification. Inaccurate land cover classification results in inaccurate assessments of potential tree planting sites when pervious sites without trees are misclassified as having trees or as impervious, and impervious sites are misclassified as pervious and without trees. Our image classification assessment indicates that overall classification accuracy is 88.6 percent based on a pixel-by-pixel comparison.

Although ground-truthing of computer-based estimates of potential tree sites led to a calibration of the estimates, other errors can reduce the accuracy of estimates. For example, the computer-based method can miss potential tree sites in large open spaces because a limited number of iterations are run for each tree size class. Potential tree planting sites in parking lots in medium/high-density housing areas were not included. These types of limitations were observed during a work-

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**The benefits quantified here should be considered a conservative estimate. They do not include many other benefits that are more difficult to translate into dollar terms.**

shop in Los Angeles when 15 sample areas were reviewed by local program participants. Computer-based tree sites were confirmed, deleted, and added based on local understanding of tree planting potential. Our informal findings were that the largest discrepancies between computer- and human-based potential tree sites were for institutional and industrial land uses, whereas estimates for residential land uses were in close agreement.

Modeling error influences the accuracy of benefit estimates. In this analysis we used three representative species in two climate zones, an obvious simplification of the actual tree planting program. In reality, over 100 species will be planted throughout the city, which has a myriad of microclimates. Therefore, these results are only accurate to the extent that the actual trees planted resemble the size and foliage characteristics of the species mix we have used here.

Our numerical models do not fully account for effects of BVOC emissions from trees on O<sub>3</sub> formation, or the effects of shade from new trees on VOC emissions from parked cars and other anthropogenic sources. We also have not simulated the effects of trees on nonresidential building energy use.

Over three-quarters of total value is for aesthetic and other benefits, and our understanding of this type of benefit is least certain. To estimate this value, we rely on research conducted in Georgia that may not be directly transferable to Los Angeles. Moreover, we assume that our value fully accounts for all the other benefits associated with city trees that have not been explicitly calculated.

The benefits quantified here should be considered a conservative estimate. They do not include many other benefits that are more difficult to translate into dollar terms. For example, tree shade on streets can help offset pavement management costs by protecting paving from weathering. The asphalt paving on streets contains stone aggregate in an oil binder. Tree shade lowers the street surface temperature and reduces heating and volatilization of the binder (McPherson and Muchnick 2005). As a result, the aggregate remains protected for a longer period by the oil binder. When unprotected, vehicles loosen the aggregate, and much like sandpaper, the loose aggregate grinds down the pavement. Because most weathering of asphalt-concrete pavement occurs during the first 5 to 10 years, when new street tree plantings provide little shade, this benefit mainly applies when older streets are resurfaced.

Scientific studies confirm our intuition that trees in cities provide social and psychological benefits. Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan and Kaplan 1989). Desk workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared to those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation

and relaxation in and near cities. The act of planting trees can have social value, as bonds between people and local groups often result.

The presence of trees in cities provides public health benefits and improves the well-being of those who live, work, and play in cities. Physical and emotional stress has both short- and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving show that views of nature reduce the stress response of both body and mind (Parsons et al. 1998). Urban green also appears to have an “immunization effect” in that people show less stress response if they have had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, have a better outlook, and recover more quickly than patients without connections to nature (Ulrich 1985). Skin cancer is a particular concern in sunny southern California. Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999). Our accounting approach may not capture the full value of all benefits associated with a large-scale tree planting program in Los Angeles.

#### **Dissemination of Data—**

The GIS data on existing TCC and potential tree planting sites, as well as information on the projected benefits of 1 million new trees are valuable assets for the city and its residents. To manage and disseminate this information, we suggest the following:

- The city designate a central clearinghouse for GIS data related to the Million Trees LA program. Data from this and other studies could be accessed through the clearinghouse.
- Million Trees LA develop a handout that summarizes key points from this study, particularly the future benefits to be gained from investment in tree planting and stewardship.
- To document all aspects of this research and make it readily accessible, the Center for Urban Forest Research publish a General Technical Report, peer-reviewed and available at no cost to the public through the U.S. Forest Service.
- Important aspects of this study be summarized and posted on the Million Trees LA Web site.

#### **Implementation of the program—**

Information on the benefits of this large-scale tree planting program can be helpful in developing partnerships with investors. For example, corporations may invest in the program because they can report carbon credits from trees that help offset

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**To attract serious investment, the program will have to demonstrate that the benefits from these trees will be permanent and quantifiable. To do this will entail a commitment to accountability through annual monitoring and reporting.**

their emissions. Similarly, if the South Coast Air Quality Management District includes trees as an air quality improvement measure in their State Implementation Plan, more funds for tree planting and management would become available. To capitalize on these opportunities, the Million Trees LA program will need a credible process for tracking tree planting and monitoring the survival, growth, and functionality of its trees. To attract serious investment, the program will have to demonstrate that the benefits from these trees will be permanent and quantifiable. To do this will entail a commitment to accountability through annual monitoring and reporting.

