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Northern California Coast Community Tree Guide

Benefits, Costs, and Strategic Planting

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Abstract

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Trees make our cities more attractive and provide many ecosystem services, including air quality improvement, energy conservation, stormwater interception, and atmospheric carbon dioxide reduction. These benefits must be weighed against the costs of maintaining trees, including planting, pruning, irrigation, administration, pest control, liability, cleanup, and removal. We present benefits and costs for representative small, medium, and large deciduous trees and coniferous trees in the Northern California Coast region derived from models based on research carried out in Berkeley, California. Average annual net benefits (benefits minus costs) increase with mature tree size and differ based on location: $29 (public) to $41 (yard) for a small tree, $42 (public) to $60 (yard) for a medium tree, $101 (public) to $122 (yard) for a large tree, $142 (public) to $146 (yard) for a large conifer. Two hypothetical examples of planting projects are described to illustrate how the data in this guide can be adapted to local uses, and guidelines for maximizing benefits and reducing costs are given.

Keywords: Ecosystem services, urban forestry, benefit-cost analysis.

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Green infrastructure is a significant component of communities in the Northern California Coast region.

Summary

Benefits and costs quantified

This report quantifies benefits and costs for small, medium, and large broadleaf trees and a coniferous tree in the Northern California Coast region: the species chosen as representative because of their size at about 20 years after planting are camphor (*Cinnamomum camphora*), cherry plum (*Prunus cerasifera*), velvet ash (*Fraxinus velutina*) and Monterey pine (*Pinus radiata*), respectively (see "Common and Scientific Names" section). The analysis describes "yard" trees (those planted in residential sites) and "public" trees (those planted on streets or in parks). We assume a 55-percent survival rate over a 40-year timeframe. Tree care costs and mortality rates are based on results from a survey of municipal and commercial arborists. Benefits are calculated by using tree growth curves and numerical models that consider regional climate, building characteristics, air pollutant concentrations, and prices.

The measurements used in modeling environmental and other benefits of trees are based on indepth research carried out in Berkeley, California. Given the Northern California Coast region's large and diverse geographical area, this approach provides first-order approximations. It is a general accounting that can be easily adapted and adjusted for local planting projects. Two examples are provided that illustrate how to adjust benefits and costs to reflect different aspects of local planting projects.

Average annual benefits

Large trees provide the greatest benefits. Average annual benefits over 40 years increase with mature tree size:

- $41 to $51 for a small tree (18 ft tall 20 years after planting)
- $57 to $71 for a medium tree (22 ft tall 20 years after planting)
- $115 to $135 for a large tree (34 ft tall 20 years after planting)
- $161 to $176 for a conifer (38 ft tall 20 years after planting)

Benefits associated with increased property value and energy savings account for the largest proportion of total benefits in this region. Reduced stormwater runoff, lower levels of air pollutants, and less carbon dioxide in the air are the next most important benefits.

Energy conservation benefits differ with tree location as well as size. Trees located opposite west-facing walls provide the greatest net heating and cooling energy savings. Reducing heating and cooling energy needs reduces carbon dioxide (CO_2) emissions and thereby reduces atmospheric CO_2. Similarly, energy savings that reduce pollutant emissions at powerplants account for important reductions in gases that produce ozone, a major component of smog.

Average annual costs over 40 years for tree care range from $10 to $33 per tree.

Costs

- $10 (yard) and $17 (public) for a small tree
- $11 (yard) and $24 (public) for a medium tree
- $13 (yard) and $28 (public) for a large tree
- $15 (yard) and $33 (public) for a conifer

Planting, pruning, and tree removal are the greatest costs for trees (annualized to $2 to $22 per tree per year). Tree care expenditures tend to increase with mature tree size because of increased labor and equipment costs.

Average annual net benefits

Average annual net benefits (benefits minus costs) per tree for a 40-year period are as follows:

- $29 to $41 for a small tree
- $42 to $60 for a medium tree
- $101 to $122 for a large tree
- $142 to $146 for a conifer

The environmental benefits alone, including energy savings, stormwater-runoff reduction, improved air quality, and reduced atmospheric CO_2, are greater than tree care costs.

Net benefits summed over 40 years

Net benefits for a yard tree opposite a west wall and a public tree are substantial when summed over the entire 40-year period:

- $1,640 (yard) and $1,179 (public) for a small tree
- $2,392 (yard) and $1,679 (public) for a medium tree
- $4,868 (yard) and $4,034 (public) for a large tree
- $5,855 (yard) and $5,685 (public) for a conifer

Private trees produce higher net benefits than public trees. Our survey results indicate that this is primarily due to higher maintenance costs for street and park trees. The standard of care is often higher for public trees because municipalities need to manage risk, maintain required clearances for pedestrians and vehicles, and repair damage to sidewalks and curbing caused by tree roots.

To demonstrate how communities can adapt the information in this report to their needs, the benefits and costs of different planting projects are determined for two fictional cities interested in increasing their urban forest. In the hypothetical city of Martha Falls, net benefits and benefit-cost ratios (BCRs) are calculated for a planting of 1,000 trees (15 gal or No. 15). Energy prices, planting, and monitoring costs are adjusted to reflect local prices and anticipated project costs. Total project costs are $1,162,736, benefits total $4.2 million, and net benefits are $3.0 million ($76 per tree per year). The BCR is 3.61:1, indicating that $3.61 is returned for every $1 invested. The net benefits and BCRs by mature tree size are:

- $37,956 (2.01:1) for 50 small trees
- $181,992 (2.19:1) for 150 medium trees
- $2.3 million (3.79:1) for 700 large trees
- $485,619 (4.53:1) for 100 pine trees

Increased property values (77 percent) and reduced energy costs (17 percent) account for more than 90 percent of the estimated benefits. Reduced stormwater runoff (4 percent), improved air quality (1 percent) and atmospheric CO_2 reduction (1 percent) make up the remaining benefits.

In the fictional city of Melvinville, long-term planting and tree care costs and benefits were compared to determine if a proposed policy that favors planting small-stature trees would be cost effective compared to the current policy of planting large-stature trees where space permits. Over a 40-year period, the net benefits are:

- $707 per tree for a small tree
- $1,185 per tree for a medium tree
- $3,427 per tree for a large tree

Based on this analysis, the city of Melvinville decided to retain their policy. They now require tree shade plans that show how developers will achieve 50 percent shade over streets, sidewalks, and parking lots within 15 years of development.

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The Northern California Coast region is characterized by gently rolling hills, numerous views of oceans, rivers, and streams, and a diverse tree cover.

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Chapter 1: Introduction

The Northern California Coast Region

Geographic scope of the Northern California Coast region

From small towns surrounded by vineyards, forests, and the sea, to the city of San Francisco, the Northern California Coast region (fig.1) contains a diverse assemblage of communities. Home to approximately 8 million people, this region extends south along a band bordering the Pacific Ocean from the Oregon border to Santa Maria and Lompoc. It sweeps inland around the San Francisco Bay to include the cities of Richmond, Oakland, and San Jose. Boundaries correspond with Sunset Climate Zones 15 through 17 (Brenzel 2001) and USDA Hardiness Zones 9

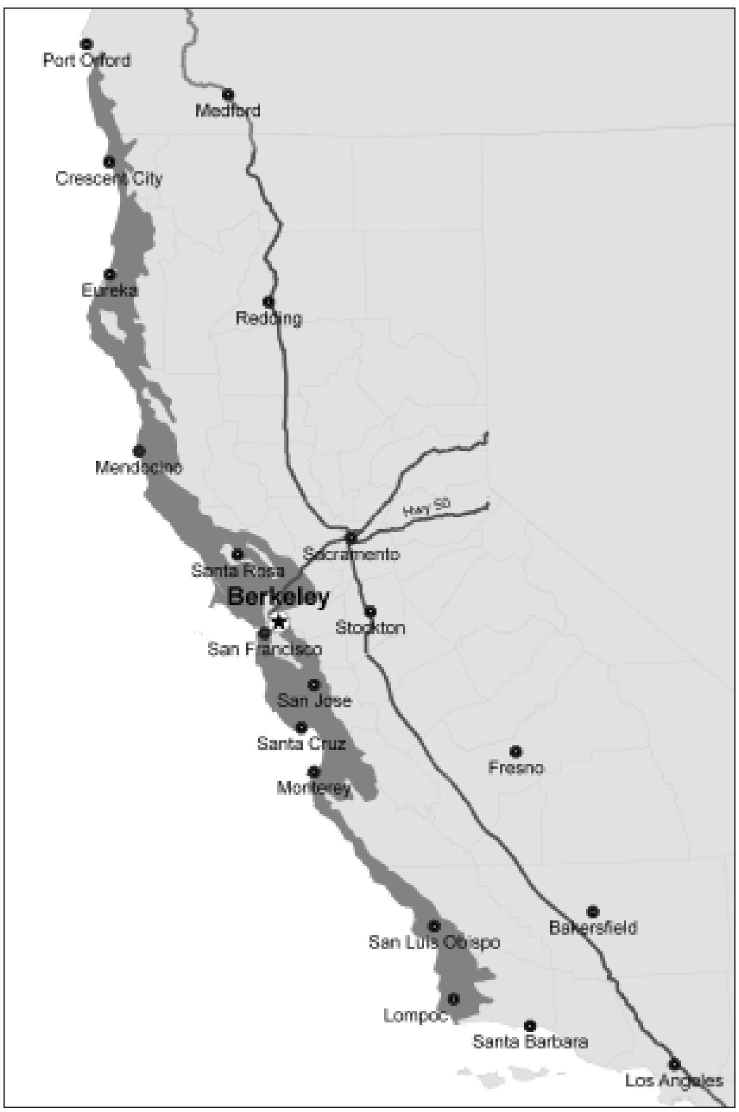

Figure 1—The Northern California Coast region (shaded area) extends south along a band bordering the Pacific Ocean from the Oregon border to Santa Maria, and sweeps inland around the San Francisco Bay.

and 10. The Pacific Ocean influences the **climate**[1] in this region, allowing a greater number of tree species to thrive than in regions farther north and inland. The annual temperature cycle is relatively mild, with chilly winters and mild summers. Temperatures are influenced by marine air much of the time, and some areas are almost frostless. A humidifying blanket of fog tends to moderate summer temperatures in the northern parts of this region. Summer afternoon winds are an integral part of this climate and can be dispersed by plantings on the windward side of buildings. Annual precipitation throughout the region ranges from 20 to 50 in annually, with nearly all rainfall during winter (November–April).

Northern California Coast communities can derive many benefits from community forests

In the Northern California Coast region, as elsewhere, urban forest canopies protect us from the elements, clean the water we drink and the air we breathe, generally improve the quality of life, and form a living connection to earlier generations who planted and tended these trees.

As the region's communities continue to expand during the coming decades, sustaining healthy **community forests** is integral to the quality of life that residents experience. The role of urban forests in enhancing the environment, increasing community attractiveness and livability, and fostering civic pride takes on greater significance as communities strive to balance economic growth with environmental quality and social well-being. The simple act of planting trees provides opportunities to connect residents with nature and with each other. Neighborhood tree plantings and stewardship projects stimulate involvement and investment by local citizens, businesses, and governments for the betterment of their communities (fig. 2). Community forests bring opportunity for economic renewal, combating development woes, improving human health, and increasing the quality of life for community residents.

Quality of life improves with trees

Northern California Coast communities can promote energy efficiency through tree planting and stewardship programs that strategically locate trees to save energy and minimize conflicts with urban infrastructure. The same trees can provide additional benefits by reducing stormwater runoff; improving local air, soil, and water quality; reducing atmospheric CO_2; providing wildlife habitat; increasing property values; slowing vehicular traffic; enhancing community attractiveness and investment; and promoting human health and well-being.

This guide builds upon previous studies by the U.S. Department of Agriculture Forest Service in the San Francisco Bay Area (Simpson and McPherson 2007), San Francisco (Maco et al. 2003, Nowak et al. 2007), Berkeley (Maco et al. 2005),

[1] Words in bold are defined in the glossary.

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Figure 2—Tree planting and stewardship programs provide opportunities for local residents to work together to build better communities.

Scope defined

Chicago and Sacramento (McPherson 1998, McPherson et al. 1997), and Tree Guides for the San Joaquin Valley, Southern California Coast and other regions (McPherson et al. 1999, 2000) to extend existing knowledge of urban forest services in the Northern California Coast. The guide:

- Quantifies benefits of trees on a per-tree basis rather than on a canopy-cover basis (it should not be used to estimate benefits for trees growing in forest stands).
- Describes management costs and benefits.
- Details benefits and costs for trees in residential yards and along streets and in parks.
- Illustrates how to use this information to estimate benefits and costs for local tree planting projects.

These guidelines are specific to the Northern California Coast and are based on measurements and calculations from open-growing urban trees in this region.

Audience and objectives

Street, park, and privately owned shade trees are integral to urban communities. They impact every resident. Their benefits are myriad. However, with municipal tree programs dependent on taxpayer-supported general funds, communities are forced to ask whether trees are worth the price to plant and care for over the long term, thus requiring urban forestry programs to demonstrate their cost-effectiveness (McPherson 1995). If tree plantings are proven to benefit communities, then monetary commitment to tree programs will be justified. Therefore, the objective of this tree guide is to identify and describe the benefits and costs of planting trees in Northern California Coast communities—providing a tool for municipal tree managers, planners, arborists, and community and environmental groups to increase public awareness and support for trees (Dwyer and Miller 1999).

What will this tree guide do?

This tree guide addresses a number of questions about the environmental and aesthetic benefits of community tree plantings in Northern California Coast communities:

- How can tree-planting programs improve environmental quality, conserve energy, and add value to communities?
- Where should residential yard and public trees be placed to maximize their benefits?
- How can conflicts between trees and power lines, sidewalks, and buildings be minimized?

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Trees in Northern California Coast communities enhance quality of life.

Chapter 2: Identifying Benefits and Costs of Urban and Community Forests

This chapter describes benefits and costs of public and privately managed trees. Services and associated economic value of community forests are described. Expenditures related to tree care and management are assessed—a necessary process for creating cost-effective programs (Dwyer et al. 1992, Hudson 1983).

Benefits

Saving Energy

How trees work to save energy

Energy is essential to maintain quality of life and sustain economic growth. Conserving energy with shade trees can reduce the need for building new powerplants. For example, while California was experiencing energy shortages in 2001, its 177 million city trees were providing shade and conserving energy. Annual savings to utilities was an estimated $500 million in wholesale electricity and generation purchases (McPherson and Simpson 2003). Planting 50 million more shade trees in strategic locations would provide savings equivalent to seven 100-megawatt powerplants. The cost of peak load reduction was $63/kW, considerably less than the $150/kW amount that is deemed cost-effective for energy conservation measures by the California Energy Commission (see http://www.fs.fed.us/psw/programs/cufr/products/3/cufr_148.pdf). Like electric utilities throughout the country, utilities in the Northern California Coast region could invest in shade tree programs as a cost-effective energy conservation measure.

Trees modify climate and conserve building energy use in three principal ways (fig. 3):

- Shading reduces the amount of heat absorbed and stored by built surfaces.
- **Evapotranspiration** converts liquid water to water vapor and thus cools the air by using solar energy that would otherwise result in heating of the air.
- Windspeed reduction reduces the infiltration of outside air into interior spaces, especially where conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees lower temperatures

Trees and other vegetation on individual building sites may lower air temperatures 5 °F compared with sites outside the **greenspace**. At larger scales (6 mi^2), temperature differences of more than 9 °F have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992). These “hot spots” in cities

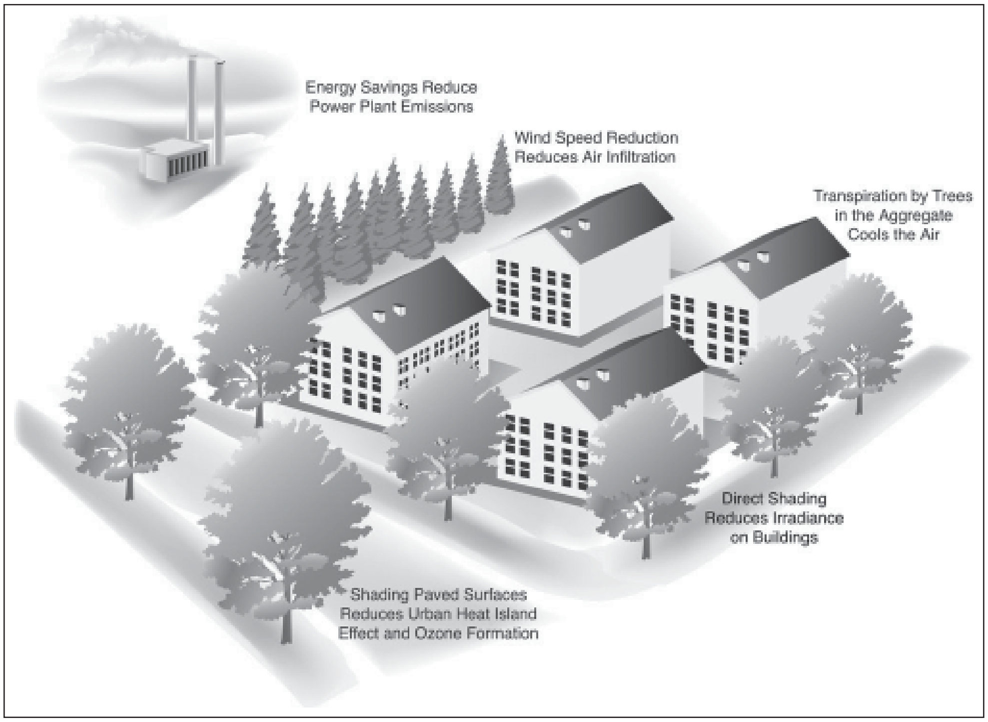

Figure 3—Trees save energy for heating and cooling by shading buildings, lowering summertime temperatures, and reducing windspeeds. Secondary benefits from energy conservation are reduced water consumption and reduced pollutant emissions by powerplants (drawing by Mike Thomas).

are called **urban heat islands**. A recent study for New York City compared trees, living roofs, and light surfaces and found that curbside tree planting was the most effective heat island mitigation strategy (Rosenzweig et al. 2006).

Trees increase home energy efficiency and save money

For individual buildings, strategically placed trees can increase energy efficiency in the summer and winter. Because the summer sun is low in the east and west for several hours each day, solar angles should be considered. Trees that shade west-facing walls help keep buildings cool (fig. 4). In the winter, allowing the sun to strike the southern side of a building can warm interior spaces. However, the trunks and bare branches of **deciduous** trees that shade south- and east-facing walls may increase heating costs during winter by blocking 40 percent or more of winter irradiance (McPherson 1984).

Windbreaks reduce heat loss

Rates at which outside air infiltrates a building can increase substantially with windspeed. In cold, windy weather, the entire volume of air, even in newer or tightly sealed homes, may change every 2 to 3 hours. Windbreaks reduce windspeed and resulting air infiltration by up to 50 percent, translating into potential annual heating savings of 10 to 12 percent (Heisler 1986). Reductions in windspeed

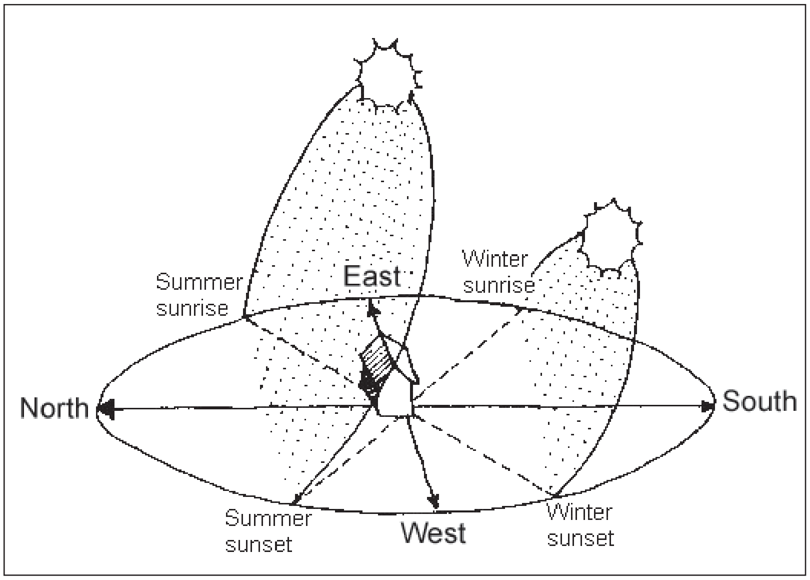

Figure 4—Paths of the sun on winter and summer solstices (from Sand 1991). Summer heat gain is primarily through east- and west-facing windows and walls. The roof receives most irradiance, but insulated attics reduce heat gain to living spaces. The winter sun, at a lower angle, strikes the south-facing surfaces.

reduce heat transfer through conductive materials as well. Cool winter winds, blowing against windows, can contribute significantly to the heat loss of buildings by increasing the gradient between inside and outside temperatures. Windbreaks reduce air infiltration and conductive heat loss from buildings.