The Center for Urban Forest Research proposes working with Million Trees LA to develop a GIS Decision-Support System (GDSS) that provides a user-friendly interface for making use of the data from this study for planning and implementation of neighborhood tree planting projects by tree planting coordinators such as NorthEast Trees and TreePeople. The GDSS will allow users without extensive GIS experience to examine different parcels, select and locate trees to provide the greatest benefits, budget for planting and maintenance costs, project the future stream of benefits, assess the ecological stability of the planting at a population level, and track future tree survival and growth. The GDSS will help Los Angeles maximize its return on investment in tree planting through application of state-of-the-art science and technology. The project will require 1 year and cost approximately \$175,000.

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**The Center for Urban Forest Research proposes to collaborate with other scientists in southern California to study the effects of trees on the social, economic, and environmental health of Los Angeles and its nearly 4 million residents.**

Approximately 20 percent of the target TCC for Los Angeles is paved parking lot area. Planting trees in parking lots poses technical and financial challenges. However, if done judiciously, there are opportunities for parking lot tree plantings to substantially improve air quality, reduce stormwater runoff, cool urban heat islands, and improve community attractiveness. To accomplish this, the program could establish new partnerships aimed at developing the technical specifications, financial means, and community support for a major parking lot greening effort in Los Angeles that could serve as a model for cities around the world.

The Center for Urban Forest Research proposes to collaborate with other scientists in southern California to study the effects of trees on the social, economic, and environmental health of Los Angeles and its nearly 4 million residents. In particular, we need to better understand:

- Barriers to tree planting and incentives for different markets
- Effects of trees on the urban heat island and air quality
- Effects of drought stress on tree survival and ability to remove air pollutants
- Primary causes of tree mortality

- Best management practices to promote tree survival
- Citywide policy scenarios to promote urban tree canopy, neighborhood desirability, and economic development
- How to link TCC goals to other city goals: increasing community health, neighborhood quality of life, environmental literacy, and sustainability.

#### Future Research—

As the second largest city in the United States, Los Angeles manages an extensive municipal forest. Its management could set the standard for the region and the country. To do so, the Center for Urban Forest Research and the city of Los Angeles could cooperate to conduct a tree inventory and assessment that provides information on the existing urban forest:

- Structure (species composition, diversity, age distribution, condition, etc.)
- Function (magnitude of environmental and aesthetic benefits)
- Value (dollar value of benefits realized)
- Management needs (sustainability, maintenance, costs)
- Management recommendations aimed at increasing resource sustainability.

Los Angeles is a vibrant city that will continue to grow. As it grows it should also continue to invest in its tree canopy. This is no easy task given financial constraints and trends toward higher density development that may put space for trees at a premium. The challenge ahead is to better integrate the green infrastructure with the gray infrastructure by increasing tree planting, providing adequate space for trees, and designing plantings to maximize net benefits over the long term, thereby perpetuating a resource that is both functional and sustainable. The Center for Urban Forest Research looks forward to working with the city of Los Angeles and its many professionals to meet that challenge in the years ahead.

## Common and Scientific Names

| Common name   | Scientific name                               |
|---------------|-----------------------------------------------|
| Camphor       | <i>Cinnamomum camphora</i> (L.) J. Presl      |
| Crapemyrtle   | <i>Lagerstroemia indica</i> L.                |
| Evergreen ash | <i>Fraxinus uhdei</i> (Wenzig) Lingelsh.      |
| Jacaranda     | <i>Jacaranda mimosifolia</i> D. Don           |
| Yew           | <i>Podocarpus macrophyllus</i> (Thunb.) Sweet |

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## Metric Equivalents

| When you know:                        | Multiply by: | To find:                             |
|---------------------------------------|--------------|--------------------------------------|
| Inches (in)                           | 2.54         | Centimeters (cm)                     |
| Feet (ft)                             | .305         | Meters (m)                           |
| Square feet (ft <sup>2</sup> )        | .0929        | Square meters (m <sup>2</sup> )      |
| Square miles (mi <sup>2</sup> )       | 2.59         | Square kilometers (km <sup>2</sup> ) |
| Cubic feet (ft <sup>3</sup> )         | .028         | Cubic meters (m <sup>3</sup> )       |
| Acres                                 | .404         | Hectares (ha)                        |
| Gallons (gal)                         | .00378       | Cubic meters (m <sup>3</sup> )       |
| Pounds (lb)                           | .454         | Kilograms (kg)                       |
| Tons (ton)                            | .907         | Metric tonne (t)                     |
| Thousand British thermal units (kBtu) | 1.05         | Megajoules (MJ)                      |