Shading and **climate effects** of 36,485 municipal trees in Berkeley, California, reduced annual electricity used for air conditioning by 3,469 **MWh**, for a retail savings of $458,994 ($12.58/tree) (Maco et al. 2005). Total annual savings of natural gas for heating was 7,209 **MBtu**, for a savings of $94,072 ($2.58/tree). Net energy savings were split: 17 percent winter heating and 83 percent summer air conditioning. Citywide savings totaled $553,066, and the average savings per tree was $15.16, but exceeded $30 for large species like London planetree (see “Common and Scientific Names” section).

Retrofit for more savings

In the San Francisco Bay Area, 6.6 million existing trees provide annual energy savings valued at $327 million (Simpson and McPherson 2007). In the Northern California Coast region there is ample opportunity to “retrofit” communities with more sustainable landscapes through strategic tree planting and care of existing trees.

Reducing Atmospheric Carbon Dioxide

Global temperatures have increased since the late 19th century, with major warming periods from 1910 to 1945 and from 1976 to the present (IPCC 2007). Human activities, primarily fossil-fuel consumption, are adding greenhouse gases to the atmosphere, and current research suggests that the recent increases in temperature can be attributed in large part to increases in greenhouse gases (IPCC 2007). Higher global temperatures are expected to have a number of adverse effects, including melting polar ice caps, which could raise sea level by 6 to 37 in (Hamburg et al. 1997). With more than one-third of the world's population living in coastal areas (Cohen et al. 1997), the effects could be disastrous. Increasing frequency and duration of extreme weather events will continue to tax emergency management resources. Some plants and animals may become extinct as habitat becomes restricted.

Trees reduce CO_2

Urban forests have been recognized as important storage sites for carbon dioxide (CO_2), the primary greenhouse gas (Nowak and Crane 2002). At the same time, private markets dedicated to reducing CO_2 emissions by trading carbon credits are emerging (McHale et al. 2007). Damage costs of CO_2 emissions range from about $5 to $15 per **metric tonne** (t) (Tol 2005). For every $18 spent on a tree planting project in Arizona, 1t of atmospheric CO_2 was reduced (McPherson and Simpson 1999). The Climate Action Reserve's (2008) Urban Forest Project Reporting Protocol provides guidance for tree planting and stewardship projects aimed at providing monetary resources for community forestry programs.

Urban forests can reduce atmospheric CO_2 in two ways (fig. 5):

- Trees directly sequester CO_2 in their stems and leaves while they grow.
- Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with power production.

Some tree-related activities release CO_2

On the other hand, vehicles, chain saws, chippers, and other equipment release CO_2 during the process of planting and maintaining trees. And eventually, all trees die, and most of the CO_2 that has accumulated in their biomass is released into the atmosphere through burning or decomposition. The rate of release into the atmosphere depends on if and how the wood is reused. For instance, recycling of urban wood waste into products such as furniture can delay the rate of decomposition compared to its reuse as mulch.

Avoided CO_2 emissions

Typically, CO_2 released owing to tree planting, maintenance, and other program-related activities is about 2 to 8 percent of annual CO_2 reductions obtained through **sequestration** and reduced powerplant emissions (McPherson and Simpson

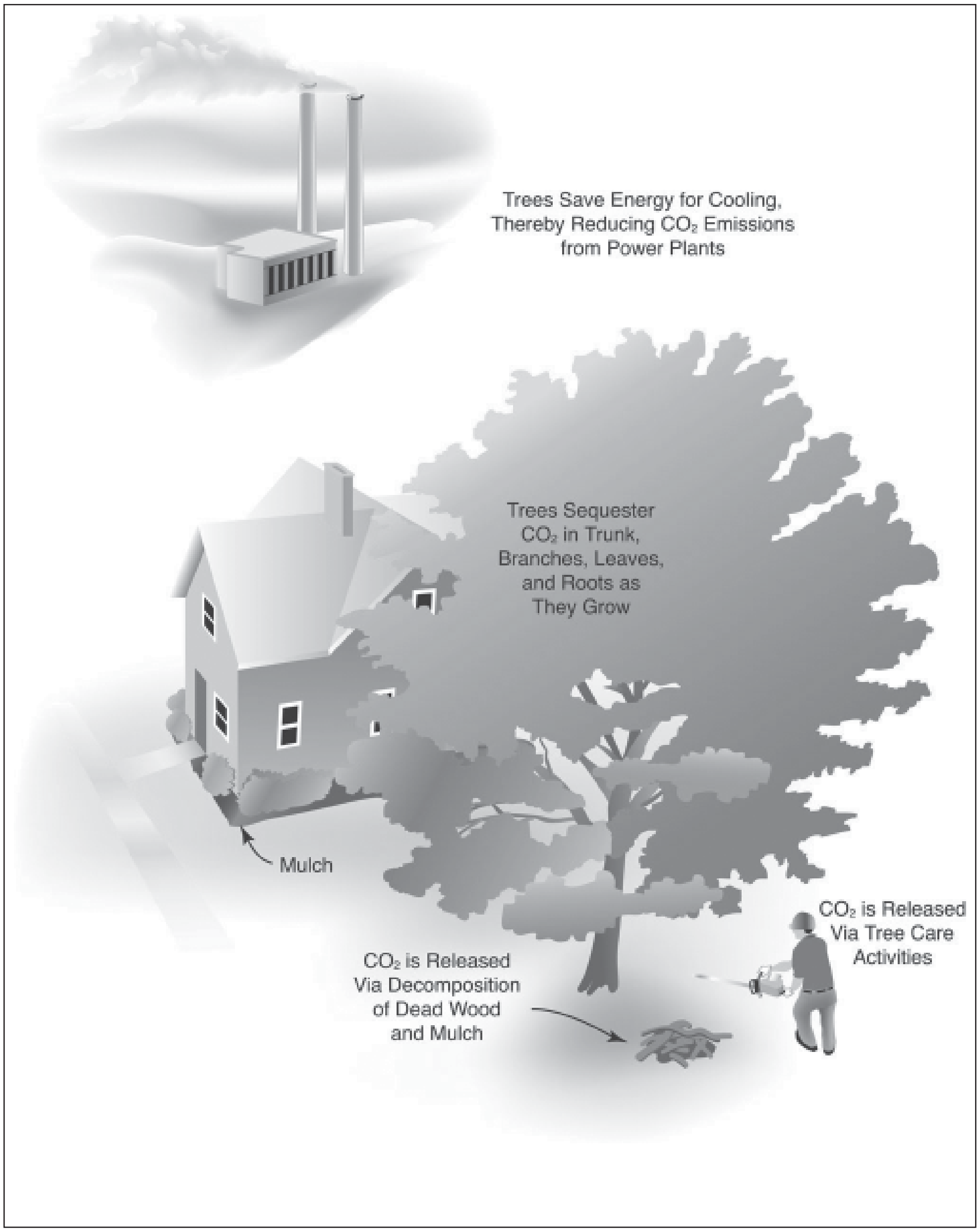

Figure 5—Trees sequester carbon dioxide (CO_2) as they grow and indirectly reduce CO_2 emissions from powerplants through energy conservation. At the same time, CO_2 is released through decomposition and tree care activities that involve fossil fuel consumption (drawing by Mike Thomas).

1999). To provide a complete picture of atmospheric CO_2 reductions from tree plantings, it is important to consider CO_2 released into the atmosphere through tree planting and tree maintenance operations, as well as decomposition of wood from pruned or dead trees.

Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential CO_2 emission reductions. The regional weighted average emission rate is 651 lbs CO_2**/kWh** (US EPA 2003), a relatively small amount because of the clean mix of fuels that produce energy to heat and cool buildings. The region's relatively low CO_2 emission rate means smaller benefits from reduced energy demand relative to other regions with higher emission rates. Nevertheless, tree planting programs targeted to maximize energy savings will provide climate protection dividends in the Northern California Coast region.

A study of Berkeley's municipal forest found that 36,485 trees sequestered 3025 t of atmospheric CO_2 annually, valued at $49,602 (Maco et al. 2005). Net sequestration of CO_2 by the San Francisco Bay Area's 6.6 million trees is 696,686 t worth $2.3 million annually (Simpson and McPherson 2007).

A study in Chicago focused on the carbon sequestration benefit of residential tree canopy cover. Tree canopy cover in two residential neighborhoods was estimated to sequester on average 0.112 lb/ft^2, and pruning activities released 0.016 lb/ft^2 (Jo and McPherson 1995). Net annual carbon uptake was 0.096 lb/ft^2.

A comprehensive study of CO_2 reduction by Sacramento's urban forest found the region's 6 million trees offset 1.8 percent of the total CO_2 emitted annually as a byproduct of human activities (McPherson 1998). This savings could be substantially increased through strategic planting and long-term stewardship that maximizes future energy savings from new tree plantings.

CO_2 reduction through community forestry

Since 1990, the Sacramento Tree Foundation, a nonprofit organization, has partnered with the Sacramento Municipal Utility District to plant trees for energy savings and atmospheric CO_2 reduction. Nearly 500,000 trees have been planted with the help of local residents. These trees are estimated to have offset CO_2 emissions by 807,394 t and provided 12,313 GWh of cooling energy savings and 3.54 MW of capacity savings (Sarkovich 2009).

Improving Air Quality

Trees improve air quality

In the United States, approximately 159 million people live in areas where ozone (**O_3**) concentrations violate federal air quality standards. About 100 million people live in areas where dust and other small particle matter (**PM_{10}**) exceeds levels for healthy air. Air pollution is a serious health threat to many city dwellers, causing asthma, coughing, headaches, respiratory and heart disease, and cancer (Smith 1990). Short-term increases in O_3 concentrations have been statistically associated with increased mortality for 95 large U.S. cities (Bell et al. 2004). Impaired health results in increased social costs for medical care, greater absenteeism, and reduced longevity.

Six counties in the Northern California Coast region have been designated nonattainment areas for the 8-hour O_3 standard: Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara (US EPA 2009). Tree planting is one practical strategy for communities in these areas to meet and sustain mandated air quality standards.

The U.S. Environmental Protection Agency (EPA) has recognized tree planting as a measure for reducing O_3 in state implementation plans (Nowak et al. 2006). Air quality management districts in California have funded tree planting projects to control PM_{10} and other air pollutants. These policy decisions are creating new opportunities to plant and care for trees as a method for controlling air pollution (Bond 2006, Hughes 2008, Luley and Bond 2002; for more information see www.treescleanair.org).

Urban forests provide several air quality benefits (fig. 6):

- They absorb gaseous pollutants (e.g., O_3, nitrogen dioxide [**NO_2**], and sulfur dioxide [**SO_2**]) through leaf surfaces.
- They intercept PM_{10} (e.g., dust, ash, pollen, smoke).
- They release oxygen through **photosynthesis**.
- They transpire water and shade surfaces, which lowers air temperatures, thereby reducing O_3 levels.
- They reduce energy use, which reduces emissions of pollutants from powerplants, including NO_2, SO_2, PM_{10}, and volatile organic compounds (**VOCs**).

Trees affect ozone formation

Trees can adversely affect air quality. Most trees emit **biogenic volatile organic compounds** (BVOCs) such as isoprenes and monoterpenes that can contribute to O_3 formation. The contribution of BVOC emissions from city trees to O_3 formation depends on complex geographic and atmospheric interactions that have not been studied in most cities. Some complicating factors include variations with temperature and atmospheric levels of NO_2. As well, the O_3-forming potential differs considerably for different tree species (Benjamin and Winer 1998). Genera having the greatest relative effect on increasing O_3 are sweetgum, blackgum, sycamore, poplar, and oak (Nowak 2000). A computer simulation study for Atlanta found that it would be very difficult to meet EPA ozone standards by using trees because of the high BVOC emissions from pines and other vegetation (Chameides et al. 1988). Although removing trees reduced BVOC emissions, this effect was overwhelmed by increased hydrocarbon emissions from natural and **anthropogenic** sources owing to the increased air temperatures associated with tree removal (Cardelino and Chameides 1990). In the Los Angeles basin, increased

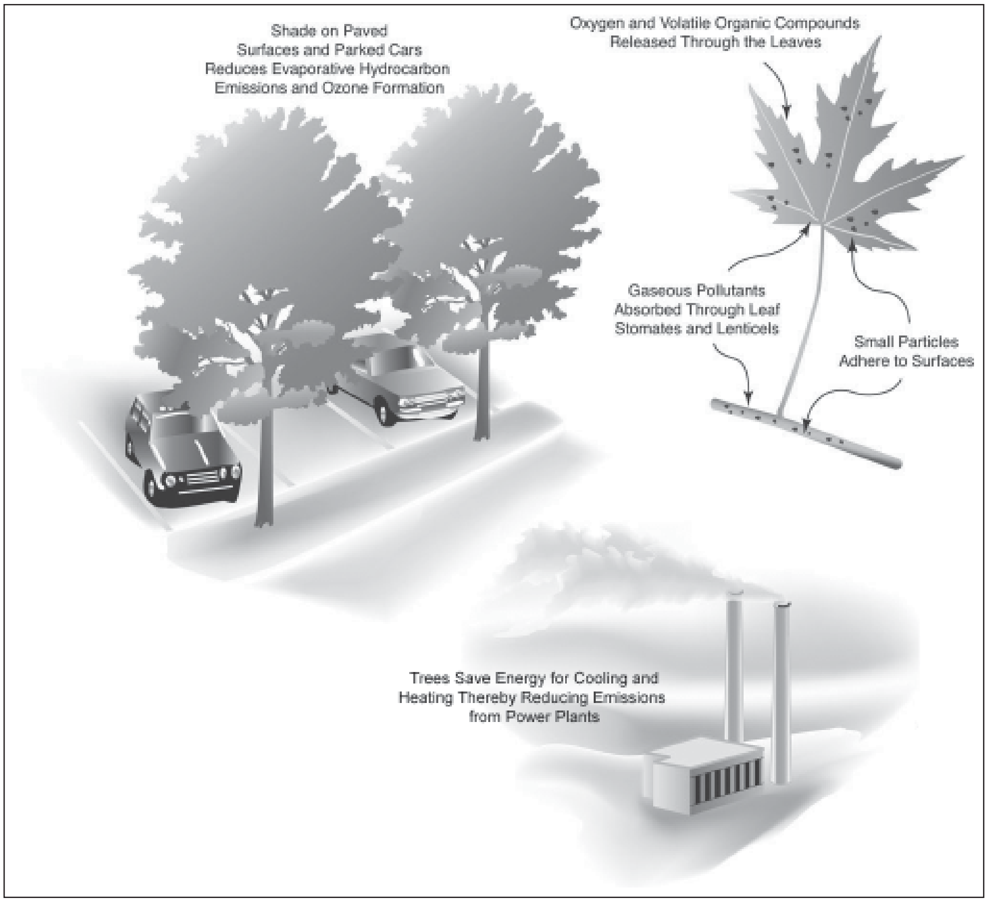

Figure 6—Trees absorb gaseous pollutants, retain particles on their surfaces, and release oxygen and volatile organic compounds. By cooling urban heat islands and shading parked cars, trees can reduce ozone formation (drawing by Mike Thomas).

planting of low BVOC-emitting tree species would reduce O_3 concentrations, whereas planting of medium and high emitters would increase overall O_3 concentrations (Taha 1996). A study in the Northeastern United States, however, found that species mix had no detectable effects on O_3 concentrations (Nowak et al. 2000). Although new trees increased BVOC emissions, ambient VOC emissions were so high that additional BVOCs had little effect on air quality. These potentially negative effects of trees on one kind of air pollution must be considered in light of their great benefit in other areas.

Trees absorb gaseous pollutants

Trees absorb gaseous pollutants through leaf stomata: tiny openings in the leaves. Secondary methods of pollutant removal include adsorption of gases on plant surfaces and uptake through bark pores (lenticels). Once gases enter the leaf, they diffuse into intercellular spaces, where some react with inner leaf surfaces and others are absorbed by water films to form acids. Pollutants can damage plants by altering their metabolism and growth. At high concentrations, pollutants cause visible damage to leaves, such as stippling and bleaching (Costello et al. 2003). Although they may pose health hazards to plants, pollutants such as nitrogenous gases can be sources of essential nutrients for trees.

Trees intercept particulate matter

Trees intercept small airborne particles. Some particles that impact a tree are absorbed, but most adhere to plant surfaces. Species with hairy or rough leaf, twig, and bark surfaces are efficient interceptors (Smith and Dochinger 1976). Intercepted particles are often resuspended to the atmosphere when wind blows the branches, and rain washes some particulates off plant surfaces. The ultimate fate of these pollutants depends on whether they fall onto paved surfaces and enter the stormwater system, or fall on pervious surfaces, where they are filtered in the soil.

Trees release oxygen

Urban forests release oxygen as a product of photosynthesis. Net annual oxygen production differs depending on tree species, size, health, and location. A healthy tree, for example, a 32-ft-tall ash, produces about 260 lb of net oxygen annually (McPherson 1997). A typical person consumes 386 lb of oxygen per year. Therefore, two medium-sized, healthy trees can supply the oxygen required for a single person over the course of a year. In colder climates, oxygen release will be less than in areas with longer growing seasons.

Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions of PM_{10}, SO_2, NO_2, and VOCs associated with electric power production. Emissions avoided because of trees can be sizable. For example, a strategically located tree can save 100 kWh in electricity for cooling annually (McPherson and Simpson 1999, 2002, 2003). Assuming that this conserved electricity comes from a new coal-fired powerplant, the tree reduces emissions of SO_2 by 0.38 lb, NO_2 by 0.27 lb, and PM_{10} by 0.84 lb (US EPA 1998). The same tree is responsible for conserving 60 gal of water in cooling towers and reducing CO_2 emissions by 200 lb.

Although air pollutants removed and avoided owing to energy savings from Berkeley's municipal forest had substantial value ($143,228 annually), the releases of BVOCs meant the trees produced a negative net air-quality benefit ($20,621) (Maco et al. 2005). The ability of trees to produce net air-quality benefits differed dramatically among species; those without high BVOC emissions produced significant benefits. Large-canopied trees with large leaf surface areas and low BVOC emissions produced the greatest benefits. Annually, on a per-tree basis, the most valuable street tree species included many large, old trees, such as American and Chinese elm.

A tree **canopy** cover of 23 percent in the San Francisco Bay Area was estimated to remove 247 tons of air pollution at an estimated value of $8.8 million (Simpson and McPherson 2007). Over one-half of this total benefit accrued in Santa Clara County. Increasing the region's tree canopy cover by 3 percent (4.3 million additional trees) was estimated to remove additional air pollutants, a service valued at $783,000 each year.

Tree shade prevents evaporative hydrocarbon emissions

Trees in a Davis, California, parking lot were found to improve air quality by reducing air temperatures 1 to 3 °F (Scott et al. 1999). By shading asphalt surfaces and parked vehicles, trees reduce hydrocarbon emissions (VOCs) from gasoline that evaporates out of leaky fuel tanks and worn hoses (fig. 7). These evaporative emissions are a principal component of smog, and parked vehicles are a primary source. In California, parking lot tree plantings can be funded as an air quality improvement measure because of the associated reductions in evaporative emissions.

Reducing Stormwater Runoff and Improving Hydrology

Urban stormwater runoff is a major source of pollution entering wetlands, streams, lakes, and oceans. Healthy trees can reduce the amount of runoff and pollutants in

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Figure 7—Trees planted to shade parking areas can reduce hydrocarbon emissions and improve air quality.

receiving waters (Cappiella et al. 2005). This is important because federal law requires states and localities to control nonpoint source pollution, such as runoff from pavement surfaces, buildings, and landscapes. Also, many older cities have combined sewer outflow systems, and during large rain events excess runoff can mix with raw sewage. Rainfall **interception** by trees can reduce the magnitude of this problem during large storms. Trees are mini-reservoirs, controlling runoff at the source, thereby reducing runoff volumes and erosion of watercourses, as well as delaying the onset of **peak flows**. Trees can reduce runoff in several ways (fig. 8):

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flow.
- Roots increase the rate at which rainfall infiltrates soil by creating root channels. This increases the capacity of soil to store water, reducing overland flow.
- Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.
- **Transpiration** through tree leaves reduces soil moisture, increasing the soil's capacity to store rainfall. This benefit is minimal during winter.