## References

- Ambrosia, V.; Buechel, S.W.; Brass, J.A.; Peterson, J.R.; Davies, R.H.; Kane, R.J.; Spain, S. 1998.** An integration of remote sensing, GIS, and information distribution for wildfire detection and management. *Photogrammetric Engineering and Remote Sensing*. 64(10): 977–985.
- American Forests. 2002a.** Projected benefits of community tree planting: a multi-site model urban forest project in Atlanta. Washington, DC. 12 p.
- American Forests. 2002b.** Urban ecological analysis for the Washington, DC, metropolitan area. Washington, DC. 16 p.
- American Forests. 2002c.** Urban ecological analysis, Roanoke, Virginia. Washington, DC. 8 p.
- Anderson, L.M.; Cordell, H.K. 1988.** Residential property values improve by landscaping with trees. *Southern Journal of Applied Forestry*. 9: 162–166.
- Benjamin, M.T.; Winer, A.M. 1998.** Estimating the ozone-forming potential of urban trees and shrubs. *Atmospheric Environment*. 32: 53–68.
- Brenzel, K.N., ed. 2001.** Sunset Western garden book. 7<sup>th</sup> ed. Menlo Park, CA: Sunset Books. 624 p.
- California Association of Realtors. 2006.** Median home sales prices in Los Angeles - December, 2006. <http://www.car.org/index.php?id=MzcwNDg#>. (March 5, 2007).
- Condon, P.; Moriarty, S., eds. 1999.** Second nature: adapting LAs landscape for sustainable living. Los Angeles: TreePeople. 116 p.
- Galvin, M.F.; Grove, M.J.; O’Neil-Dunne, J. 2006.** A report on Baltimore City’s present and potential urban tree canopy. Annapolis, MD: Maryland Forest Service. 17 p.
- Gauderman, W.J.; Avol, E.; Gilliland, F.; Vora, H.; Thomas, D.; Kiros, B.; McConnell, R.; Kuenzli, N.; Lurmann, F.; Rappaport, E.; Margolis, H.; Bates, D.; Peters, J. 2004.** The effect of air pollution on lung development from 10 to 18 years of age. *The New England Journal of Medicine*. 351(11): 1057–1067.
- Gauderman, W.J.; Avol, E.; Lurmann, F.; Kuenzli, N.; Gilliland, F.; Peters, J.; McConnell, R. 2005.** Childhood asthma and exposure to traffic and nitrogen dioxide. *Epidemiology*. 16(6): 737–743.

- Given, S.; Pendleton, L.H.; Boehm, A.B. 2006.** Regional public health cost estimates of contaminated coastal waters: a case study of gastroenteritis at Southern California beaches. *Environmental Science and Technology*. 40: 4851–4858.
- Goetz, S.J.; Wright, R.K.; Smith, A.J.; Zinecker, E.; Schaub, E. 2003.** IKONOS imagery for resource management: tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. *Remote Sensing of the Environment*. 88: 195–208.
- Gong, P.; Howarth, P.J. 1990.** The use of structural information for improving land-cover classification accuracies at the rural-urban fringe. *Photogrammetric Engineering and Remote Sensing*. 56(1): 67–73.
- Gonzalez, S. 2004.** Personal communication. Assistant maintenance superintendent, City of Vallejo, 111 Amador St., Vallejo, CA 94590.
- Grove, J.M.; O’Neil-Dunne, J.; Pelletier, K.; Nowak, D.; Walton, J. 2006.** A report on New York City’s present and possible urban tree canopy. South Burlington, VT: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 25 p.
- Irani, F.W.; Galvin, M.F. 2003.** Strategic urban forests assessment: Baltimore, Maryland. In: *Technology: converging at the top of the world*. Proceedings of the American Society of Photogrammetry and Remote Sensing annual conference, Bethesda, MD: American Society of Photogrammetry and Remote Sensing: 85–94.
- Jones & Stokes Associates, Inc. 1998.** Cost-benefit analysis for the T.R.E.E.S. project. Sacramento, CA. 152 p.
- Kaler, D.; Ray, C. 2005.** City of Vancouver canopy report, GIS analysis using 2002 LIDAR. Vancouver, WA: Clark County GIS Division and Vancouver-Clark Parks and Recreation. 32 p.
- Kaplan, R. 1992.** Urban forestry and the workplace. In: Gobster, P.H., ed. *Managing urban and high-use recreation settings*. Gen. Tech. Rep. NC-163. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 41–45.
- Kaplan, R.; Kaplan, S. 1989.** The experience of nature: a psychological perspective. Cambridge, United Kingdom: Cambridge University Press. 352 p.
- Kellert, S.R.; Wilson, W.O., eds. 1993.** The biophilia hypothesis. New York: Island Press. 483 p.