Trees reduce runoff

Rainfall that is stored temporarily on canopy leaf and bark surfaces is called intercepted rainfall. Intercepted water evaporates, drips from leaf surfaces, and flows down stem surfaces to the ground. Tree-surface saturation generally occurs after 1 to 2 in of rain has fallen (Xiao et al. 2000). During large storm events, rainfall exceeds the amount that the tree **crown** can store, about 50 to 100 gal per tree. The interception benefit is the amount of rainfall that does not reach the ground because it evaporates from the crown. As a result, the volume of runoff is reduced and the time of peak flow is delayed. Trees protect water quality by substantially reducing runoff during small rainfall events that are responsible for most pollutant washoff into receiving water bodies. Therefore, urban forests generally produce more benefits through water quality protection than through flood control (Xiao et al. 1998, 2000).

The amount of rainfall trees intercept depends on tree architecture, rainfall patterns, and climate. Tree-crown characteristics that influence interception are the trunk, stem, and surface areas, textures, area of gaps, period when leaves are present, and dimensions (e.g., tree height and diameter). Trees with coarse surfaces retain more rainfall than those with smooth surfaces. Large trees generally intercept more rainfall than small trees do because greater surface areas allow for greater evaporation rates. Tree crowns with few gaps reduce **throughfall** to the ground.

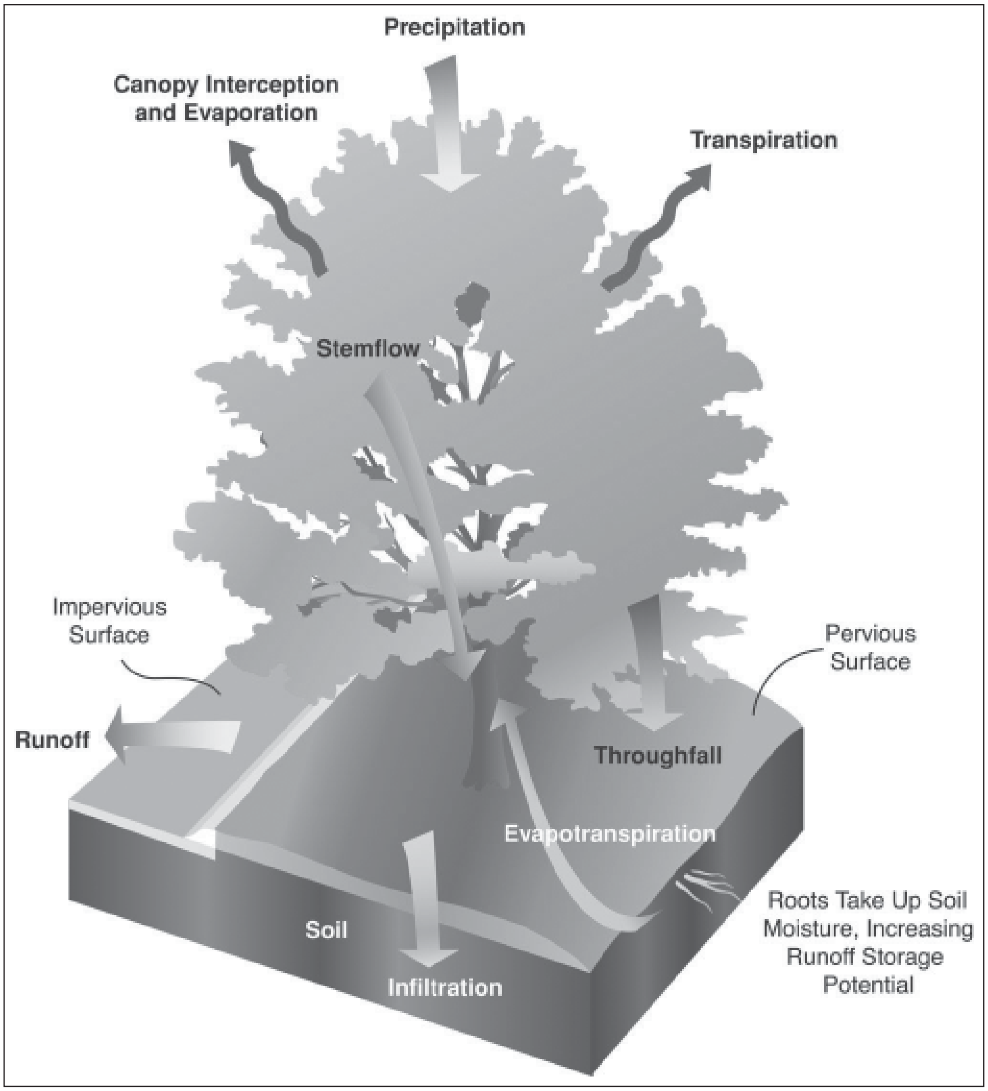

Figure 8—Trees intercept a portion of rainfall that evaporates and never reaches the ground. Some rainfall runs to the ground along branches and stems (stemflow), and some falls through gaps or drips off leaves and branches (throughfall). Transpiration increases soil moisture storage potential (drawing by Mike Thomas).

Species that are in leaf when rainfall is plentiful are more effective than deciduous species that have dropped their leaves during the rainy season.

Studies that have simulated urban forest effects on stormwater runoff have reported reductions of 2 to 7 percent. Annual interception of rainfall by Sacramento's urban forest for the total urbanized area was only about 2 percent because of the winter rainfall pattern and lack of **evergreen** species (Xiao et al. 1998). However, average tree canopy interception ranged from 6 to 13 percent (150 gal per tree), close to values reported for rural forests. Broadleaf evergreens and **conifers** intercept more rainfall than deciduous species in areas where rainfall is highest in fall, winter, or spring (Xiao and McPherson 2002).

In Berkeley, California, the municipal forest reduced runoff by 7.2 million ft^3, valued at $215,645 per year (Maco et al. 2005). Tree species with the highest rate of interception were coast redwood, Monterey cypress, American elm, and blue gum. In the San Francisco Bay area, the existing canopy (23 percent) reduced runoff by 2.5 million ft^3, with an estimated value of $102 million (Simpson and McPherson 2007).

Urban forests can treat wastewater

Urban forests can provide other hydrologic benefits, too. For example, tree plantations or nurseries can be irrigated with partially treated wastewater. Infiltration of water through the soil can be a safe and productive means of water treatment. Reused wastewater applied to urban forest lands can recharge aquifers, reduce stormwater-treatment loads, and create income through sales of nursery or wood products. Recycling urban wastewater into greenspace areas can be an economical means of treatment and disposal while at the same time providing other environmental benefits (USDA NRCS 2005). However, the use of reclaimed water for irrigation has limitations. For example, many species are sensitive to high salinity levels.

Aesthetics and Other Benefits

Beautification

Trees provide a host of aesthetic, social, economic, and health benefits that should be included in any benefit-cost analysis. One of the most frequently cited reasons that people plant trees is for beautification. Trees add color, texture, line, and form to the landscape. In this way, trees soften the hard geometry that dominates built environments. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality (Schroeder and Cannon 1983).

Attractiveness of retail settings

Consumer surveys have found that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers shop more often and longer in well-landscaped business districts. They were willing to pay more for parking and up to 11 percent more for goods and services (Wolf 2005).

Public safety benefits

Research in public housing complexes found that outdoor spaces with trees were used significantly more often than spaces without trees. By facilitating interactions among residents, trees can contribute to reduced levels of domestic violence, as well as foster safer and more sociable neighborhood environments (Sullivan and Kuo 1996).

Property value benefits

Well-maintained trees increase the "curb appeal" of properties (fig. 9). Research comparing sales prices of residential properties with different numbers of trees suggests that people are willing to pay 3 to 7 percent more for properties with ample trees versus few or no trees. One of the most comprehensive studies of the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1-percent increase in sales price (Anderson and Cordell 1988). A value of 9 percent ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988). In Portland, Oregon, street trees added on average $7,020 to the sales price of a home (Donovan and Butry 2008).

Social and psychological benefits

Scientific studies confirm our intuition that trees in cities provide social and psychological benefits. Humans derive substantial pleasure from trees, whether it is inspiration from their beauty, a spiritual connection, or a sense of meaning (Dwyer et al. 1992, Lewis 1996). After natural disasters, people often report a sense of loss if their community forest has been damaged (Hull 1992). Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan and Kaplan 1989). Deskworkers 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

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Figure 9—Trees beautify a neighborhood, increasing property values and creating a more sociable environment.

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.

Human health benefits

The presence of trees in cities provides public health benefits and improves the well-being of those who live, work, and play in cities. Physical and emotional stress has both short-term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving 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 sunnier parts of the Northern California Coast region. Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

Noise reduction

Certain environmental benefits from trees are more difficult to quantify than those previously described, but can be just as important. Noise can reach unhealthy levels in cities. Trucks, trains, and planes can produce noise that exceeds 100 decibels, twice the level at which noise becomes a health risk. Thick strips of vegetation in conjunction with landforms or solid barriers can reduce highway noise by 6 to15 decibels. Plants absorb more high-frequency noise than low frequency, which is advantageous to humans, as higher frequencies are most distressing to people (Cook 1978).

Wildlife habitat

Numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Remnant woodlands and **riparian habitats** within cities can connect a city to its surrounding bioregion (fig. 10). Wetlands, greenways (linear parks), and other greenspace can provide habitats that conserve **biodiversity** (Platt et al. 1994). Native plants are particularly valuable because they support wildlife. Also, regionally appropriate and native plant selections reduce potential resource inputs.

Jobs and environmental education

Urban forestry can provide jobs for both skilled and unskilled labor. Public service programs and grassroots-led urban and community forestry programs provide horticultural training to volunteers across the United States. Also, urban and community forestry provides educational opportunities for residents who want

Figure 10—Natural areas within cities are refuges for wildlife and help connect city dwellers with their ecosystems.

to learn about nature through first-hand experience (McPherson and Mathis 1999). Local nonprofit tree groups and municipal volunteer programs often provide educational material and hands-on training in the care of trees and work with area schools.

Shade can reduce street maintenance

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 asphalt is 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 (fig. 11).

Costs

Planting and Maintaining Trees

The environmental, social, and economic benefits of urban and community forests come at a price. A national survey reported that communities in the California

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Figure 11—Although shade trees can be expensive to maintain, their shade can reduce the costs of resurfacing streets (McPherson and Muchnick 2005), promote pedestrian travel, and improve air quality directly through pollutant uptake and indirectly through reduced emissions of volatile organic compounds from cars.

Coast region spent an average of $14.73 per tree, in 1994, for street- and park-tree management (Tschantz and Sacamano 1994). This amount is relatively high compared with average expenditures in other regions. Nationwide, the single largest expenditure was for tree pruning, followed by tree removal/disposal, and tree planting.

Municipal costs of tree care

Our survey of **municipal foresters** in Berkeley, Pleasanton, Redwood City, and San Jose indicates that on average they are spending about $10 to $20 per tree annually. Most of this amount is for pruning ($5 to $15 per tree) and removal and disposal ($1 to $2 per tree), and administration ($1 per tree). Other municipal departments incur costs for infrastructure repair and trip-and-fall claims resulting from root-buckled pavement that range from $0 to $25 per tree depending on city policy.

Frequently, trees in new residential subdivisions are planted by developers, whereas cities and counties and volunteer groups plant trees on existing streets and parklands. In some cities, tree planting has not kept pace with removals. Moreover, limited growing space in cities or preferences for flowering trees results in increased planting of smaller, shorter lived species that provide fewer benefits than larger trees do.

Residential costs vary

Annual expenditures for tree management on private property have not been well documented. Costs differ considerably, ranging from some commercial or residential properties that receive regular professional landscape service to others that are virtually "wild" and without maintenance. An analysis of data for Sacramento suggested that households typically spent about $5 to $10 annually per tree for pruning and pest and disease control (Summit and McPherson 1998). Our survey of four commercial arborists in the Northern California Coast region indicated that expenditures typically range from $10 to $20 per tree. Expenditures are usually greatest for planting, pruning, and pest and disease control.

Conflicts With Urban Infrastructure

Tree roots can damage sidewalks

Costs of conflicts

Like other cities across the United States, communities in the Northern California Coast region are spending millions of dollars each year to manage conflicts between trees and power lines, sidewalks, sewers, and other elements of the urban infrastructure (Randrup et al. 2001a). In a survey of 18 California cities, it was reported that on average, cities spend $11.22 per tree on the repair of sidewalks damaged by tree roots each year (McPherson 2000). As well, the figures for California apply only to street trees and do not include repair costs for damaged sewer lines, building foundations, parking lots, and various other **hardscape** elements.

In parts of the Bay area, tree growth and deteriorating infrastructure in tight municipal budget times are causing cities to shift repair costs to homeowners. This shift has significant impacts on residents in older areas, where large trees have outgrown small sites and infrastructure has deteriorated. It should be noted that trees should not always bear full responsibility. In older areas, in particular, sidewalks and curbs may have reached the end of their 20- to 25-year service life or may have been poorly constructed in the first place (Sydnor et al. 2000).

Efforts to control the costs of these conflicts are having alarming effects on urban forests (Bernhardt and Swiecki 1993, Thompson and Ahern 2000):

- Cities are downsizing their municipal forests by planting smaller trees. Although small trees are appropriate under power lines and in small planting sites, they are less effective than large trees at providing shade, absorbing air pollutants, and intercepting rainfall.

- Sidewalk damage was the second most common reason that street and park trees were removed. Thousands of healthy urban trees are lost each year and their benefits forgone because of this problem.
- Most cities surveyed were removing more trees than they were planting. Residents forced to pay for sidewalk repairs may not want replacement trees.

Cost-effective strategies to retain benefits from large street trees while reducing costs associated with infrastructure conflicts are described in *Reducing Infrastructure Damage by Tree Roots* (Costello and Jones 2003). Matching the growth characteristics of trees to the conditions at the planting site is one important strategy. Other strategies include meandering sidewalks around trees, suspending sidewalks above tree roots, and replacing concrete sidewalks with recycled rubber sidewalks.

Tree roots can also damage old sewer lines that are cracked or otherwise susceptible to invasion (Randrup et al. 2001b). Sewer repair companies estimate that sewer damage is minor until trees and sewers are over 30 years old, and roots from trees in yards are usually more of a problem than roots from trees in planter strips along streets. The latter assertion may be due to the fact that sewers are closer to the root zone as they enter houses than at the street. Repair costs typically range from $100 for sewer rodding (inserting a cleaning implement to temporarily remove roots) to $1,000 or more for sewer excavation and replacement.

Cleaning up after trees

Most communities sweep their streets regularly to reduce surface-runoff pollution entering local waterways. Street trees drop leaves, flowers, fruit, and branches year round that constitute a significant portion of debris collected from city streets. When leaves fall and winter rains begin, **tree litter** can clog sewers, dry wells, and other elements of flood-control systems. Costs include additional labor needed to remove leaves and property damage caused by localized flooding. Windstorms also incur cleanup costs. Although serious natural catastrophes are infrequent, they can result in large expenditures.

Large trees under power lines can be costly

The cost of addressing conflicts between trees and power lines is reflected in electric rates. Large trees under power lines require frequent pruning, which can make them unattractive (fig. 12). Frequent crown reduction reduces the benefits these trees could otherwise provide. Moreover, increased costs for pruning are passed on to customers.

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Figure 12—Large trees planted under power lines can require extensive pruning, which increases tree care costs and reduces the benefits of those trees, including their appearance.

Wood Salvage, Recycling, and Disposal

Recycling green waste may pay for itself

According to our survey, most Northern California Coast region cities are recycling green waste from urban trees as mulch, compost, and firewood. Some powerplants will use this wood to generate electricity, thereby helping defray costs for hauling and grinding. Generally, the net costs of waste-wood disposal are less than 1 percent of total tree-care costs, and cities and contractors may break even. Hauling and recycling costs can be nearly offset by revenues from sales of mulch, milled lumber, and firewood. The cost of wood disposal may be higher depending on geographic location and the presence of exotic pests that require elaborate waste-wood disposal (Bratkovich 2001). Growing markets for urban wood products and biomass feedstock for biopower plants could turn this cost into a revenue source.

Chapter 3: Determining Benefits and Costs of Community Forests in Northern California Coast Communities

This chapter presents estimated benefits and costs for trees planted in typical residential yards and public sites. Because benefits and costs vary with tree size, we report results for representative small, medium, and large broadleaf trees and for a representative conifer.

Estimates of benefits and costs are initial approximations, as some benefits and costs are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). Limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable throughout the region. Benefits and costs also vary, depending on differences in climate, air pollutant concentrations, tree-maintenance practices, and other factors. Given the Northern California Coast region's large geographical area, with many different climates, soils, and types of community forestry programs, the approach used here provides first-order approximations. These findings can be used for general planning purposes, but should not be applied to estimate benefits produced by individual trees in the landscape. The tree benefit values reported here can be easily adapted and adjusted to provide a general accounting for local planting projects. They provide a basis for decisions that set priorities and influence management direction, but are not suitable for determining whether a specific tree should be removed or retained (Maco and McPherson 2003).

Overview of Procedures

Approach

In this study, annual benefits and costs are estimated over a 40-year planning horizon for newly planted trees in three residential yard locations (about 27 ft from the east, south, and west walls of the residence) and a public streetside or park location. Henceforth, we refer to trees in these hypothetical locations as "yard" trees and "public" trees, respectively. Prices are assigned to each cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability) and benefit (e.g., heating/cooling energy savings, air pollutant mitigation, stormwater runoff reduction, property value increase) through direct estimation and implied valuation of benefits as environmental externalities. This approach makes it possible to estimate the net benefits of plantings in "typical" locations using "typical" tree species. More information on data collection, modeling procedures, and assumptions can be found in appendix 3.

To account for differences in the mature size and growth of different tree species, we report results for a small broadleaf evergreen tree, the camphor (*Cinnamomum camphora*), a medium deciduous tree, the cherry plum (*Prunus cerasifera*), a large deciduous tree, the velvet ash (*Fraxinus velutina*), and a conifer, the Monterey pine (*Pinus radiata*) (See "Common and Scientific Names" section) (figs. 13 through 16). The conifer is included as a windbreak tree located more than 50 ft from the residence so it does not shade the building. Tree dimensions are derived from growth curves developed from street trees in Berkeley, California (Maco et al. 2005) (fig. 17). Although camphor is often considered a medium or large tree, it is slow growing. Our data from street trees in Berkeley found that 20 years after planting it was 4 ft shorter, 2 ft narrower, and had 44 percent of the leaf surface area of the cherry plum. The latter difference is significant because leaf area drives benefit production. Although camphor can ultimately become a large-stature tree, it is representative of a small tree in this 40-year analysis because of its relatively slow growth and small leaf area. Similarly, although cherry plum is often considered a small tree, it is representative of a medium tree here because of its relatively rapid growth (reaches a height of 30 ft in 40 years) and large leaf surface area.

The selection of these species was based on data availability, and not intended to endorse their use in large numbers. In fact, the cherry plum has a poor form for a street tree, Monterey pine is subject to pitch canker, and velvet ash is susceptible to mistletoe and the emerald ash borer, the latter a potentially serious pest that may threaten all ash trees in California. Relying on too few species can increase the likelihood of catastrophic loss owing to pests, disease, or other threat.

Tree care costs based on survey findings

Frequency and costs of tree management are estimated based on surveys with municipal foresters from Berkeley, Pleasanton, Redwood City, and San Jose. In addition, commercial arborists from Arborwell, Bartlett Tree Experts, Mayne Tree Expert Co., and S.P. McClenahan Co. provided information on tree-management costs on residential properties.

Benefits are calculated with numerical models and data from the region (e.g., powerplant pollutant emission factors for emission reductions owing to energy savings) and from local sources (e.g., San Francisco Bay area climate data for energy effects). Changes in building energy use from tree shade were based on computer simulations that incorporated building, climate, and shading effects. Sequestration, the net rate of CO_2 storage in above- and belowground biomass over the course of

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Figure 13—The camphor tree represents small trees in this guide.