- Kohavi, R.; Provost, F. 1998.** Glossary of terms. *Machine Learning*. 30: 271–274.
- Kollin, C. 2006.** How green infrastructure measures up to structural stormwater services. *Stormwater*. 7(5): 138–144.
- Lakshmi, V.; Murthy, M.; Dutt, C. 1998.** Efficient forest resources management through GIS and remote sensing. *Current Science*. 75(3): 272–282.
- Luley, C.J.; Bond, J. 2002.** A plan to integrate management of urban trees into air quality planning. Report to the North East State Foresters Association. Naples, NY: Davey Resource Group. 61 p.
- McBride, J.R.; Jacobs, D.F. 1986.** Presettlement forest structure as a factor in urban forest development. *Urban Ecology*. 9(3–4): 245–266.
- McPherson, E.G. 1992.** Accounting for benefits and costs of urban greenspace. *Landscape and Urban Planning*. 22: 41–51.
- McPherson, E.G. 1993.** Evaluating the cost effectiveness of shade trees for demand-side management. *The Electricity Journal*. 6(9): 57–65.
- McPherson, E.G. 1998.** Structure and sustainability of Sacramento’s urban forest. *Journal of Forestry*. 24(4): 174–190.
- McPherson, E.G. 2001.** Sacramento’s parking lot shading ordinance: environmental and economic costs of compliance. *Landscape and Urban Planning*. 57: 105–123.
- McPherson, E.G.; Muchnick, J. 2005.** Effects of tree shade on asphalt concrete pavement performance. *Journal of Arboriculture*. 31(6): 303–309.
- McPherson, E.G.; Simpson, J.R. 1999.** Guidelines for calculating carbon dioxide reductions through urban forestry programs. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 p.
- McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Scott, K.I.; Xiao, Q. 2000.** Tree guidelines for coastal southern California communities. Sacramento, CA: Local Government Commission. 98 p.
- McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Xiao, Q.; Pittenger, D.R.; Hodel, D.R. 2001.** Tree guidelines for Inland Empire communities. Sacramento, CA: Local Government Commission. 116 p.
- Montgomery County. 2000.** Forest preservation strategy, a task force report. Rockville, MD: County of Montgomery. 16 p.

- Myeong, S.; Nowak, D.J.; Hopkins, P.F.; Brock, R.H. 2001.** Urban cover mapping using digital, high-spatial resolution aerial imagery. *Urban Ecosystems*. 5: 243–256.
- Nowak, D.J.; Rowntree, R.A.; McPherson, E.G.; Sisinni, S.M.; Kerkmann, E.R.; Stevens, J.C. 1996.** Measuring and analyzing urban tree cover. *Landscape and Urban Planning*. 36: 49–57.
- Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R. 2003.** The Urban Forest Effects (UFORE) model: field data collection procedures. Syracuse, NY: U.S. Department of Agriculture, Forest Service. 30 p.
- Parsons, R.; Tassinary, L.G.; Ulrich, R.S.; Hebl, M.R.; Grossman-Alexander, M. 1998.** The view from the road: implications for stress recovery and immunization. *Journal of Environmental Psychology*. 18(2): 113–140.
- Pearce, D. 2003.** The social cost of carbon and its policy implications. *Oxford Review of Economic Policy*. 19(3): 362–384.
- Pillsbury, N.H.; Reimer, J.L.; Thompson, R.P. 1998.** Tree volume equations for fifteen urban species in California. Tech. Rep. 7. San Luis Obispo, CA: Urban Forest Ecosystems Institute, California Polytechnic State University. 56 p.
- Poracsky, J.; Lackner, M. 2004.** Urban forest canopy cover in Portland, Oregon, 1972–2002: final report. Portland, OR: Geography Department, Portland State University. 38 p.
- Price, K.; Guo, X.; Stiles, J. 2002.** Optimal Landsat TM band combinations and vegetation indices for discrimination of six grassland types in eastern Kansas. *International Journal of Remote Sensing*. 23(23): 5031–5042.
- Sanders, R.A. 1984.** Some determinants of urban forest structure. *Urban Ecology*. 8: 13–27.
- Sarkovich, M. 2006.** Personal communication. Demand-side specialist, Sacramento Municipal Utility District, 1708 59<sup>th</sup> St., Sacramento, CA 95817-1889.
- Scott, K.I.; McPherson, E.G.; Simpson, J.R. 1998.** Air pollutant uptake by Sacramento's urban forest. *Journal of Arboriculture*. 24(4): 224–234.
- Shao, G.; Young, D.; Porter, J.; Hayden, B. 1998.** An integration of remote sensing and GIS to examine the responses of shrub thicket distributions to shoreline changes on Virginia Barrier Islands. *Journal of Coastal Research*. 14(1): 299–307.