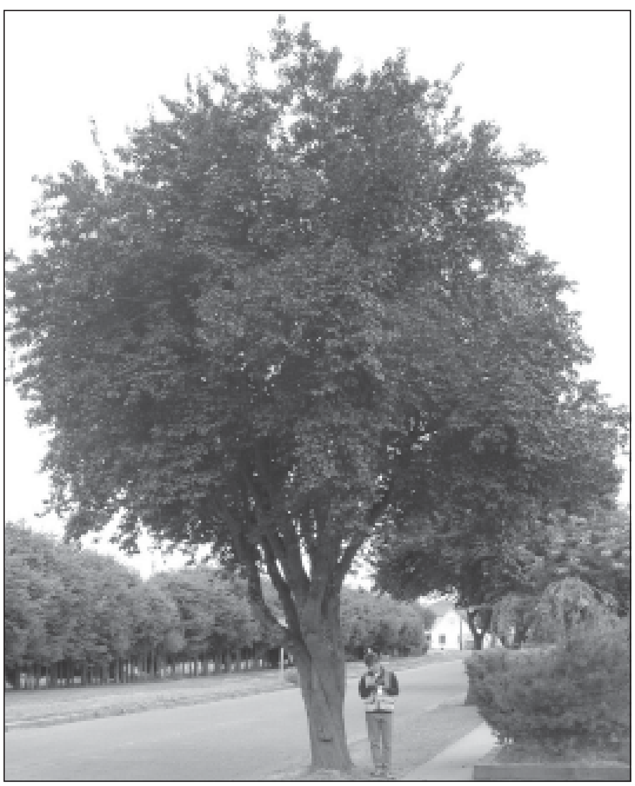

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Figure 14—The cherry plum represents medium trees in this guide.

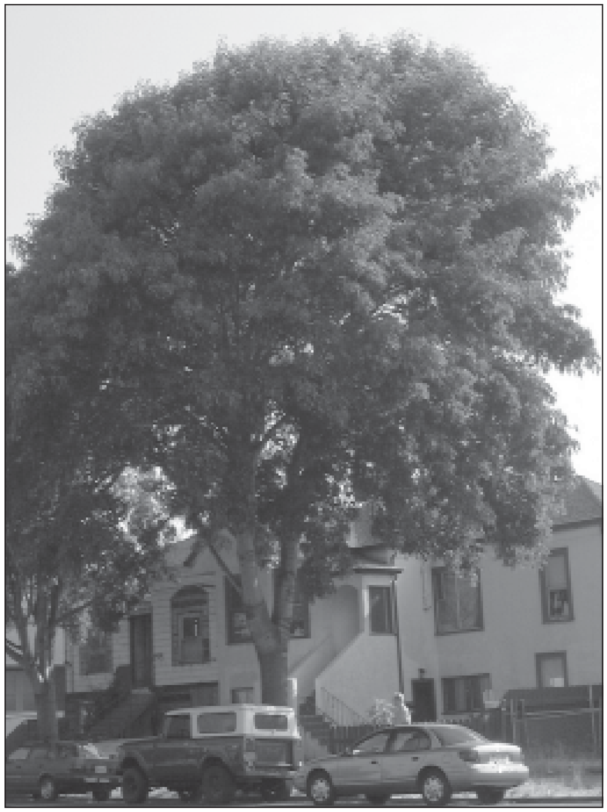

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Figure 15—The velvet ash represents large trees in this guide.

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Figure 16—The Monterey pine represents coniferous trees in this guide.

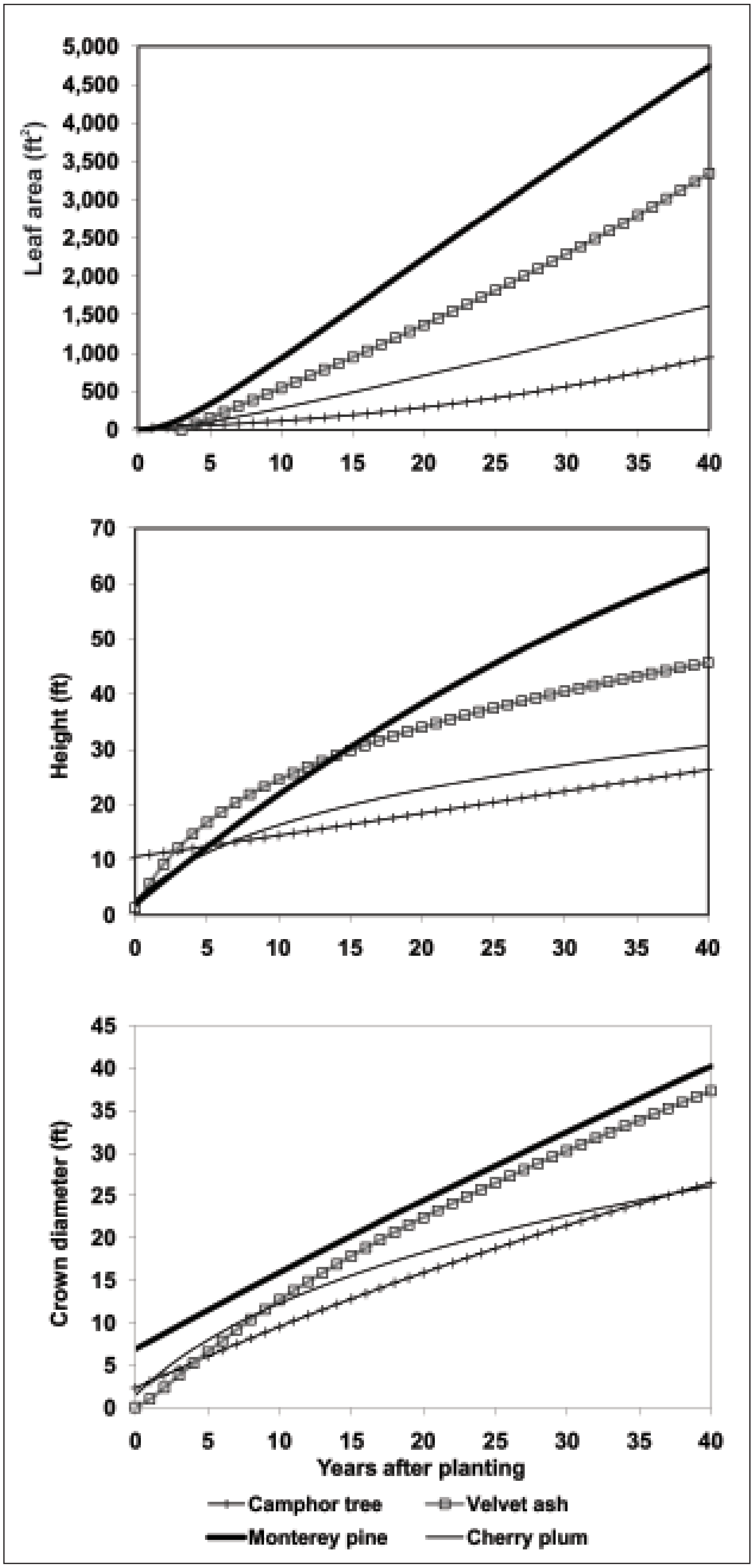

Figure 17—Tree growth curves are based on data collected from street trees in Berkeley, California. Data for representative small, medium, and large broadleaf trees and conifer trees are for the camphor, cherry plum, velvet ash, and Monterey pine, respectively. Differences in leaf surface area among species are most important for this analysis because functional benefits such as summer shade, rainfall interception, and pollutant uptake are related to leaf area.

Tree benefits based on numerical models

one growing season, was calculated with tree growth data and biomass equations for urban trees. Emission reductions were calculated as the product of energy savings and CO_2 emission factors for electricity and heating. Annual consumption of gasoline and diesel fuel by the community forestry divisions was converted into CO_2 equivalent emissions to estimate CO_2 released by tree maintenance activities. Hourly meteorological data for windspeed, solar radiation, and precipitation, as well as hourly concentrations for NO_2, O_3, SO_2, and PM_{10} were used with a numerical model to calculate pollutant dry deposition per tree. Energy savings resulting in reduced emissions of criteria air pollutants (VOCs, NO_2, PM_{10}) from powerplants and space heating equipment were calculated using utility-specific emission factors for electricity and heating fuels. A numerical interception model accounted for the volume of rainfall stored in tree crowns using information on crown projection areas (area under tree dripline), leaf areas, and water depths on canopy surfaces with hourly meteorological and rainfall data. The value of aesthetic and other benefits was captured from research that has quantified differences in sales prices of properties that are associated with trees. Anderson and Cordell (1988) found that each large front-yard tree was associated with a 0.88-percent increase in sales price. In this analysis, aesthetic benefits reflect the contribution of a large front-yard tree to local residential sales prices, with adjustments that account for the location of the tree (e.g., front or back yard, residential or commercial land use) and its growth rate.

Regional electricity and natural gas prices are used in this study to quantify the dollar value of energy savings. Costs of preventing or repairing damage from pollution, flooding, or other environmental risks were 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 gal of treated and controlled runoff to meet minimum standards, then the stormwater runoff mitigation value of a tree that intercepts 1,000 gal of rainfall, eliminating the need for control, should be $10. Appendix 3 contains more detailed information on methods used to calculate benefits and costs and assign monetary value to tree services.

Reporting Results

Tree mortality included

Results are reported in terms of annual value per tree planted. To make these calculations realistic, however, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, this analysis assumes that 45 percent of the planted trees will die over the 40-year period. Annual mortality rates are 3 percent per year for the first 5 years and 0.57 percent per year for the remainder of the 40-year period. This accounting approach "grows" trees in different locations and uses computer simulation to directly calculate the annual flow of benefits and costs as trees mature and die (McPherson 1992). In appendix 2, results are reported at 5-year intervals for 40 years.

Findings of This Study

Average Annual Net Benefits

Average annual net benefits (benefits minus costs) per tree increase with mature tree size (for detailed results see app. 2):

Average annual net benefits increase with tree size

- $29 to $41 for a small tree
- $42 to $60 for a medium tree
- $101 to $122 for a large tree
- $142 to $146 for a conifer

Benefits associated with increased property value and energy savings account for the largest proportion of total benefits in this region. Reduced stormwater runoff, lower levels of air pollutants and less CO_2 in the air are the next most important benefits.

Energy conservation benefits differ with tree location as well as size. Trees located opposite west-facing walls provide the greatest net heating and cooling energy savings. Reducing heating and cooling energy needs reduces CO_2 emissions and thereby reduces atmospheric CO_2. Similarly, energy savings that reduce pollutant emissions at powerplants account for important reductions in gases that produce ozone, a major component of smog. Environmental benefits alone, including energy savings, stormwater-runoff reduction, improved air quality, and reduced atmospheric CO_2, are greater than tree care costs.

Large trees provide the most benefits

Our findings demonstrate that average annual net benefits from large trees, like the velvet ash and Monterey pine, can be substantially greater than those from small trees. Average annual net benefits for the small, medium, and large deciduous public tree are $29, $42, and $101, respectively. Conifers provide the highest level of benefits, on average $142 for a public tree. The largest average annual net benefits from yard trees stemmed from a tree opposite the west-facing wall of a house: $41, $60, and $122 for small, medium, and large broadleaf trees, respectively. The pine tree windbreak provides an average annual net benefit of $146 per tree regardless of location because it is too far away to shade the residence.

Net annual benefits at year 40

The large yard tree opposite a west wall produces a net annual benefit of $170 at year 40. In the same location, 40 years after planting, the small, medium, and pine produce annual net benefits of $80, $81, and $172, respectively.

Forty years after planting at a typical public site, the small, medium, and large trees and the conifer provide annual net benefits of $60, $41, $133, and $157, respectively.

Net benefits for a yard tree opposite a west house wall and a public tree also increase with size when summed over the entire 40-year period:

- $1,640 (yard) and $1,179 (public) for a small tree
- $2,392 (yard) and $1,679 (public) for a medium tree
- $4,868 (yard) and $4,034 (public) for a large tree
- $5,855 (yard) and $5,685 (public) for a conifer

Year 20: environmental benefits exceed tree care costs

Twenty years after planting, average annual benefits for all trees exceed costs of tree planting and management (tables 1 and 2). For a large velvet ash in a yard 20 years after planting, the total value of environmental benefits alone ($55) is five times the total annual cost ($11). Environmental benefits total $25, $34, and $48 for the small, medium, and pine tree, whereas tree care costs are lower, $5, $11, and $15, respectively. Adding the value of aesthetics and other benefits to the environmental benefits results in substantial net benefits.

Net benefits are slightly less for public trees (table 2) than yard trees. Based on our survey findings, public trees are about twice as expensive to maintain as private trees. The standard of care is often high for public trees because of their prominence and potential risk.

Average Annual Costs

Costs of tree care

Averaged over 40 years, the annual costs for yard and public trees, respectively, are as follows:

- $10 (yard) and $17 (public) for a small tree
- $11 (yard) and $24 (public) for a medium tree
- $13 (yard) and $28 (public) for a large tree
- $15 (yard) and $33 (public) for a conifer

Costs increase with mature tree size because of added expenses for pruning and removing larger trees.

Table 1—Estimated annual benefits and costs for a private tree (residential yard) opposite the west-facing wall 20 years after planting

Benefit category	Camphor tree, Small tree, 18 ft tall, 16-ft spread, LSA = 313 ft^2		Cherry plum, Medium tree, 22 ft tall, 18-ft spread, LSA = 705 ft^2		Velvet ash, Large tree, 34 ft tall, 22-ft spread, LSA = 1,372 ft^2		Monterey pine, Conifer tree, 38 ft tall, 24-ft spread, LSA = 2,235 ft^2	
	Resource units	Total value	Resource units	Total value	Resource units	Total value	Resource units	Total value
		Dollars		*Dollars*		*Dollars*		*Dollars*
Electricity savings ($0.2131/kWh)	94 kWh	19.99	134 kWh	28.58	215 kWh	45.85	143 kWh	30.58
Natural gas savings ($0.0173/kBtu)	122 kBtu	2.10	157 kBtu	2.71	234 kBtu	4.04	469 kBtu	8.11
Carbon dioxide ($0.003/lb)	84 lb	0.28	143 lb	0.48	189 lb	0.63	191 lb	0.64
Ozone ($1.25/lb)	0.12 lb	0.16	0.14 lb	0.17	0.20 lb	0.25	0.29 lb	0.36
Nitrous oxide ($1.25/lb)	0.10 lb	0.12	0.11 lb	0.14	0.17 lb	0.21	0.24 lb	0.30
Sulfur dioxide ($1.77/lb)	0.02 lb	0.04	0.03 lb	0.04	0.04 lb	0.07	0.04 lb	0.08
Small particulate matter ($2.92/lb)	0.26 lb	0.77	0.17 lb	0.50	0.28 lb	0.80	0.22 lb	0.63
Volatile organic compounds ($0.53/lb)	0.00 lb	0.00	0.01 lb	0.00	0.01 lb	0.00	0.01 lb	0.00
Biogenic volatile organic compounds ($0.53/lb)	0.00 lb	0.00	0.00 lb	0.00	0.00 lb	0.00	-0.27 lb	- 0.14
Rainfall interception ($0.006/gal)	315 gal	1.73	321 gal	1.76	535 gal	2.94	1,402 gal	7.71
Environmental subtotal		25.19		34.39		54.80		48.28
Other benefits		18.70		38.14		74.52		112.45
Total benefits		43.89		72.53		129.32		160.73
Total costs		4.74		10.56		11.20		14.96
Net benefits		39.15		61.97		118.12		145.77

LSA = leaf surface area.

Table 2—Estimated annual benefits and costs for a public tree (street/park) 20 years after planting

Benefit category	Camphor tree Small tree 18 ft tall 16-ft spread LSA = 313 ft² Resource units	Total value	Cherry plum Medium tree 22 ft tall 18-ft spread LSA = 705 ft² Resource units	Total value	Velvet ash Large tree 34 ft tall 22-ft spread LSA = 1,372 ft² Resource units	Total value	Monterey pine Conifer tree 38 ft tall 24-ft spread LSA = 2,235 ft² Resource units	Total value
		Dollars		*Dollars*		*Dollars*		*Dollars*
Electricity savings ($0.2131/kWh)	65 kWh	13.78	89 kWh	18.96	127 kWh	27.04	143 kWh	30.58
Natural gas savings ($0.0173/kBtu)	142 kBtu	2.46	180 kBtu	3.10	261 kBtu	4.50	469 kBtu	8.11
Carbon dioxide ($0.003/lb)	67 lb	0.23	116 lb	0.39	135 lb	0.45	192 lb	0.64
Ozone ($1.25/lb)	0.12 lb	0.16	0.14 lb	0.17	0.20 lb	0.25	0.29 lb	0.36
Nitrous oxide ($1.25/lb)	0.10 lb	0.12	0.11 lb	0.14	0.17 lb	0.21	0.24 lb	0.30
Sulfur dioxide ($1.77/lb)	0.02 lb	0.04	0.03 lb	0.04	0.04 lb	0.07	0.04 lb	0.08
Small particulate matter ($2.92/lb)	0.26 lb	0.77	0.17 lb	0.50	0.28 lb	0.80	0.22 lb	0.63
Volatile organic compounds ($0.53/lb)	0.00 lb	0.00	0.01 lb	0.00	0.01 lb	0.00	0.01 lb	0.00
Biogenic volatile organic compounds ($0.53/lb)	0.00 lb	0.00	0.00 lb	0.00	0.00 lb	0.00	0.00 lb	- 0.14
Rainfall interception ($0.006/gal)	315 gal	1.73	321 gal	1.76	535 gal	2.94	1,402 gal	7.71
Environmental subtotal		19.28		25.07		36.27		48.28
Other benefits		21.22		43.28		84.56		127.59
Total benefits		40.50		68.35		120.83		175.87
Total costs		9.23		22.54		23.07		26.24
Net benefits		31.27		45.81		97.76		149.63

LSA = leaf surface area.

Over the 40-year period, tree planting is the single greatest cost for private trees, averaging approximately $4 per tree per year (see app. 2). Based on our survey, we assume in this study that a 15-gal yard tree is planted at a cost of $145. Annualized expenditures for tree pruning are the most important cost for public trees ($10 to $22 per tree per year).

Table 3 shows annual management costs 20 years after planting for yard trees to the west of a house and for public trees. Annual costs for yard trees range from $5 to $15, whereas public tree care costs average $9 to $26.

Average Annual Benefits

Average annual benefits over 40 years, including energy savings, stormwater runoff reduction, aesthetic value, air quality improvement, and carbon dioxide (CO_2) sequestration increase with mature tree size (figs. 18 and 19, for detailed results see app. 2):

- $41 to $51 for a small tree
- $57 to $71 for a medium tree
- $115 to $135 for a large tree
- $161 to $176 for a conifer

Energy savings—

Energy benefits are crucial

In the Northern California Coast region, trees provide significant energy benefits that tend to increase with tree size. For example, average annual net energy benefits over 40 years are $27 for the small camphor opposite a west-facing wall, and $51 for the larger velvet ash. Average annual net energy benefits for public trees are slightly less than for yard trees because public trees are assumed to provide general climate effects but do not shade buildings as effectively. Annual benefits range from $19 for the small public tree to $36 for the large public velvet ash. For species of all sizes, energy savings increase as trees mature and their leaf surface areas increase (figs. 18 and 19).

As expected in a region with warm summers and mild winters, cooling savings account for most of the total energy benefit. Average annual cooling savings for the small and large trees range from $17 to $24 and $31 to $47, respectively. The Monterey pine in a windbreak reduces heating costs by $8 on average.

Average annual net energy benefits for residential trees are greatest for a tree located west of a building because the effect of shade on cooling costs is maximized. A yard tree located east of a building produces the least net energy benefit because it has the least benefit during summer, and the greatest adverse effect on

Table 3—Estimated annual costs 20 years after planting for a private tree opposite the west-facing wall and a public tree

Costs	Camphor tree Small tree 18 ft tall 16-ft spread LSA = 313 ft^2		Cherry plum Medium tree 22 ft tall 18-ft spread LSA = 705 ft^2		Velvet ash Large tree 34 ft tall 22-ft spread LSA = 1,372 ft^2		Monterey pine Conifer tree 38 ft tall 24-ft spread LSA = 2,235 ft^2	
	Private: west	Public tree	Private: west	Public tree	Private: west	Public tree	Private: west	Public tree
	$/yr/tree							
Tree and planting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pruning	0.26	5.46	5.19	18.02	5.19	18.02	5.19	18.02
Remove and dispose	1.26	1.02	1.51	1.22	1.69	1.36	2.75	2.22
Pest and disease	2.93	0.01	3.52	0.01	3.93	0.01	6.39	0.01
Infrastructure	0.24	1.72	0.29	2.07	0.33	2.31	0.53	3.76
Irrigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cleanup	0.04	0.30	0.05	0.36	0.06	0.40	0.09	0.65
Liability and legal	0.00	0.03	0.00	0.03	0.01	0.04	0.01	0.06
Administration and other	0.00	0.70	0.00	0.84	0.00	0.94	0.00	1.53
Total costs	4.74	9.23	10.56	22.54	11.20	23.07	14.96	26.24
Total benefits	43.89	40.50	72.53	68.35	129.31	120.83	160.72	175.87
Total net benefits	39.15	31.27	61.96	45.81	118.11	97.76	145.76	149.63

Note: Prices for removal and disposal are included to account for expected mortality of citywide planting.
LSA = leaf surface area.

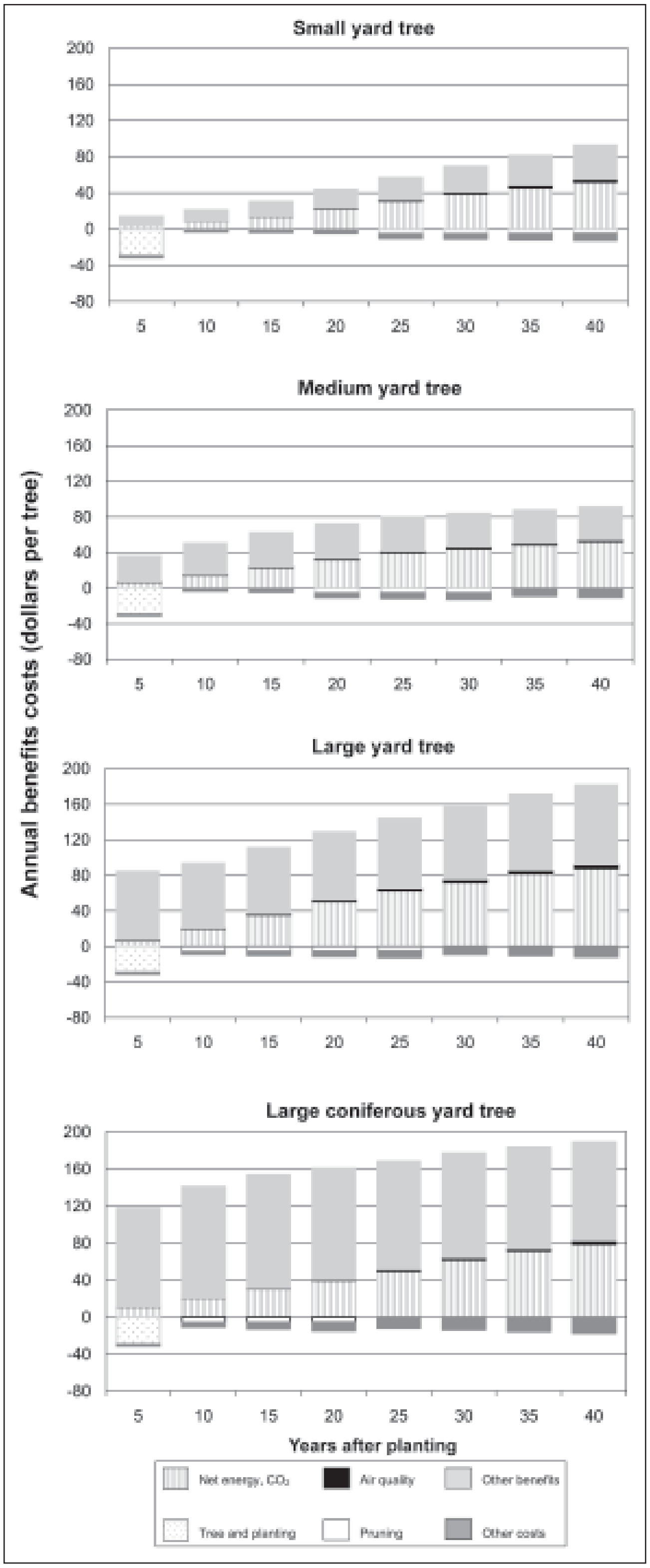

Figure 18—Estimated annual benefits and costs for a small (camphor), medium (cherry plum), and large (velvet ash) broadleaf tree, and a conifer (Monterey pine) located west of a residence. Costs are greatest during the initial establishment period, and benefits increase with tree size.

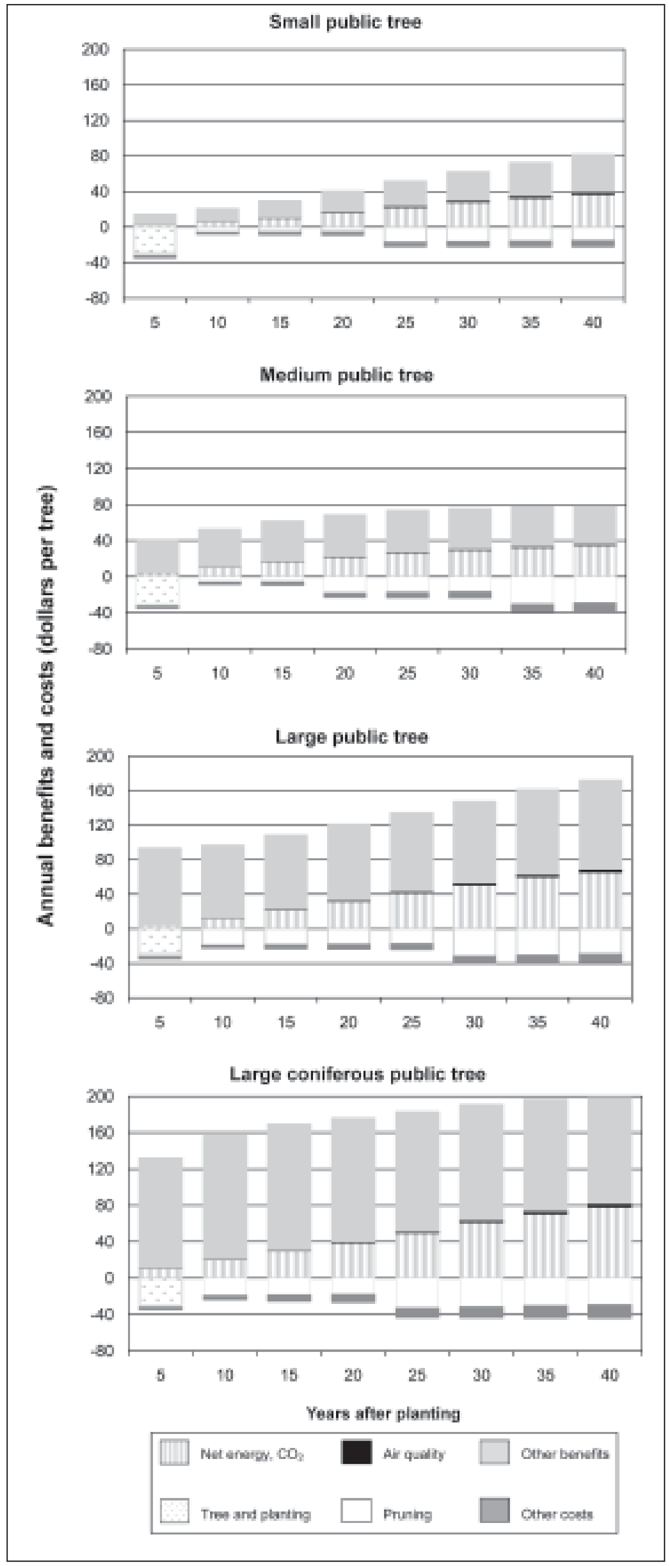

Figure 19—Estimated annual benefits and costs for public small (camphor), medium (cherry plum), and large (velvet ash) broadleaf tree, and a conifer (Monterey pine).

heating costs from shade in winter (see also fig. 4). Trees located south of a building provide intermediate net benefits. Net energy benefits also reflect species-related traits such as size, form, branch pattern and density, and time in leaf.

Stormwater runoff reduction—

Benefits associated with rainfall interception, reducing stormwater runoff, are substantial for all tree types. The camphor, a broadleaf evergreen tree, intercepts 420 gal/year on average over a 40-year period with an estimated annual value of $2. The cherry plum, velvet ash, and Monterey pine intercept 369 gal/year, 673 gal/year, and 1,673 gal/year on average, with annual values of $2, $4, and $9, respectively. The camphor intercepts more rainfall than the larger cherry plum because of its evergreen foliage.

As metropolitan areas in the region grow, the amount of impervious surface increases. The role that trees can play in protecting water quality by reducing stormwater runoff is substantial.

Aesthetic and other benefits—

Aesthetic benefits are substantial

Benefits associated with property value account for the largest portion of total benefits. As trees grow and become more visible, they can increase a property's sales price. Average annual values associated with these aesthetic and other benefits for yard trees are $21, $36, $77, and $105 for the small, medium, and large deciduous trees and for the conifer, respectively. The values for public trees are $23, $40, $88, and $119, respectively. The values for yard trees are slightly less than for public trees because off-street trees contribute less to a property's curb appeal than more prominent street trees. Because these estimates are based on median home sale prices, the effects of trees on property values and aesthetics will vary depending on local economies and market fluctuations.

Carbon dioxide reduction—

Net atmospheric CO_2 reductions accrue for all tree types. Average annual net reductions range from a low of 57 lbs ($0.19) for the small tree on the eastern side of the house to a high of 226 lbs ($0.75) for a large conifer tree. The deciduous ash tree opposite west-facing house walls produced 204 lbs of CO_2 reduction owing in part to reduced powerplant emissions associated with energy savings. The values for the camphor are lowest for CO_2 reduction because of the relatively small impacts of shade from the small-growing tree on energy consumption and emission reductions.

Forty years after planting, average annual avoided emissions and sequestered and released CO_2 for a yard tree opposite a west wall are 202, 299, 363, and 413 lbs, respectively, for the small, medium, and large broadleaf trees and the conifer.

Air quality improvement—

Air quality benefits are defined as the sum of pollutant uptake by trees and avoided powerplant emissions owing to energy savings minus **biogenic** volatile organic compounds (BVOCs) released by trees. Average annual air quality benefits range from $1 to $2 per tree. The large-stature Monterey pine produces the greatest benefit because of its size, although it does emit 0.34 lbs of BVOCs on average each year.

Annual air quality benefits average $1 to $2 per tree

The ability of trees to reduce particulates, ozone, and nitrogen dioxides in the air has the highest monetary value. For example, the average annual monetary value for an ash tree is estimated to be $1.06 for particulates, $0.32 for ozone, and $0.25 for nitrogen dioxides. The value of reducing sulfur dioxides and VOCs is less.

Forty years after planting, the average annual monetary values of air quality improvement for a yard tree opposite a west wall are $3, $1, $4, and $4, respectively, for the small, medium, and large trees and the conifer.

Chapter 4: Estimating Benefits and Costs for Tree Planting Projects in Your Community

This chapter shows two ways that benefit-cost information presented in this guide can be used. The first hypothetical example demonstrates how to adjust values from the guide for local conditions when the goal is to estimate benefits and costs for a proposed tree planting project. The second example explains how to compare net benefits derived from planting different types of trees. The last section discusses actions communities can take to increase the cost effectiveness of their tree programs.

Applying Benefit-Cost Data

Martha Falls City Example

The hypothetical city of Martha Falls is located in the Northern California Coast region and has a population of 24,000. Most of its street trees were planted in the 1930s, with sweetgum and London planetrees as the dominant species. Currently, the tree canopy cover is sparse because most of the trees have died and not been replaced. Many of the remaining street trees are in declining health. The city hired an urban forester 2 years ago, and an active citizens' group, the Green Team, has formed (fig. 20).

Initial discussions among the Green Team, local utilities, the urban forester, and other partners led to a proposed urban forestry program. The program intends to plant 1,000 trees in Martha Falls over a 5-year period. Trained volunteers will plant 15-gal trees in the following proportions: 70 percent large-maturing, 15 percent medium-maturing, and 5 percent small-maturing deciduous trees and 10 percent conifers. One hundred trees will be planted in parks, and the remaining 900 trees will be planted along Main Street and other downtown streets.

The Martha Falls City Council has agreed to maintain the current funding level for management of existing trees. Also, they will advocate formation of a municipal tree district to raise funds for the proposed tree-planting project. A municipal tree district is similar in concept to a landscape assessment district, which receives revenues based on formulas that account for the services different customers receive. For example, the proximity of customers to greenspace in a landscape assessment district may determine how much they pay for upkeep. A municipal tree district might receive funding from air quality districts, stormwater management agencies, electric utilities, businesses, and residents in proportion to the value of

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Figure 20—The Green Team is motivated to re-green their community by planting 1,000 trees in 5 years.

future benefits these groups will receive from trees in terms of air quality, hydrology, energy, carbon dioxide (CO_2) reduction, and property value. Such a district would require voter approval of a special assessment that charges recipients for tree planting and maintenance costs in proportion to the tangible benefits they receive from the new trees. The council needs to know the amount of funding required for tree planting and maintenance, as well as how the trees' services will be distributed over the 40-year life of the project.

The first step: determine tree planting numbers

As a first step, the Martha Falls city forester and Green Team decided to use the values in appendix 2, tables 6 to 17, to quantify total cumulative benefits and costs over 40 years for the proposed planting of 1,000 public trees—700 large, 150 medium, and 50 small trees and 100 conifers.

Before setting up a spreadsheet to calculate benefits and costs, the team considered which aspects of Martha Fall's urban and community forestry project differ from the regional values used in this guide (the methods for calculating the values in appendix 2 are described in appendix 3):

1. The prices of electricity and natural gas in Martha Falls are $0.11/kWh and $0.0125/kBtu, respectively. They are not $0.213/kWh and $0.0173/kBtu as assumed in this guide. It is assumed that the buildings that will be shaded by the new street trees have air conditioning and natural-gas heating.
2. The Green Team projected future annual costs for monitoring tree health and implementing their stewardship program. Administration costs are estimated to average $2,500 annually for the life of the trees or $2.50 per tree each year. This guide assumed an average annual administration cost of about $1 per tree for large public trees. Thus, an adjustment is necessary.
3. Planting will cost $140 per tree. The guide assumes planting costs of $145 per public tree. The costs will be slightly lower for Martha Falls because some labor will be provided by trained volunteers.

The second step: adjust for local prices of benefits

To calculate the dollar value of total benefits and costs for the 40-year period, the forester created a spreadsheet table (table 4). Each benefit and cost category is listed in the first column. Prices, some adjusted for Martha Falls where necessary, are entered into the second column. The third column contains the **resource units** (RU) per tree per year associated with the benefit or the cost per tree per year, which can be found in appendix 2. For aesthetic and other benefits, the dollar values for public trees are placed in the RU columns. The fourth column lists the 40-year total dollar values, obtained by multiplying the RU values by tree numbers, prices, and 40 years.

To adjust for different electricity prices, the forester multiplied electricity saved for a large public tree in the RU column (145.5 kWh) by the Martha Falls price for electricity ($0.11/kWh). This value ($16.01 per tree per year) was then multiplied by the number of trees planted and 40 years ($16.01 × 700 trees × 40 years = $448,171) to obtain cumulative air-conditioning energy savings for the large public trees (table 4). The process was carried out for all benefits and all tree types.

The third step: adjust for local costs

To adjust cost figures, the city forester changed the planting cost from $145 assumed in the guide to $140 (table 4). This planting cost was annualized by dividing the cost per tree by 40 years ($140/40 = $3.50 per tree per year). Total planting costs were calculated by multiplying this value by 700 large trees and 40 years ($98,000).

Table 4—Spreadsheet calculations of benefits and costs for the Martha Falls planting project (1,000 trees) over 40 years

Benefits	Price (adjusted)	700 large trees Annual per tree	700 large trees Total value	150 medium trees Annual per tree	150 medium trees Total value	50 small trees Annual per tree	50 small trees Total value	100 conifer trees Annual per tree	100 conifer trees Total value	1,000 total trees Total value	1,000 total trees Annual per tree	Percentage of positive services
	Dollars	*Resource units*	*Dollars*	*Resource units*	*Dollars*	*Resource units*	*Dollars*	*Resource units*	*Dollars*	*Dollars*	*Dollars*	*Percent*
Electricity (kWh)	0.1100	145.51	448,171	89.57	59,116	77.84	17,125	169.48	74,571	598,983	14.97	14.28
Natural gas (kBtu)	0.0125	274	95,900	184	13,800	162	4,050	491	24,550	138,300	3.46	3.30
Net carbon dioxide (lb)	0.0033	158	14,776	134	2,685	82	548	226	3,019	21,029	0.53	0.50
Ozone (lb)	1.25	0.26	9,106	0.16	1,201	0.16	400	0.37	1,851	12,558	0.31	1.50
Nitrous oxide (lb)	1.25	0.20	7,005	0.12	901	0.12	300	0.29	1,451	9,656	0.24	
Sulfur dioxide (lb)	1.77	0.04	1,981	0.03	318	0.03	106	0.05	354	2,759	0.07	
Small particulate matter (lb)	2.92	0.36	29,469	0.16	2,807	0.35	2,046	0.35	4,093	38,415	0.96	
Volatile organic compounds (lb)	0.53	0.01	148	0.01	32	0.00	0	0.01	21	201	0.01	
Biogenic volatile organic compounds (lb)	0.53	0.00	0	0.00	0	0.00	0	-0.34	-719	-719	-0.02	
Hydrology (gal)	0.0055	673	103,642	369	12,177	420	4,620	1,673	36,806	157,245	3.93	3.75
Aesthetics and other benefits ($)		87.52	2,450,560	40.39	242,340	23.26	46,520	119.27	477,080	3,216,500	80.41	76.68
Total benefits			3,160,757		335,377		75,716		623,077	4,194,927	104.87	100.00

Costs	Price (adjusted)	Annual per tree	Total value	Annual per tree	Total value	Annual per tree	Total value	Annual per tree	Total value	Total value	Value per tree	Percentage of costs
		Dollars										*Percent*
Tree and planting	140	3.50	98,000	3.50	21,000	3.50	7,000	3.50	14,000	140,000	3.50	12.04
Pruning		19.46	544,878	15.69	94,141	9.62	19,242	21.57	86,298	744,558	18.61	64.03
Remove and dispose		1.59	44,404	1.43	8,567	1.20	2,408	2.45	9,781	65,160	1.63	5.60
Pest and disease		0.01	192	0.01	37	0.01	10	0.01	44	283	0.01	0.02
Infrastructure repair		2.30	64,499	2.05	12,318	1.72	3,449	3.65	14,585	94,851	2.37	8.16
Irrigation		0.00	0	0.00	0	0.00	0	0.00	0	0	0.00	0.00
Cleanup		0.40	11,083	0.35	2,117	0.30	593	0.63	2,506	16,299	0.41	1.40
Liability and legal		0.04	1,078	0.03	206	0.03	58	0.06	244	1,585	0.04	0.14
Admin. and other	2.50	2.50	70,000	2.50	15,000	2.50	5,000	2.50	10,000	100,000	2.50	8.60
Total costs			834,133		153,385		37,760		137,458	1,162,736	29.07	100.00
Net benefit			2,326,624		181,992		37,956		485,619	3,032,191	75.80	
Benefit/cost ratio			3.79		2.19		2.01		4.53	3.61		
Net benefit per tree			83.09		30.33		18.98		121.40			

Note: Adjusted values are for electricity, natural gas, tree and planting, and administrative and other costs.

The administration, inspection, and outreach costs are expected to average $2.50 per tree per year, or a total of $100 per tree for the project's life. Consequently, the total administration cost for large trees is $2.50 × 700 large trees × 40 years ($70,000). The same procedure was followed to calculate costs for the medium and small deciduous trees and conifers.

Subtracting total costs from total benefits yields net benefits:

The fourth step: calculate net benefits and benefit-cost ratios for public trees

- $37,956 for 50 small trees
- $181,992 for 150 medium trees
- $2.3 million for 700 large trees
- $485,619 for 100 conifer trees

Annual benefits over 40 years total $4.2 million ($105 per tree per year), and annual costs total $1.2 million ($29 per tree per year). The total net annual benefits for all 1,000 trees over the 40-year period are $3.0 million, or $76 per tree. To calculate this average annual net benefit per tree, the forester divided the total net benefit by the number of trees planted (1,000) and 40 years ($3,032,191/1,000 trees/40 years = $75.80). Dividing total benefits by total costs yielded benefit-cost ratios (BCRs) of 2.01, 2.19, 3.79, and 4.53 for small, medium, and large deciduous trees and conifers. The BCR for the entire planting is 3.61, indicating that $3.61 will be returned for every $1 invested.

It is important to remember that this analysis assumes 45 percent of the planted trees die and are not replaced. Also, it does not account for the time value of money from a municipal capital investment perspective. Use the municipal discount rate to compare this investment in tree planting and management with alternative municipal investments.