- Tou, J.T.; Gonzalez, R.C. 1974.** Pattern recognition principles. Reading, MA: Addison-Wesley.
- Tretheway, R.; Manthe, A. 1999.** Skin cancer prevention: another good reason to plant trees. In: McPherson, E.G.; Mathis, S., eds. Proceedings of the Best of the West summit. Davis, CA: University of California: 72–75.
- Ulrich, R.S. 1985.** Human responses to vegetation and landscapes. *Landscape and Urban Planning*. 13: 29–44.
- Urban Forestry Task Force. 2003.** Urban forestry plan, an element of the vision plan. Roanoke, VA: City of Roanoke. 41 p.
- U.S. Department of Commerce, Census Bureau [U.S. Census Bureau]. 2000.** Population finder, Census 2000. <http://www.census.gov/>. (27 March 2007).
- Wang, M.Q.; Santini, D.J. 1995.** Monetary values of air pollutant emissions in various U.S. regions. *Transportation Research Record* 1475: 33–41.
- Xiao, Q.; McPherson, E.G.; Simpson, J.R.; Ustin, S.L. 2000.** Winter rainfall interception by two mature open grown trees in Davis, California. *Hydrological Processes*. 14(4): 763–784.
- Xiao, Q.; McPherson, E.G. 2005.** Tree health mapping with multispectral remote sensing data at UC Davis, California. *Urban Ecosystems* 8: 349–361.
- Xiao, Q.; Ustin, S.L.; McPherson, E.G. 2004.** Using AVIRIS data and multiple-masking techniques to map urban forest species. *International Journal of Remote Sensing*. 25(24): 5637–5654.