The final step: determine how services are distributed, and link these to sources of revenue

The city forester and Green Team now know that the project will cost about $1.2 million over 40 years, and the average annual cost will be about $29,000 ($1,162,736 / 40 years); however, expenditures are front-loaded because relatively more funds will be needed initially for planting and stewardship. The fifth and last step is to identify the distribution of services that the trees will provide. The last column in table 4 shows the distribution of services as a percentage of the total:

- Energy savings = 17 percent (cooling = 14 percent, heating = 3 percent)
- Carbon dioxide reduction = 1 percent
- Stormwater-runoff reduction = 4 percent
- Aesthetics/property value increase = 77 percent
- Air quality = 1 percent

Distributing costs of tree management to multiple parties

With this information, the planning team can determine how to distribute the costs for tree planting and maintenance based on who benefits from the services the trees will provide. For example, assuming the goal is to generate enough annual revenue to cover the total costs of managing the trees ($1.2 million), fees could be distributed in the following manner:

- $204,000 from electric and natural gas utilities for energy savings (17 percent). (It is more cost-effective for utility companies to plant trees to reduce peak energy demand than to meet peak needs through added infrastructure).
- $6,000 from local industry for atmospheric CO_2 reduction offsets (1 percent).
- $44,000 from the stormwater-management district for water quality improvement associated with reduced runoff (4 percent).
- $891,000 from property owners for increased property values (77 percent).
- $17,000 from air quality management district for net reduction in air pollutants (1 percent).

Whether project funds are sought from partners, the general fund, or other sources, this information can assist managers in developing policy, setting priorities, and making decisions. The Center for Urban Forest Research has developed a computer program called i-Tree Street (formerly STRATUM), part of the i-Tree software suite, that simplifies these calculations for analysis of existing street tree populations (http://www.itreetools.org).

City of Melvinville Example

As a municipal cost-cutting measure, the hypothetical city of Melvinville plans to stop planting street trees in areas of new development. Instead, developers will be required to plant front-yard trees, thereby reducing costs to the city. The community forester and concerned citizens believe that, although this policy will result in cost savings for the city, developers may plant trees with smaller mature size than the city would have. Currently, Melvinville’s policy is to plant large-growing trees based on each site’s available growing space (fig. 21). Planting smaller stature trees could result in services “forgone” whose value will exceed cost savings. To evaluate this possible outcome, the community forester and concerned citizens decided to compare costs and benefits of planting small, medium, and large trees for a hypothetical street-tree planting project in Melvinville.

Figure 21—The fictional city of Melvinville's policy to plant as large a tree as the site will handle has provided ample benefits in the past. Here, a large-stature tree has been planted.

The first step: calculate benefits and costs over 40 years

As a first step, the city forester and concerned citizens decided to quantify the total cumulative benefits and costs over 40 years for a typical street tree planting of 1,500 trees in Melvinville. For comparison purposes, the planting includes 500 small trees, 500 medium trees, and 500 large trees. Data in appendix 2 are used for the calculations; however, three aspects of Melvinville's urban and community forestry program are different than assumed in this tree guide:

- The price of electricity is $0.17/kWh, not $0.213/kWh.
- The trees will be irrigated for the first 5 years at a cost of approximately $0.50 per tree annually.
- Planting costs are $450 per tree for 24-in box trees instead of the $145 per 15-gal container tree.

The second step: adjust for local prices of benefits

To calculate the dollar value of total benefits and costs for the 40-year period, the last column in appendix 2 (40-year average), tables 6 to 14, is multiplied by 40 years. As this value is for one tree, it must be multiplied by the total number of trees planted in the respective small, medium, or large tree size classes. To adjust for higher electricity prices for cooling we multiply electricity saved for each tree type in the RU column by the number of trees and 40 years (large public tree: 146 kWh × 500 trees × 40 years = 2,920,000 kWh). This value is multiplied by the price of electricity in Melvinville ($0.17/kWh × 2,920,000 kWh = $496,400) to obtain cumulative air-conditioning energy savings for the project (table 5).

All the benefits are summed for each size tree for a 40-year period. The 500 small trees provide $851,400 in total benefits. The medium and large trees provide $1.2 million and $2.4 million, respectively.

The third step: adjust for local costs

To adjust cost figures, we add a value for irrigation by multiplying the annual cost by the number of trees by the number of years irrigation will be applied ($0.50 × 500 trees × 5 years = $1,250). We multiply 500 trees by the unit planting cost ($450) to obtain the adjusted cost for planting in Melvinville (500 × $450 = $225,000). The average annual 40-year costs for other items are taken from appendix 2 and multiplied by 40 years and the appropriate number of trees to compute total costs. These 40-year cost values are entered into table 5.

Subtracting total costs from total benefits yields net benefits for the small ($353,560), medium ($592,409), and large ($1.7 million) trees. The total net benefit for the 40-year period is $2.7 million (total benefits -total costs), or $1,773 per tree ($2.7 million/1,500 trees) on average (table 5).

The net benefits per public tree planted are as follows:

- $707 for a small tree
- $1,185 for a medium tree
- $3,427 for a large tree

The fourth step: calculate cost savings and benefits forgone

By not investing in street-tree planting, the city would save $675,000 in initial planting costs. There is a risk, however, that developers will not plant the largest trees possible. If the developer planted 1,500 small trees, benefits would total $1.1 million (3 × $353,560 for 500 small trees). If 1,500 large trees were planted, benefits would total $5.1 million. Planting all small trees would cost the city $4 million in forgone services. This amount far exceeds the savings of $675,000 obtained by requiring developers to plant new street trees, and suggests that, when turning over the responsibility for tree planting to others, the city should be very careful to develop and enforce a street tree ordinance that requires planting large trees where feasible.

Based on this analysis, the city of Melvinville decided to retain the policy of promoting planting of large trees where space permits. They now require tree shade plans that show how developers will achieve 50 percent shade over streets, sidewalks, and parking lots within 15 years of development.

Table 5—Spreadsheet calculations of benefits and costs for the Melvinville planting project (1,500 trees) over 40 years

Benefits	Price (adjusted)	500 large Resource units	500 large Total value	500 medium Resource units	500 medium Total value	500 small Resource units	500 small Total value	1,500 tree total Resource units	1,500 tree total Total value	Average/ tree	Percentage of positive services
	Dollars		*Dollars*		*Dollars*		*Dollars*		*Dollars*	*Dollars*	*Percent*
Electricity (kWh)	0.17	2,920,000	496,400	1,800,000	306,000	1,560,000	265,200	6,280,000	1,067,600	711.73	23.66
Natural gas (kBtu)	0.0173	5,480,000	68,600	3,680,000	46,000	3,240,000	40,600	12,400,000	155,200	103.47	3.44
Net carbon dioxide (lb)	0.0033	3,160,000	10,600	2,680,000	9,000	1,640,000	5,400	7,480,000	25,000	16.67	0.55
Ozone (lb)	1.25	5,190	6,400	3,140	4,000	3,200	4,000	11,530	14,400	9.60	0.32
Nitrous oxide (lb)	1.25	3,960	5,000	2,390	3,000	2,390	3,000	8,740	11,000	7.33	0.24
Sulfur dioxide (lb)	1.77	890	1,600	540	1,000	520	1,000	1,950	3,600	2.40	0.08
Small particulate matter (lb)	2.92	7,220	21,200	3,140	9,200	7,100	20,800	17,460	51,200	34.13	1.13
Volatile organic compounds (lb)	0.53	170	0	100	0	90	0	360	0	0.00	0.00
Biogenic volatile organic compounds (lb)	0.53	0	0	-60	0	0	0	-60	0	0.00	0.00
Hydrology (gal)	0.0055	13,460,000	74,000	7,380,000	40,600	8,400,000	46,200	29,240,000	160,800	107.20	3.56
Aesthetics and other benefits ($)			1,750,400		807,800		465,200		3,023,400	2,015.60	67.01
Total benefits			2,434,200		1,226,600		851,400		4,512,200	3,008.13	100.00

Costs	Price (adjusted)	500 large Total value	500 medium Total value	500 small Total value	1,500 tree total Total value	Average/ tree	Percentage of costs
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Percent*
Tree and planting	450	225,000	225,000	225,000	675,000	450.00	36.43
Pruning		389,198	313,802	192,417	895,417	596.94	48.33
Remove and dispose		31,717	28,557	24,082	84,356	56.24	4.55
Pest and disease		137	122	103	363	0.24	0.02
Infrastructure		46,071	41,060	34,491	121,622	81.08	6.56
Irrigation	0.05	1,250	1,250	1,250	3,750	2.50	0.20
Cleanup		7,917	7,056	5,927	20,899	13.93	1.13
Liability and legal		770	686	576	2,032	1.35	0.11
Admin and other		18,692	16,659	13,994	49,345	32.90	2.66
Total costs		720,752	634,191	497,840	1,852,783	1,235.19	100.00
Net benefits		1,713,448	592,409	353,560	2,659,417	1,772.94	
Benefit/cost ratio		3.38	1.93	1.71	2.44		
(Net benefit per tree)		3,426.90	1,184.82	707.12	1,772.94		

Note: Adjusted values are for electricity, tree and planting, and irrigation.

This analysis assumed 45 percent of the planted trees died. It did not account for the time value of money from a capital investment perspective, but this could be done by using the municipal discount rate.

Increasing Program Cost-Effectiveness

What if costs are too high?

What if the program you have designed is promising in terms of stormwater-runoff reduction, energy savings, volunteer participation, and additional benefits, but the costs are too high? This section describes some steps to consider that may increase benefits and reduce costs, thereby increasing cost-effectiveness.

Increasing Benefits

Work to increase survival rates

Improved stewardship to increase the health and survival of recently planted trees is one strategy for increasing cost-effectiveness. An evaluation of the Sacramento Shade program found that tree survival rates had a substantial impact on projected benefits (Hildebrandt et al. 1996). Higher survival rates increase energy savings and reduce tree removal and planting costs.

Target tree plantings with highest return

Improved tree selection can increase benefits. For example, conifers and broadleaf evergreens intercept rainfall, which is during the winter in this region. Also, they intercept particulate matter year round as well as reduce windspeeds and provide shade, which lowers summer cooling and winter heating costs. Locating trees with evergreen foliage in yards, parks, school grounds, and other open-space areas can increase benefits.

Customize planting locations

You can further increase energy benefits by planting a higher percentage of trees in locations that produce the greatest energy savings, such as opposite west-facing walls and close to buildings with air conditioning. Keep in mind that evergreen trees should not be planted on the east and southern side of buildings, because their branches and leaves block the warm rays of the winter sun. By customizing tree locations to increase numbers in high-yield sites, energy savings can be boosted.

Reducing Program Costs

Cost effectiveness is influenced by program costs as well as benefits:

Cost effectiveness = Total net benefit / total program cost

Reduce upfront and establishment costs

Cutting costs is one strategy to increase cost effectiveness. A substantial percentage of total program costs occur during the first 5 years and are associated with tree planting and establishment (McPherson 1993). Some strategies to reduce these costs include:

- Plant bare-root or smaller tree stock.
- Use trained volunteers for planting and young tree care, irrigation, and structural pruning (fig. 22).
- Provide improved followup care to increase tree survival and reduce replacement costs.
- Select and locate trees to avoid conflicts with infrastructure.
- Select quality nursery stock with well-formed roots and crowns, which often results in reduced pavement damage, improved survival, and less pruning.

Tree Trust

Figure 22—Trained volunteers can plant and maintain young trees, allowing the community to accomplish more at less cost and providing satisfaction for participants.

- Maintain a single dominant leader by pruning young trees to reduce future pruning costs. Also, prune young trees to eliminate and minimize defects. This will reduce the risk of failure, increase longevity, and reduce conflicts with vehicles.
- Increase planting space; make cutouts larger, meander sidewalks, and use structural soils to reduce future costs associated with infrastructure conflicts.
- Select species that are tolerant of harsh conditions and with a low potential to damage nearby pavement.
- Mulch newly planted trees to conserve soil moisture.
- Minimize competition from turf and weeds to encourage rapid establishment.

Use less expensive stock where appropriate

Where growing conditions are likely to be favorable, such as yard or garden settings, it may be cost-effective to use smaller, less expensive stock or bare-root trees. In highly urbanized settings and sites subject to vandalism, however, large stock may survive the initial establishment period better than small stock.

Investing in the resources needed to promote tree establishment during the first 5 years after planting is usually worthwhile, because once trees are established they have a high probability of continued survival. If your program has targeted trees on private property, then encourage residents to attend tree-care workshops. Develop standards of "establishment success" for different types of tree species. Perform periodic inspections to alert residents to tree health problems, and reward those whose trees meet your program's establishment standards. Replace dead trees as soon as possible, and identify ways to improve survivability.

Although organizing and training volunteers requires labor and resources, it is usually less costly than contracting the work. A cadre of trained volunteers can easily maintain trees until they reach a height of about 20 ft and limbs are too high to prune from the ground with pole pruners/saws. By the time trees reach this size, they are well established. Pruning during this establishment period should result in trees that will require less care in the long term. Training young trees can provide a strong branching structure that requires less structural and corrective pruning (Costello 2000). Ideally, young trees should be inspected and pruned every other year for the first 5 years after planting. Pruning thereafter, depending on species, should occur about every 5 years to correct structural problems. For most trees, it's a good idea to maintain a single leader to height of no less than about 20 ft. This will facilitate clearance pruning of street trees to prevent conflicts with vehicles.

Prune early

As trees grow larger, pruning costs may increase on a per-tree basis. The frequency of pruning will influence these costs, as it takes longer to prune a tree that has not been pruned in 10 years than one that has been pruned every 3 to 5 years; frequent pruning is also less stressful. Specifications should be developed for tree pruning for each species and should emphasize structural development, not thinning or shaping. Although pruning frequency varies by species and location, a return frequency of about 5 to 8 years is usually sufficient for mature trees (Miller 1997).

Match tree to site

Carefully select and locate trees to avoid conflicts with overhead power lines, sidewalks, and underground utilities. Time spent planning the planting will result in long-term savings. Also consider soil type and irrigation, microclimate, and the type of activities occurring around the tree that will influence its growth and management.

It all adds up—trees pay us back

When evaluating the bottom line, do not forget to consider services other than the stormwater-runoff reductions, energy savings, atmospheric CO_2 reductions, and other tangible benefits. The magnitude of benefits related to employment opportunities, job training, community building and pride, reduced violence, and enhanced human health and well-being can be substantial (fig. 23). Moreover, these benefits extend beyond the site where trees are planted, furthering collaborative efforts to build better communities.

For more information on urban and community forestry program design and implementation, see the list of additional resources in appendix 1.

Figure 23—Trees pay us back in both tangible and intangible ways.

Chapter 5: General Guidelines for Selecting and Placing Trees

In this chapter, general guidelines for selecting and locating trees are presented. Residential trees and trees in public places are considered.

Guidelines for Energy Savings

Maximizing Energy Savings From Shading

Where should shade trees be planted?

The right tree in the right place can save energy and reduce tree care costs. In midsummer, the sun shines on the east side of a building in the morning, passes over the roof near midday, and then shines on the west side in the afternoon (fig. 4). Electricity use for cooling is highest during the afternoon when temperatures are warmest and incoming sunshine is greatest. Most heat gain comes through the west-facing window and wall. Therefore, the west side of a home is the most important side to shade (Sand 1994).

Depending on building orientation and window placement, sun shining through windows can heat a home quickly during the morning hours. The south and east side are the next most important sides to shade when considering the net impact of tree shade on energy savings (fig. 24). Deciduous trees provide summer shade and allow more winter solar heat gain than evergreens.

Trees located too far from south walls do not provide summer shade and may block winter sunshine depending on leaf retention. This can increase heating costs because during winter the sun is lower in the sky and shines on the south side of homes (fig. 25). The warmth the sun provides is an asset, so do not plant evergreen

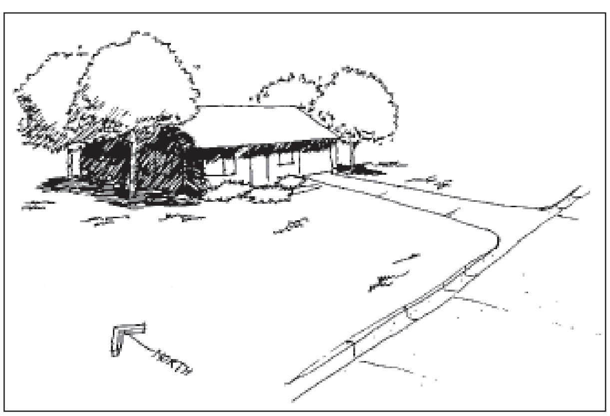

Figure 24—Locate trees to shade west and east windows (from Sand 1993).

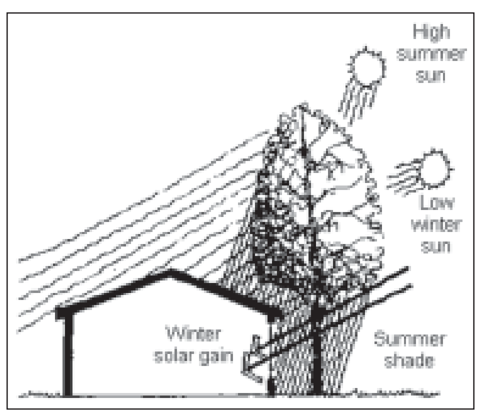

Figure 25—Select solar-friendly trees for southern exposures and locate them close enough to provide winter solar access and summer shade (from Sand 1991).

trees closer than 50 feet from the south side of a home. Depending on size, they are likely to block southern exposures and solar collectors. Use **solar-friendly trees** to the south and east because their crowns are dense during summer, sparse during winter, and they are early to drop leaves and late to leaf out. The bare branches of these deciduous trees allow most sunlight to strike the building (some solar-unfriendly deciduous trees can reduce sunlight striking the south side of buildings by 50 percent even without leaves) (Ames 1987). Examples of solar-friendly trees include most species and **cultivars** of maples, hackberry, honey locust, Kentucky coffeetree, and Japanese pagoda tree (see "Common and Scientific Names" section). Some solar-unfriendly trees include most oaks, sycamore, most elms, basswood, river birch, and horse chestnut (McPherson et al. 1994).

To maximize summer shade and minimize winter shade, locate shade trees no farther than 10 to 20 ft south of the home. As trees grow taller, prune lower branches to allow more sun to reach the building if this will not weaken the tree's structure (fig. 26).

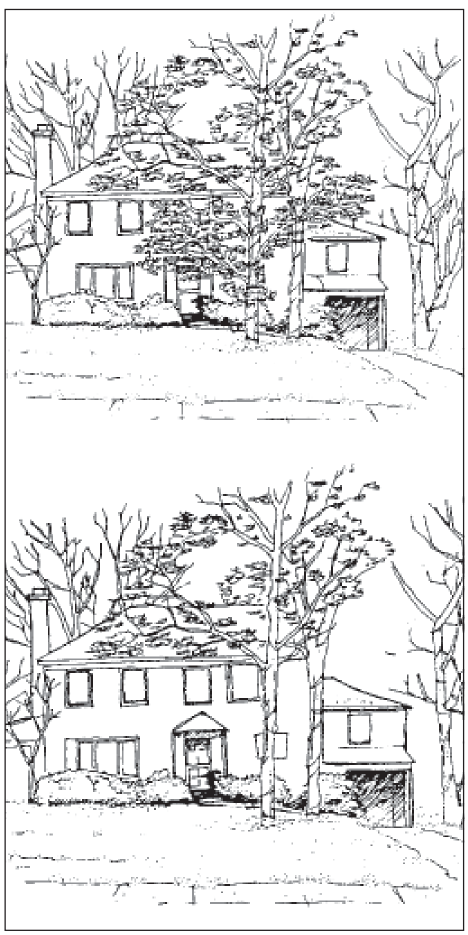

Figure 26—Trees south of a home before and after pruning. Lower branches are pruned up to increase heat gain from winter sun (from Sand 1993).

Although the closer a tree is to a home the more shade it provides, roots of trees that are too close can damage the foundation. Branches that impinge on the building can make it difficult to maintain exterior walls and windows. To avoid these conflicts, keep trees at least 10 ft away from the home depending on mature crown spread. Trees beyond 50 ft of the home do not effectively shade windows and walls. In fire-prone areas, conifers should not be planted within about 30 ft of a home. A few individual specimens, though, can be planted within 30 ft, assuming they are well maintained and sufficiently pruned up.

Paved patios and driveways can become **heat sinks** that warm the home during the summer. Shade trees can make them cooler and more comfortable spaces. If a home is equipped with an air conditioner, shading can reduce its energy use, but do not plant vegetation so close that it will obstruct the flow of air around the unit.

Plant only small-growing trees under overhead power lines and avoid planting directly above underground water and sewer lines if possible. Contact your local utility location service before planting to determine where underground lines are located and which tree species should not be planted below power lines.

Planting Windbreaks for Heating Savings

A tree's size and crown density can make it ideal for blocking wind, thereby reducing the impacts of cold winter weather. Locate rows of trees perpendicular to the prevailing wind (fig. 27), usually the north and west side of homes in the Northern California Coast region.

Plant dense evergreens

Design the windbreak row to be longer than the building being sheltered because windspeed increases at the edge of the windbreak. Ideally, the windbreak should be planted upwind about 25 to 50 ft from the building and should consist of dense evergreens that will grow to twice the height of the building they shelter (Heisler 1986, Sand 1991). Avoid planting windbreaks that will block sunlight to south and east walls (fig. 28). Trees should be spaced close enough to form a dense screen, but not so close that they will block sunlight to each other, causing lower branches to self-prune. Most conifers can be spaced about 6 to 10 ft on center. If there is room for two or more rows, then space rows 10 to 15 ft apart.

Conifers are preferred over deciduous trees for windbreaks because they provide better wind protection. The ideal windbreak tree is fast growing, visually dense, has strong branch attachments, and has stiff branches that are not prone to breaking or branch shedding. Large windbreak trees for communities in the region include afghan pine and drooping she-oak. Good windbreak species for smaller sites include Arizona cypress and Canary Island pine.

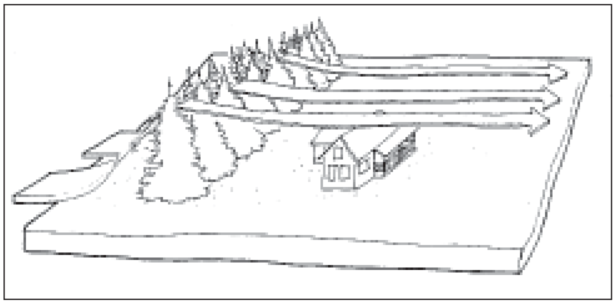

Figure 27—Evergreens protect a building from dust and cold by reducing windspeeds (from Sand 1993).

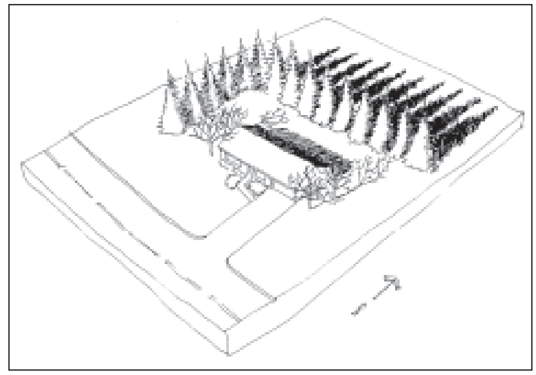

Figure 28—Midwinter shadows from a well-located windbreak and shade trees do not block solar radiation on the south-facing wall (from Sand 1993).

In settings where wildland fire is relatively unlikely, evergreens planted close to the home create air spaces that reduce air infiltration and heat loss. Allow shrubs to form thick hedges, especially along north, west, and east walls.

Selecting Trees to Maximize Benefits

There are many choices

The ideal shade tree has a fairly dense, round crown with limbs broad enough to partially shade the roof. Given the same placement, a large tree will provide more shade than a small tree. Deciduous trees allow sun to shine through leafless branches in winter. Plant small trees where nearby buildings or power lines limit aboveground space. Columnar trees are appropriate in narrow side yards. Because the best location for shade trees is relatively close to the west and east sides of buildings, the most suitable trees will be strong and capable of resisting storm damage, disease, and pests (Sand 1994). Examples of trees not to select for placement near buildings include cottonwood and silver maple because of their invasive roots, weak or brittle wood, and large size, and ginkgos because of their sparse shade and slow growth.

Picking the right tree

When selecting trees, match the tree's water requirements with those of surrounding plants. For instance, select low-water-use species for planting in areas that receive little irrigation. Also, match the tree's maintenance requirements with the amount of care and the type of use different areas in the landscape receive. For instance, tree species that drop fruit that can be a slip-and-fall problem should not be planted near paved areas that are frequently used by pedestrians. SelectTree, a Web-based tree selection program is a valuable resource for comparing tree traits (http://selectree.calpoly.edu/). Check with your local landscape professional before selecting trees to make sure that they are well suited to the site's soil and climatic conditions.

Maximizing energy savings from trees

Use the following practices to plant and manage trees strategically to maximize energy conservation benefits:

- Increase community-wide tree canopy cover, and target shade to streets, parking lots, and other paved surfaces, as well as air-conditioned buildings.
- Shade west-facing windows and walls.
- Select solar-friendly trees opposite east- and south-facing walls.
- Shade air conditioners, but don't obstruct airflow.
- Avoid planting trees too close to utilities and buildings.
- Create multirow, evergreen windbreaks where space permits, that are longer than the building.

Guidelines for Reducing Carbon Dioxide

Because trees in common areas and other public places may not shelter buildings from sun and wind and reduce energy use, carbon dioxide (CO_2) reductions from such trees are primarily due to sequestration. Fast-growing trees sequester more CO_2 initially than slow-growing trees, but this advantage can be lost if the fast-growing trees die at younger ages. Large trees have the capacity to store more CO_2 than smaller trees (fig. 29). Use the Center for Urban Forest Research Tree Carbon Calculator (CTCC) to compare sequestration rates for different tree species in this region (http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/). To maximize CO_2 sequestration, select tree species that are well suited to the site where they will be planted, relatively pest free, and long-lived. Consult resources such as *Pests of Landscape Trees and Shrubs* (Dreistadt et al. 1994), and for information on abiotic disorders, refer to *Abiotic Disorders of Landscape Plants* (Costello et al. 2003). Consult online resources at www.ipm.ucdavis.edu, *Sunset Western Garden Book* (Brenzel 2001), and your local University of California Cooperative Extension Horticulture Advisors, landscape professionals, and arborists to select the right tree for your site. Trees that are not well adapted will grow slowly, show symptoms of stress, or die at an early age. Unhealthy trees do little to reduce atmospheric CO_2 and can be unsightly liabilities in the landscape.

Design and management guidelines that can increase CO_2 reductions include the following:

- Maximize use of woody plants, especially trees, as they store more CO_2 than do herbaceous plants and grasses.
- Plant more trees where feasible and immediately replace dead trees to compensate for CO_2 lost through tree and stump removal.

Center for Urban Forest Research

Figure 29—Compared with small trees, large trees can store more carbon, filter more air pollutants, intercept more rainfall, and provide greater energy savings.

- Use native trees, particularly oaks, whenever practical and appropriate.
- Create a diverse assemblage of habitats, with trees of different ages and species, to promote a continuous canopy cover over time. Do not rely on a few favored species such as sycamores. Diversity is a key to developing sustainable landscapes. New, introduced insect and disease pests are a constant threat to urban trees. It is also important to avoid species that are invasive and can spread in natural habitats.
- Group species with similar environmental tolerances and irrigation needs.
- Reduce the areas devoted to unused turf. Turf requires irrigation and maintenance often associated with relatively large amounts of greenhouse gas emissions. Consider environmentally friendly landscapes such as low-water-use vegetation, coarse wood chip mulch, and decomposed granite.

- Consider the project's lifespan when selecting species. Although fast-growing species, e.g., willows, poplars, tulip poplars, alders, Monterey pines, etc., will sequester more CO_2 initially than slow-growing species, many are short-lived and begin to decline in 30 years or less. Redwoods on the other hand, are fast-growing, but generally long-lived. Unfortunately they require ample irrigation to thrive unless situated along the coast.
- Avoid removing trees by considering other alternatives. Alternatives should include, but are not limited to:
    - Crown reduction to improve safety
    - Changing project design
    - Bridging over roots
    - Ramping sidewalks
    - Using flexible paving materials or thinner sections
    - Using permeable paving materials and enlarging tree wells (cut-outs)
    - Reducing sidewalk width
    - Relocating pavement
    - Use of geogrids or other "no-dig" pavement systems
    - Using a coarse gravel base material under sidewalks
    - Using reinforced concrete sidewalk panels supported on piers
    - Covering surface roots with soil
- Provide ample space (favorable rooting space) belowground for tree roots to grow so that they grow reasonably well and can maximize CO_2 sequestration and tree longevity.
- When trees die or are removed, salvage as much wood as possible for use in furniture, art pieces, and other long-lasting products to delay decomposition.
- Plant trees, shrubs, and vines (e.g., grape arbors) in strategic locations to maximize summer shade and reduce winter shade, thereby reducing atmospheric CO_2 emissions associated with power production.

Guidelines for Reducing Stormwater Runoff

Trees are mini-reservoirs, controlling stormwater runoff at the source because their leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and erosion of watercourses, as well as delaying the onset of peak flows. Rainfall interception by large trees is a relatively inexpensive first line of defense in the battle to control nonpoint-source pollution.

When considering trees to maximize rainfall interception benefits, consider the following:

- Select tree species with architectural features that maximize interception, such as large leaf surface area and rough surfaces that store water (Metro 2002).
- Increase interception by planting large trees where possible.
- Plant evergreen tree species and those that retain their leaves throughout much of the winter when precipitation is greatest (e.g., southern magnolia, camphor, coast live oak).
- Select conifers because they have high interception rates, but avoid shading south-facing windows to maximize solar heat gain in winter.
- Plant low-water-use tree species where appropriate and native species that, once established, require little supplemental irrigation.
- In bioretention areas, such as roadside swales, select species that tolerate seasonal inundation, are long-lived, wide-spreading, and fast-growing (Metro 2002).
- Along streets, sidewalks, and parking lots, plant trees in engineered soils designed to capture runoff from adjacent paving and promote deep root growth (fig. 30).
- Do not pave over streetside planting strips for easier weed control; this can reduce tree health and increase runoff.

Guidelines for Improving Air Quality Benefits

Trees, sometimes called the "lungs of our cities," are important because of their ability to remove contaminants from the air. The amount of gaseous pollutants and particulates removed by trees depends on their size and architecture, as well as local meteorology and pollutant concentrations.

Along streets, in parking lots, and in commercial areas, locate trees to maximize shade on paving and parked vehicles. Shade trees reduce heat that is stored or reflected by paved surfaces. By cooling streets and parking areas, trees reduce emissions of evaporative hydrocarbons from parked cars and thereby reduce smog formation (Scott et al. 1999). Large trees can shade a greater area than smaller trees, but should be used only where space permits. Remember that a tree needs space for both branches and roots.

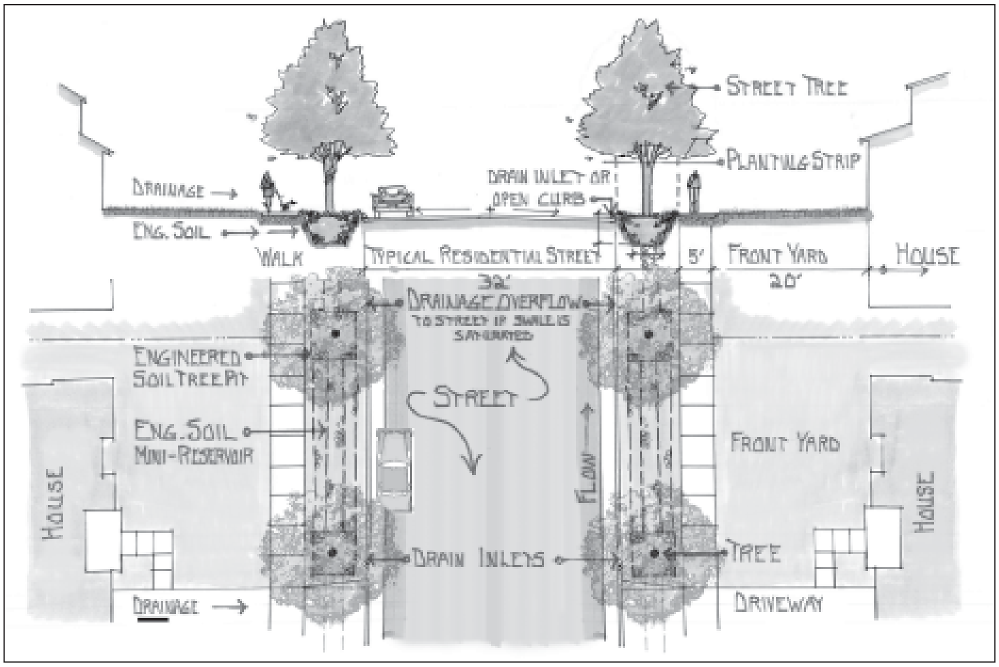

Figure 30—Trees can create a continuous canopy for maximum rainfall interception, even in commercial areas. In this example, a swale in the median filters runoff and provides ample space for large trees. Parking space-sized planters contain the soil volume required to grow healthy, large trees (from Metro 2002).

Tree planting and management guidelines to improve air quality include the following (Nowak 2000, Smith and Dochinger 1976):

- It is important to allow adequate space for root growth to ensure long-term survival. Planting projects should emphasize large cut-outs, wide planting strips, increasing space every time pavement must be repaired due to root-pavement conflicts, and avoiding soil compaction where trees and landscapes are planned. Engineered soil mixes can also be used to facilitate root development in mass-graded sites and planting areas surrounded by pavement.
- Select species that tolerate pollutants that are present in harmful concentrations. For example, in areas with high ozone concentration, avoid sensitive species such as white and green ash, tulip poplar, and Austrian pine (Noble et al. 1988).
- Conifers have high surface-to-volume ratios and retain their foliage year round, which may make them more effective than deciduous species.

- Species with long leaf stems (e.g., ash, maple) and hairy plant parts (e.g., oak, birch, and sumac) are especially efficient interceptors.
- Effective uptake depends on proximity to the pollutant source and the amount of biomass. Where space permits, plant multilayered stands near the source of pollutants.
- Consider the local meteorology and topography to promote airflow that can "flush" pollutants out of the city along streets and greenspace corridors. Use columnar-shaped trees instead of spreading forms to avoid trapping pollutants under the canopy and obstructing airflow.
- In areas with unhealthy ozone concentrations, maximize use of plants that emit low levels of biogenic volatile organic compounds to reduce ozone formation (e.g., birches, elms, maples). Consider beneficial effects from large trees, such as urban heat island reduction and pollutant uptake, relative to their species-based biogenic volatile organic compound emissions.
- To reduce emissions of volatile organic compounds and other pollutants, plant trees to shade parked cars and conserve energy.
- Sustain large, healthy trees; they produce the most benefits.

Avoiding Tree Conflicts With Infrastructure

Conflicts between trees and infrastructure create lose-lose situations. Examples include trees growing into power lines, blocking traffic signs, and roots heaving sidewalks. Trees lose because often they must be altered or removed to rectify the problem. People lose directly because of the additional expense incurred to eliminate the conflict. They lose indirectly owing to benefits forgone when a large tree is replaced with a smaller tree, or too frequently, no tree at all. Tree conflicts with infrastructure are usually avoidable with good planning and judicious tree selection. SelectTree, a Web-based tree selection program contains a wealth of information on trees for the region (http://selectree.calpoly.edu/).

- Before planting, contact your local utility company, such as PG&E's Call Before You Dig, to locate underground water, sewer, gas, and telecommunications lines.
- Avoid locating trees where they will block streetlights or views of traffic and commercial signs.
- Check with local transportation officials for sight visibility requirements. Keep trees at least 30 ft away from street intersections to ensure visibility.

- Avoid planting shallow-rooting species near sidewalks, curbs, and paving. Tree roots can heave pavement if planted too close to sidewalks and patios. Generally, avoid planting within 3 ft of pavement, and remember that trunk flare at the base of large trees can displace soil and paving for a considerable distance. When space is limited, use smaller trees. Use strategies to reduce infrastructure damage by tree roots, such as meandering sidewalks around trees, ramping sidewalks over tree roots, root barriers, and deflectors (Costello and Jones 2003).
- Select only small trees (<25 ft tall) for location under overhead power lines, and do not plant directly above underground water and sewer lines (fig. 31). Avoid locating trees where they will block illumination from streetlights or views of street signs in parking lots, commercial areas, and along streets.

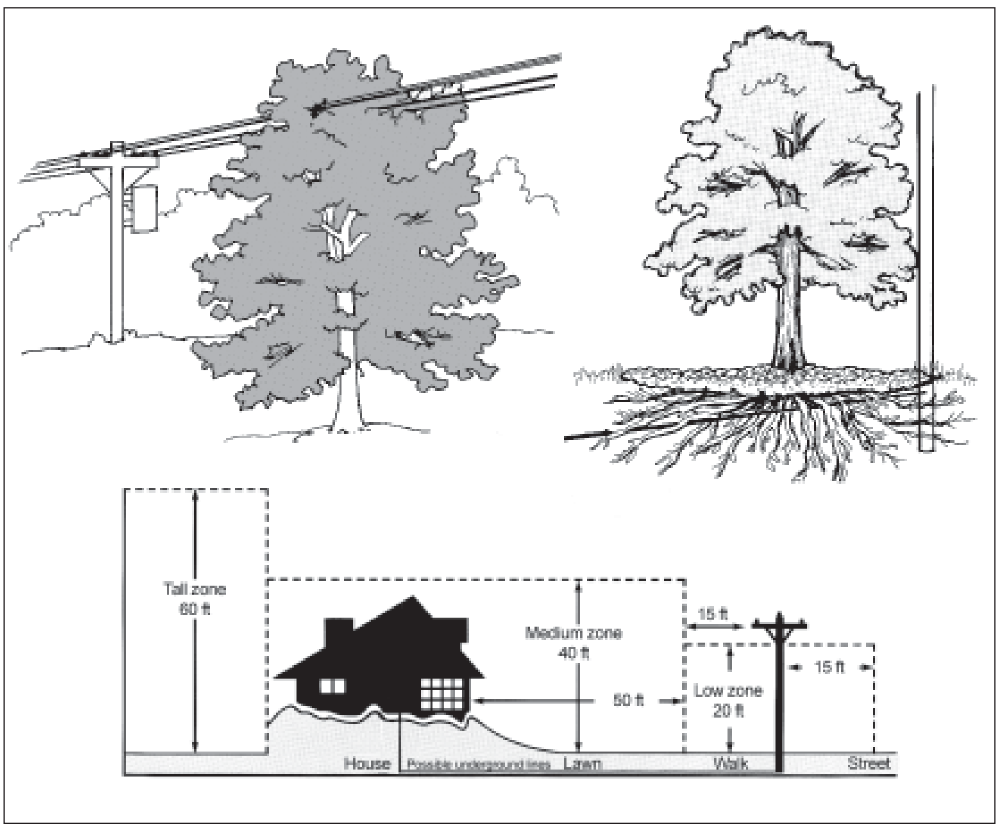

Figure 31—Know where power lines and other utility lines are before planting. Under power lines use only small-growing trees ("low zone") and avoid planting directly above underground utilities. Larger trees may be planted where space permits ("medium" and "tall zones") (from ISA 1992).

For trees to deliver benefits over the long term, they require enough soil volume to grow and remain healthy. Matching tree species to the site's soil volume can reduce sidewalk and curb damage as well. Figure 32 shows recommended soil volumes for different size trees.

Maintenance requirements and public safety issues influence the type of trees selected for public places. The ideal public tree is not susceptible to wind damage and branch drop, does not require frequent pruning, produces negligible litter, is deep-rooted, has few serious pest and disease problems, and tolerates a wide range of soil conditions, irrigation regimes, and air pollutants. Because relatively few trees have all these traits, it is important to match the tree species to the planting site by determining what issues are most important on a case-by-case basis. For example, parking-lot trees should be tolerant of hot, dry conditions, have strong branch attachments, and be resistant to attacks by pests that leave vehicles covered with sticky exudates. Check with your local landscape professional for horticultural information on tree traits.