## Appendix

**Table 15—Land cover distributions by neighborhood council<sup>a</sup>**

| Neighborhood councils                            | Area  | Tree canopy cover |                             | Irrigated grass cover       |                             | Dry grass/bare soil         |                             | Impervious/other            |              | Mountain |
|--------------------------------------------------|-------|-------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|--------------|----------|
|                                                  |       | <i>Acres</i>      | <i>Acres</i> <i>Percent</i> | <i>Acres</i> <i>Percent</i> | <i>Acres</i> <i>Percent</i> | <i>Acres</i> <i>Percent</i> | <i>Acres</i> <i>Percent</i> | <i>Acres</i> <i>Percent</i> | <i>Acres</i> |          |
| Arleta                                           | 2,089 | 350               | 16.8                        | 217                         | 10.4                        | 231                         | 11.1                        | 1,291                       | 61.8         |          |
| Arroyo Seco                                      | 1,698 | 781               | 46.0                        | 64                          | 3.8                         | 145                         | 8.5                         | 708                         | 41.7         | 523      |
| Atwater Village                                  | 1,305 | 188               | 14.4                        | 180                         | 13.8                        | 62                          | 4.7                         | 874                         | 66.9         |          |
| Bel Air-Beverly Crest                            | 6,964 | 3,715             | 53.3                        | 699                         | 10.0                        | 194                         | 2.8                         | 2,356                       | 33.8         | 3,997    |
| Boyle Heights                                    | 3,668 | 418               | 11.4                        | 278                         | 7.6                         | 46                          | 1.3                         | 2,926                       | 79.8         |          |
| Canoga Park                                      | 2,361 | 357               | 15.1                        | 208                         | 8.8                         | 135                         | 5.7                         | 1,660                       | 70.3         |          |
| Central Alameda                                  | 861   | 84                | 9.8                         | 86                          | 10.0                        | 34                          | 4.0                         | 616                         | 71.5         |          |
| Central Hollywood                                | 786   | 66                | 8.3                         | 21                          | 2.7                         | 11                          | 1.4                         | 689                         | 87.6         | 0        |
| Central San Pedro                                | 1,386 | 134               | 9.7                         | 91                          | 6.6                         | 67                          | 4.8                         | 1,094                       | 79.0         | 0        |
| Chatsworth                                       | 5,348 | 909               | 17.0                        | 659                         | 12.3                        | 454                         | 8.5                         | 3,327                       | 62.2         | 1,950    |
| Coastal San Pedro                                | 2,287 | 233               | 10.2                        | 515                         | 22.5                        | 174                         | 7.6                         | 1,365                       | 59.7         | 2        |
| Community and Neighbors for Ninth District Unity | 1,632 | 126               | 7.7                         | 196                         | 12.0                        | 34                          | 2.1                         | 1,276                       | 78.2         |          |
| Del Rey                                          | 1,942 | 192               | 9.9                         | 259                         | 13.3                        | 34                          | 1.7                         | 1,457                       | 75.0         | 0        |
| Downtown Los Angeles                             | 3,214 | 95                | 3.0                         | 74                          | 2.3                         | 27                          | 0.8                         | 3,017                       | 93.9         | 2        |
| Eagle Rock                                       | 2,323 | 801               | 34.5                        | 105                         | 4.5                         | 179                         | 7.7                         | 1,238                       | 53.3         | 321      |
| Elysian Valley Riverside                         | 459   | 47                | 10.2                        | 30                          | 6.5                         | 28                          | 6.2                         | 338                         | 73.7         |          |
| Empowerment Congress Central Area ndc            | 1,812 | 192               | 10.6                        | 371                         | 20.5                        | 98                          | 5.4                         | 1,152                       | 63.6         |          |
| Empowerment Congress North Area                  | 2,455 | 289               | 11.8                        | 281                         | 11.5                        | 104                         | 4.2                         | 1,781                       | 72.5         |          |
| Empowerment Congress Southeast Area              | 2,725 | 270               | 9.9                         | 481                         | 17.7                        | 42                          | 1.6                         | 1,915                       | 70.3         |          |
| Empowerment Congress Southwest Area              | 1,708 | 135               | 7.9                         | 401                         | 23.5                        | 44                          | 2.6                         | 1,127                       | 66.0         | 1        |
| Empowerment Congress West area                   | 2,091 | 279               | 13.3                        | 458                         | 21.9                        | 78                          | 3.7                         | 1,276                       | 61.0         | 0        |
| Encino                                           | 7,361 | 2,293             | 31.2                        | 1,253                       | 17.0                        | 247                         | 3.4                         | 3,583                       | 48.7         | 1,337    |
| Foothill Trails District                         | 4,010 | 958               | 23.9                        | 341                         | 8.5                         | 624                         | 15.6                        | 2,086                       | 52.0         | 8,368    |
| Glassell Park                                    | 1,531 | 292               | 19.0                        | 209                         | 13.7                        | 120                         | 7.8                         | 910                         | 59.5         | 97       |
| Granada Hills North                              | 4,600 | 1,191             | 25.9                        | 644                         | 14.0                        | 454                         | 9.9                         | 2,311                       | 50.2         | 2,770    |
| Grass Roots Venice                               | 2,048 | 334               | 16.3                        | 177                         | 8.6                         | 7                           | 0.4                         | 1,529                       | 74.7         | 1        |
| Greater Cypress Park                             | 787   | 122               | 15.5                        | 38                          | 4.8                         | 64                          | 8.1                         | 563                         | 71.5         | 41       |
| Greater Echo Park Elysian                        | 2,324 | 390               | 16.8                        | 413                         | 17.8                        | 123                         | 5.3                         | 1,370                       | 59.0         | 370      |
| Greater Griffith Park                            | 3,528 | 964               | 27.3                        | 664                         | 18.8                        | 232                         | 6.6                         | 1,561                       | 44.3         | 2,356    |
| Greater Toluca Lake                              | 961   | 308               | 32.0                        | 152                         | 15.8                        | 26                          | 2.7                         | 476                         | 49.5         |          |
| Greater Wilshire                                 | 2,538 | 682               | 26.9                        | 379                         | 14.9                        | 108                         | 4.2                         | 1,370                       | 54.0         |          |
| Harbor City                                      | 1,565 | 245               | 15.7                        | 260                         | 16.6                        | 88                          | 5.6                         | 971                         | 62.0         | 0        |
| Harbor Gateway North                             | 2,029 | 244               | 12.0                        | 370                         | 18.2                        | 33                          | 1.6                         | 1,378                       | 67.9         | 0        |
| Harbor Gateway South                             | 2,062 | 177               | 8.6                         | 316                         | 15.3                        | 34                          | 1.6                         | 1,535                       | 74.4         | 0        |
| Historic Cultural                                | 1,369 | 81                | 5.9                         | 59                          | 4.3                         | 38                          | 2.8                         | 1,148                       | 83.8         | 166      |

(Continues on next page)

**Land cover distributions by neighborhood council<sup>a</sup>** *(Continued)*

| Neighborhood councils                                                                                  | Area  | Tree canopy cover |              | Irrigated grass cover |              | Dry grass/bare soil |              | Impervious/other |              | Mountain |
|--------------------------------------------------------------------------------------------------------|-------|-------------------|--------------|-----------------------|--------------|---------------------|--------------|------------------|--------------|----------|
|                                                                                                        |       | <i>Acres</i>      | <i>Acres</i> | <i>Percent</i>        | <i>Acres</i> | <i>Percent</i>      | <i>Acres</i> | <i>Percent</i>   | <i>Acres</i> |          |
| Historic Highland Park                                                                                 | 2,423 | 648               | 26.7         | 48                    | 2.0          | 140                 | 5.8          | 1,313            | 54.2         | 274      |
| Hollywood Hills West                                                                                   | 3,525 | 1,278             | 36.3         | 363                   | 10.3         | 145                 | 4.1          | 1,635            | 46.4         | 1,330    |
| Hollywood United                                                                                       | 1,468 | 532               | 36.3         | 93                    | 6.3          | 61                  | 4.2          | 694              | 47.3         | 752      |
| LA-32                                                                                                  | 2,665 | 732               | 27.5         | 82                    | 3.1          | 229                 | 8.6          | 1,577            | 59.2         | 443      |
| Lincoln Heights                                                                                        | 1,893 | 253               | 13.4         | 47                    | 2.5          | 67                  | 3.6          | 1,491            | 78.8         | 93       |
| Macarthur                                                                                              | 334   | 20                | 6.0          | 24                    | 7.2          | 8                   | 2.4          | 282              | 84.5         |          |
| Mar Vista                                                                                              | 2,671 | 611               | 22.9         | 291                   | 10.9         | 52                  | 1.9          | 1,638            | 61.3         | 0        |
| Mid City                                                                                               | 1,113 | 137               | 12.3         | 102                   | 9.2          | 61                  | 5.5          | 813              | 73.0         |          |
| Mid City West                                                                                          | 2,641 | 457               | 17.3         | 253                   | 9.6          | 95                  | 3.6          | 1,835            | 69.5         | 1        |
| Mid-town North Hollywood                                                                               | 3,030 | 545               | 18.0         | 265                   | 8.7          | 121                 | 4.0          | 2,100            | 69.3         |          |
| Mission Hills                                                                                          | 2,302 | 422               | 18.3         | 286                   | 12.4         | 361                 | 15.7         | 1,233            | 53.6         |          |
| Nc Valley Village                                                                                      | 1,257 | 346               | 27.6         | 142                   | 11.3         | 51                  | 4.1          | 717              | 57.1         |          |
| North Hills West                                                                                       | 2,212 | 507               | 22.9         | 432                   | 19.5         | 130                 | 5.9          | 1,208            | 54.6         |          |
| North Hollywood North East                                                                             | 1,930 | 232               | 12.0         | 141                   | 7.3          | 91                  | 4.7          | 1,466            | 76.0         |          |
| Northridge East                                                                                        | 2,566 | 519               | 20.2         | 479                   | 18.7         | 176                 | 6.9          | 1,419            | 55.3         |          |
| Northridge West                                                                                        | 2,556 | 435               | 17.0         | 469                   | 18.4         | 215                 | 8.4          | 1,433            | 56.1         | 35       |
| Northwest San Pedro                                                                                    | 2,431 | 277               | 11.4         | 528                   | 21.7         | 198                 | 8.1          | 1,362            | 56.0         | 0        |
| Old Northridge                                                                                         | 857   | 122               | 14.3         | 103                   | 12.0         | 57                  | 6.7          | 574              | 67.0         |          |
| Olympic Park                                                                                           | 724   | 97                | 13.4         | 75                    | 10.3         | 41                  | 5.7          | 512              | 70.6         |          |
| P.I.C.O.                                                                                               | 1,155 | 165               | 14.3         | 132                   | 11.4         | 73                  | 6.4          | 785              | 67.9         |          |
| Pacoima                                                                                                | 3,852 | 474               | 12.3         | 239                   | 6.2          | 477                 | 12.4         | 2,612            | 67.8         | 931      |
| Palms                                                                                                  | 571   | 45                | 7.8          | 34                    | 5.9          | 14                  | 2.4          | 479              | 83.9         |          |
| Park Mesa Heights                                                                                      | 1,818 | 170               | 9.3          | 396                   | 21.8         | 84                  | 4.6          | 1,168            | 64.2         | 1        |
| Pico Union                                                                                             | 1,026 | 103               | 10.0         | 68                    | 6.6          | 24                  | 2.3          | 831              | 81.0         |          |
| Porter Ranch                                                                                           | 2,394 | 276               | 11.5         | 586                   | 24.5         | 216                 | 9.0          | 1,316            | 55.0         | 1,294    |
| Reseda                                                                                                 | 3,759 | 649               | 17.3         | 556                   | 14.8         | 294                 | 7.8          | 2,259            | 60.1         |          |
| Sherman Oaks                                                                                           | 5,016 | 1,720             | 34.3         | 552                   | 11.0         | 176                 | 3.5          | 2,567            | 51.2         | 527      |
| Silver Lake                                                                                            | 1,839 | 409               | 22.2         | 242                   | 13.1         | 67                  | 3.7          | 901              | 49.0         |          |
| South Robertson                                                                                        | 1,682 | 332               | 19.7         | 191                   | 11.4         | 74                  | 4.4          | 1,086            | 64.5         | 0        |
| Southeast/Central Ave                                                                                  | 1,662 | 107               | 6.5          | 98                    | 5.9          | 43                  | 2.6          | 1,414            | 85.1         | 0        |
| Studio City                                                                                            | 3,403 | 1,420             | 41.7         | 303                   | 8.9          | 82                  | 2.4          | 1,580            | 46.4         | 528      |
| Sun Valley Area                                                                                        | 5,260 | 551               | 10.5         | 251                   | 4.8          | 245                 | 4.7          | 4,208            | 80.0         | 314      |
| Sunland-Tujunga                                                                                        | 3,613 | 1,093             | 30.3         | 344                   | 9.5          | 320                 | 8.9          | 1,856            | 51.4         | 4,024    |
| Sylmar                                                                                                 | 6,957 | 1,185             | 17.0         | 760                   | 10.9         | 1,212               | 17.4         | 3,799            | 54.6         | 963      |
| Tarzana                                                                                                | 4,282 | 1,290             | 30.1         | 776                   | 18.1         | 285                 | 6.7          | 1,932            | 45.1         | 779      |
| United neighborhoods of the Historic<br>Arlington Heights, West Adams,<br>and Jefferson Park Community | 1,772 | 205               | 11.6         | 138                   | 7.8          | 84                  | 4.7          | 1,345            | 75.9         |          |
| Valley Glen CC                                                                                         | 2,443 | 608               | 24.9         | 301                   | 12.3         | 129                 | 5.3          | 1,405            | 57.5         |          |
| Van Nuys                                                                                               | 3,757 | 695               | 18.5         | 328                   | 8.7          | 154                 | 4.1          | 2,580            | 68.7         |          |
| Vermont Harbor                                                                                         | 1,396 | 151               | 10.8         | 176                   | 12.6         | 60                  | 4.3          | 1,009            | 72.3         |          |
| Vernon/Main                                                                                            | 1,346 | 123               | 9.1          | 134                   | 9.9          | 55                  | 4.1          | 1,035            | 76.9         |          |
| Watts                                                                                                  | 1,294 | 168               | 13.0         | 226                   | 17.4         | 77                  | 5.9          | 824              | 63.7         | 0        |

*(Continues on next page)*

**Land cover distributions by neighborhood council<sup>a</sup>** *(Continued)*

| Neighborhood councils        | Area         | Tree canopy cover |                | Irrigated grass cover |                | Dry grass/bare soil |                | Impervious/other |                | Mountain     |
|------------------------------|--------------|-------------------|----------------|-----------------------|----------------|---------------------|----------------|------------------|----------------|--------------|
|                              | <i>Acres</i> | <i>Acres</i>      | <i>Percent</i> | <i>Acres</i>          | <i>Percent</i> | <i>Acres</i>        | <i>Percent</i> | <i>Acres</i>     | <i>Percent</i> | <i>Acres</i> |
| West Adams                   | 1,387        | 168               | 12.1           | 152                   | 10.9           | 75                  | 5.4            | 992              | 71.5           | 0            |
| West Hills                   | 4,569        | 1,238             | 27.1           | 657                   | 14.4           | 114                 | 2.5            | 2,561            | 56.0           | 1,402        |
| West LA                      | 1,197        | 133               | 11.1           | 68                    | 5.7            | 33                  | 2.7            | 964              | 80.5           | 0            |
| West Van Nuys/Lake Balboa    | 5,640        | 614               | 10.9           | 546                   | 9.7            | 118                 | 2.1            | 2,416            | 42.8           |              |
| Westchester/Playa del Ray    | 9,170        | 1,170             | 12.8           | 1,887                 | 20.6           | 333                 | 3.6            | 5,721            | 62.4           | 1            |
| Westside                     | 2,405        | 606               | 25.2           | 361                   | 15.0           | 110                 | 4.6            | 1,328            | 55.2           | 2            |
| Wilmington                   | 6,033        | 303               | 5.0            | 208                   | 3.4            | 219                 | 3.6            | 4,496            | 74.5           | 673          |
| Wilshire Center - Koreatown  | 1,485        | 111               | 7.5            | 48                    | 3.3            | 35                  | 2.3            | 1,284            | 86.5           |              |
| Winnetka                     | 2,827        | 538               | 19.0           | 387                   | 13.7           | 234                 | 8.3            | 1,668            | 59.0           |              |
| Woodland Hills-Warner Center | 9,122        | 2,785             | 30.5           | 1,175                 | 12.9           | 561                 | 6.1            | 4,600            | 50.4           | 806          |

<sup>a</sup> Some neighborhood council boundaries overlap.

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