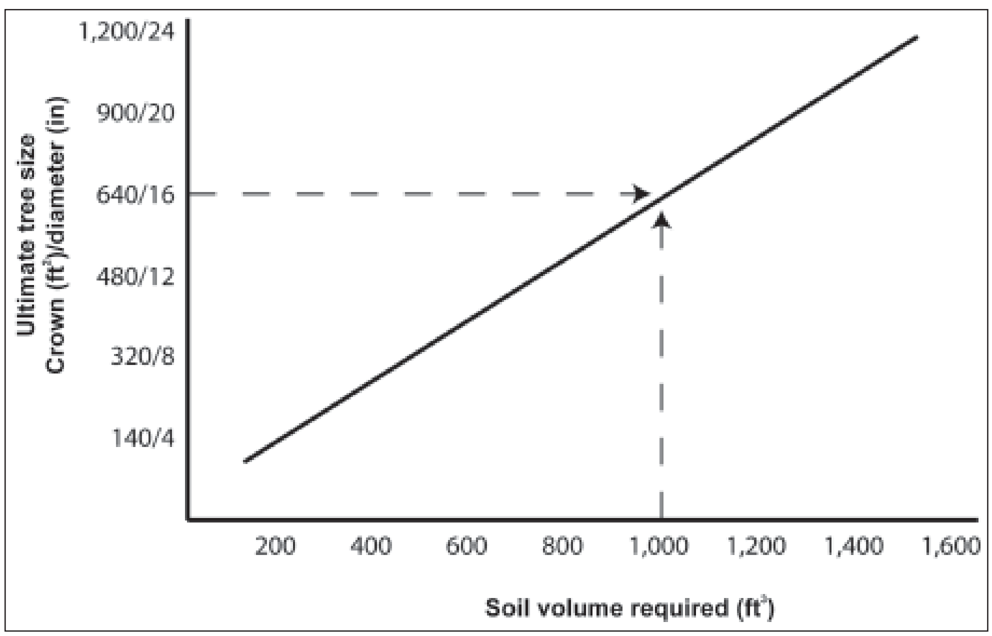

Figure 32—Developed from several sources by Urban (1992), this graph shows the relationship between tree size and required soil volume. For example, a tree with a 16-in (41-cm) diameter at breast height with 640 ft^2 (59.5 m^2) of crown projection area (under the dripline) requires 1,000 ft^3 (28 m^3) of soil (from Costello and Jones 2003). The ultimate tree size is defined by the projected size of the crown and the diameter of the tree at breast height.

General Guidelines to Maximize Long-Term Benefits

Selecting a tree from the nursery that has a high probability of becoming a healthy, trouble-free **mature tree** is critical to a successful outcome. Therefore, select the very best stock at your nursery, and when necessary, reject nursery stock that does not meet industry standards. Avoid trees that have been improperly pruned during nursery propagation to develop main scaffolds that are too low. Many nurseries prune to develop main scaffold branches 5 to 7 ft above the top of the containers. It is very difficult to prune such trees to achieve adequate clearances needed in street plantings. Make sure that the species you select is adapted to the site's growing conditions and is architecturally suited to the purpose at hand.

The health of the tree's root ball is critical to its ultimate survival. If the tree is in a container, check for matted roots by sliding off the container. Roots should penetrate to the edge of the root ball, but not densely circle the inside of the container or grow through drain holes. As well, at least two large structural roots should emerge from the trunk within 1 to 2 in of the soil surface. If there are no roots in the upper portion of the root ball, excess soil has been placed over the top of the root ball, and the root ball that has developed is undersized or poorly formed. Such trees should be avoided.

The roots of containerized trees should be shaved (outer 1/2 to 1 in of the root ball trimmed away) carefully with a sharp blade or saw to ensure that roots will grow horizontally and radially outward into the backfill and native soil. In addition, the soil on top of the root ball should also be removed down to where the first main root originates. This will prevent deep planting and future rooting problems.

A good tree is well-anchored

Another way to evaluate the quality of the tree before planting is to gently rock the trunk back and forth. A good tree trunk bends and does not move in the soil, whereas a poor trunk bends a little and pivots at or below the soil line—a tell-tale sign of a poorly anchored tree. If the tree is balled and burlapped, be careful not to move the trunk too vigorously, as this could loosen the roots. It is also a good idea to remove the burlap or fold it down at least half way. Better yet, cut as much of it away as possible without disturbing the root ball.

Plant the tree in the right size hole

Dig the planting hole 1 in shallower than the depth of the root ball to prevent settling after watering. Make the hole two to three times as wide as the root ball and loosen the sides of the hole to make it easier for roots to penetrate. Place the tree so that the root flare is at the top of the soil. If the structural roots have grown properly as described above, the top of the root ball will be slightly higher (1 to 2 in) than the surrounding soil to allow for settling. Backfill with the native soil unless it is very rocky or sandy, in which case you may want to add composted organic matter such as peat moss or shredded bark (fig. 33). Once the tree has been backfilled, loosen the surrounding soil with a shovel or digging bar to reduce compaction and encourage root growth.

Planting trees in urban plazas, commercial areas, and parking lots poses special challenges owing to limited soil volume and poor soil structure. Engineered soils and other soil volume expansion solutions can be placed under the hardscape to increase rooting space while meeting engineering requirements. For more information on engineered soils see *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies* (Costello and Jones 2003) and *Up With Roots* (Urban 2008).

Use additional soil to build a berm outside the root ball that is 6 in high and 3 ft in diameter. Soak the root ball, and gently rock it to settle it in. Apply water directly to the rootball, as water applied outside of the rootball typically will not readily move into the rootball owing to textural differences between the soil in the rootball and the backfill. Apply water to the backfill soil to encourage rooting there. Handle only the ball so the trunk is not loosened. Cover the basin with a 2- to 4-in-thick layer of mulch, but avoid placing mulch against the tree trunk. Water

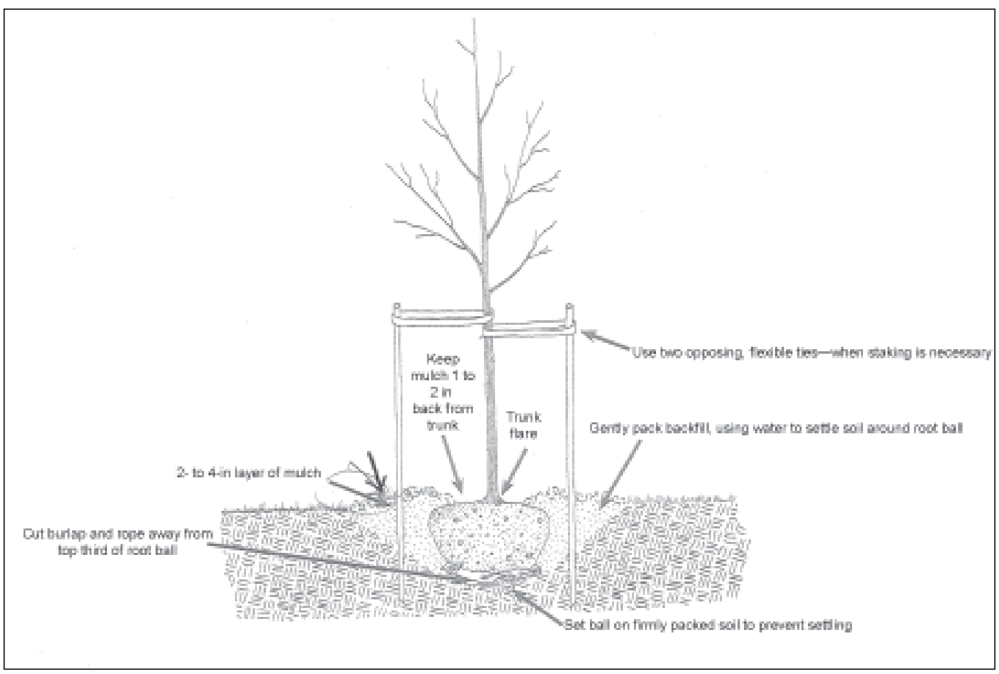

Figure 33—Prepare a broad planting area, plant the tree with the root flare at ground level, and provide a berm/water ring to retain water (drawing courtesy of ISA).

the new tree three times a week and increase the amount of water until the tree is established. Water more frequently during very hot, dry, or windy weather. Generally, a tree requires about 1 in of water per week. Add 3 to 5 gal each watering for a 15-gal tree, and more for a larger size. A rain gauge or soil moisture sensor (tensiometer) can help determine tree watering needs.

Water trees as needed to facilitate rapid establishment and rapid growth. Once established, water trees as needed to maintain reasonable growth and health.

- Inspect your tree several times a year, and contact a local landscape professional if problems develop.
- It is a good idea to stake a tree after planting to keep it from leaning because of wind. However, the stake should be removed within a year after the tree has rooted sufficiently to keep it upright. If your tree needs staking to keep it upright, remove the stake and ties after one year or as soon as the tree is rigid enough to stand alone. Staking should allow some tree movement, as this movement sends hormones to the roots causing them to grow and create greater tree stability. It also promotes trunk taper and growth. It may be necessary to stake a tree for several years until it has developed sufficient caliper to resist vandalism. Trees that have been propagated with lower laterals often don't need to be staked.
- Avoid removing lower lateral branches because they support rapid growth and help to develop taper.
- Reapply mulch and irrigate the tree as needed.
- Retain but shorten lower lateral branches during the first few years. Prune the young tree to maintain a central main trunk and equally spaced branches. For more information, see Costello (2000). As the tree matures, have it pruned by a certified arborist or other experienced professional to remove dead or damaged branches.
- Retain or develop a single, dominant leader by careful structural pruning. Lateral branches should be kept to less than half the diameter of the trunk by pruning. This will prevent lower laterals from becoming dominant (competing with the leader) and ultimately interfering with traffic.
- By keeping your tree healthy, you maximize its ability to produce shade, intercept rainfall, reduce atmospheric CO_2, and provide other benefits.

For additional information on nursery tree selection, planting, establishment, and care, see the CalFire standards and specifications located on the Urban Forest Ecosystem Institute Web site (http://www.ufei.org/Standards&Specs.html). Additional resources are listed in appendix 1.

Glossary

annual fuel utilization efficiency (AFUE)—A measure of space heating equipment efficiency defined as the fraction of energy output per energy input.

anthropogenic—Produced by humans.

avoided powerplant emissions—Reduced emissions of carbon dioxide (CO_2) or other pollutants that result from reductions in building energy use owing to the moderating effect of trees on climate. Reduced energy use for heating and cooling results in reduced demand for electrical energy, which translates into fewer emissions by powerplants.

biodiversity—The variety of life forms in a given area. Diversity can be categorized in terms of the number of species, the variety in the area's plant and animal communities, the genetic variability of the animals or plants, or a combination of these elements.

biogenic—Produced by living organisms.

biogenic volatile organic compounds (BVOCs)—Hydrocarbon compounds from vegetation (e.g., isoprene, monoterpene) that exist in the ambient air and contribute to the formation of smog or may be toxic. Emission rates (ug/g/hr) used for this report follow Benjamin and Winer (1998):

camphor—0.0 (isoprene); 0.0 (monoterpene)

cherry plum—0.0 (isoprene); 0.1 (monoterpene)

velvet ash— 0.0 (isoprene); 0.0 (monoterpene)

Monterey pine—0.0 (isoprene); 0.8 (monoterpene)

canopy—A layer or multiple layers of branches and foliage at the top or crown of a forest's trees.

canopy cover—The area of land surface that is covered by tree canopy, as seen from above.

Ccf—One hundred cubic feet.

climate—The average weather for a particular region and period (usually 30 years). Weather describes the short-term state of the atmosphere; climate is the average pattern of weather for a particular region. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hailstorms, and other measures of weather.

climate effects—Impact on residential space heating and cooling (lb CO_2/tree per year) from trees located more than 50 ft (15 m) from a building owing to associated reductions in windspeeds and summer air temperatures.

community forests—The sum of all woody and associated vegetation in and around human settlements, ranging from small rural villages to metropolitan regions.

Conifers—Trees or shrubs that retain their leaves during the winter.

contract rate—The percentage of residential trees cared for by commercial arborists; the proportion of trees contracted out for a specific service (e.g., pruning or pest management).

control costs—The marginal cost of reducing air pollutants when using best available control technologies.

crown—The branches and foliage at the top of a tree.

cultivar (derived from "cultivated variety")—Denotes certain cultivated plants that are clearly distinguishable from others by any characteristic, and that when reproduced (sexually or asexually), retain their distinguishing characteristics. In the United States, variety is often considered synonymous with cultivar.

deciduous—Trees or shrubs that lose their leaves every fall.

diameter at breast height (d.b.h.)—The diameter of a tree outside the bark measured 4.5 ft (1.37 m) above the ground on the uphill side (where applicable) of the tree.

dripline—The area beneath a tree marked by the outer edges of the branches.

emission factor—The rate of CO_2, nitrogen oxides (NO_2), sulfur dioxide (SO_2), and particulate matter (PM_{10}) output resulting from the consumption of electricity, natural gas, or any other fuel source.

evapotranspiration (ET)—The total loss of water by evaporation from the soil surface and by transpiration from plants, from a given area, and during a specified period.

evergreens—Trees or shrubs that are never entirely leafless. Evergreens may be broadleaved or coniferous (cone-bearing with needlelike leaves).

greenspace—Urban trees, forests, and associated vegetation in and around human settlements, ranging from small communities in rural settings to metropolitan regions.

hardscape—Paving and other impervious ground surfaces that reduce infiltration of water into the soil.

heat sinks—Paving, buildings, and other surfaces that store heat energy from the sun.

hourly pollutant dry deposition—Removal of gases from the atmosphere by direct transfer to natural surfaces and absorption of gases and particles by natural surfaces such as vegetation, soil, water, or snow.

interception—Rainfall held on tree leaves and stem surfaces.

kBtu—A unit of work or energy, measured as 1,000 British thermal units. One kBtu is equivalent to 0.293 kWh.

kilowatt-hour (kWh)—A unit of work or energy, measured as 1 kW (1,000 watts) of power expended for 1 hour. One kWh is equivalent to 3.412 kBtu.

leaf area index (LAI)—Total leaf area per unit area of crown if crown were projected in two dimensions.

leaf surface area (LSA)—Measurement of area of one side of a leaf or leaves.

mature tree—A tree that has reached a desired size or age for its intended use. Size, age, and economic maturity differ depending on the species, location, growing conditions, and intended use.

mature tree size—The approximate size of a tree 40 years after planting.

MBtu—A unit of work or energy, measured as 1,000,000 British thermal units. One MBtu is equivalent to 0.293 **MWh**.

metric tonne (t)—A measure of weight equal to 1,000,000 grams (1000 kg) or 2,205 lbs.

municipal forester—A person who manages public street and/or park trees (municipal forestry programs) for the benefit of the community.

MWh (megawatt-hour)—A unit of work or energy, measured as one Megawatt (1,000,000 watts) of power expended for 1 hour. One MWh is equivalent to 3.412 MBtu.

nitrogen oxides (oxides of nitrogen, NO_x)—A general term for compounds of nitric acid (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO_2 may cause numerous adverse human health effects.

NO_2—See nitrogen oxides.

O_3—See ozone.

ozone (O_3)—A strong-smelling, pale blue, reactive toxic chemical gas consisting of three oxygen atoms. It is a product of the photochemical process involving the Sun's energy. Ozone exists in the upper layer of the atmosphere as well as at the Earth's surface. Ozone at the Earth's surface can cause numerous adverse human health effects. It is a major component of smog.

peak flow (or peak runoff)—The maximum rate of runoff at a given point or from a given area, during a specific period.

photosynthesis—The process in green plants of converting water and CO_2 into sugar by using light energy; accompanied by the production of oxygen.

PM_{10} (particulate matter)—Major class of air pollutants consisting of tiny solid or liquid particles of soot, dust, smoke, fumes, and mists. The size of the particles (10 microns or smaller, about 0.0004 in or less) allows them to enter the air sacs (gas-exchange region) deep in the lungs where they may be deposited and cause adverse health effects. PM_{10} also reduces visibility.

resource unit (RU)—The value used to determine and calculate benefits and costs of individual trees. For example, the amount of air conditioning energy saved in kWh/year per tree, air-pollutant uptake in pounds/year per tree, or rainfall intercepted in gallons/year per tree.

riparian habitats—Narrow strips of land bordering creeks, rivers, lakes, or other bodies of water.

seasonal energy efficiency ratio (SEER)—Ratio of cooling output to power consumption; kBtu-output/kWh-input as a fraction. It is the Btu of cooling output during normal annual usage divided by the total electric energy input in kilowatt-hours during the same period.

sequestration—Removal of CO_2 from the atmosphere by trees through the processes of photosynthesis and respiration (lb CO_2/tree per year).

shade coefficient—The percentage of light striking a tree crown that is transmitted through gaps in the crown. This is the percentage of light that hits the ground.

shade effects—Impact on residential space heating and cooling (lb CO_2/tree per year) from trees located within 50 ft (15 m) of a building.

SO_2—See sulfur dioxide.

solar-friendly trees—Trees that have characteristics that reduce blocking of winter sunlight. According to one numerical ranking system, these traits include open crowns during the winter heating season, leaves that fall early and appear late, relatively small size, and a slow growth rate (Ames 1987).

stem flow—Rainfall that travels down the tree trunk and onto the ground.

sulfur dioxide (SO_2)—A strong-smelling, colorless gas that is formed by the combustion of fossil fuels. Powerplants, which may use coal or oil high in sulfur content, can be major sources of SO_2. Sulfur oxides contribute to the problem of acid deposition.

surface saturation storage capacity—The amount of rainfall that adheres to leaf and stem surfaces during an event, usually measured in terms of depth (centimeters or inches).

therm—A unit of heat equal to 100,000 Btus or 100 kBtu. Also, 1 kBtu is equal to 0.01 therm.

throughfall—Amount of rainfall that falls directly to the ground below the tree crown or drips onto the ground from branches and leaves.

transpiration—The loss of water vapor through the stomata of leaves.

tree or canopy cover—Within a specific area, the percentage covered by the crown of an individual tree or delimited by the vertical projection of its outermost perimeter; small openings in the crown are ignored. Used to express the relative importance of individual species within a vegetation community or to express the coverage of woody species.

tree litter—Fruit, leaves, twigs, and other debris shed by trees.

tree-related emissions—Carbon dioxide released when growing, planting, and caring for trees.

tree surface saturation storage capacity—The maximum volume of water that can be stored on a tree's leaves, stems, and bark. This part of rainfall stored on the canopy surface does not contribute to surface runoff during and after a rainfall event.

urban heat island—An area in a city where summertime air temperatures are 3 to 8 °F warmer than temperatures in the surrounding countryside. Urban areas are warmer for two reasons: (1) dark construction materials for roofs and asphalt absorb solar energy, and (2) few trees, shrubs, or other vegetation provide shade and cool the air.

volatile organic compounds (VOCs)—Hydrocarbon compounds that exist in the ambient air. VOCs contribute to the formation of smog or are themselves toxic. VOCs often have an odor. Some examples of VOCs are gasoline, alcohol, and the solvents used in paints.

willingness to pay—The maximum amount of money an individual would be willing to pay, rather than do without nonmarket, public goods and services provided by environmental amenities such as trees and forests.

Common and Scientific Names

Common name	Scientific name
Plants:	
Afghan pine	*Pinus brutia* Ten. var. *eldarica* (Medw.) Silba
Alder	*Alnus* spp. Mill.
American elm	*Ulmus americana* L.
Arizona cypress	*Cupressus arizonica* Greene
Austrian pine	*Pinus nigra* J.F. Arnold
Basswood	*Tilia* L.
Birch	*Betula* spp.
Black acacia	*Acacia melanoxylon* R. Br.
Blackgum	*Nyssa* spp.
Black locust	*Robinia pseudoacacia* L.
Black oak	*Quercus velutina* Lam.
Blue gum	*Eucalyptus globulus* Labill.
Callery pear	*Pyrus calleryana* Decne.
Camphor	*Cinnamomum camphora* (L.) J. Presl
Canary Island pine	*Pinus canariensis* C. Sm.
Cherry plum	*Prunus cerasifera* Ehrh.
Chinese elm	*Ulmus parvifolia* Jacq.
Chinese pistache	*Pistacia chinensis* Bunge
Coast live oak	*Quercus agrifolia* Née var. *oxyadenia* (Torr.) J.T. Howell
Coast redwood	*Sequoia sempervirens* (Lamb. ex D. Don) Endl.
Cottonwood	*Populus* spp.
Drooping she-oak	*Casuarina stricta* Aiton
Elms	*Ulmus* spp.
Evergreen pear	*Pyrus kawakamii* Hayata
Ginkgo	*Ginkgo biloba* L.
Green ash	*Fraxinus pennsylvanica* Marsh.
Hackberry	*Celtis* spp.
Honey locust	*Gleditsia triacanthos* L.
Horse chestnut	*Aesculus hippocastanum* L.
Japanese maple	*Acer palmatum* Thunb.
Japanese pagoda tree	*Styphnolobium japonicum* (L.) Schott
Kentucky coffeetree	*Gymnocladus dioicus* (L.) K. Koch
London planetree	*Platanus hybrida* Brot.
Maple	*Acer* spp.
Monterey cypress	*Cupressus macrocarpa* Hartw. ex Gord.
Monterey pine	*Pinus radiata* D. Don
Oak	*Quercus* spp.
Poplar	*Populus* spp.
Red maple	*Acer rubrum* L.
River birch	*Betula nigra* L.
Silver maple	*Acer saccharinum* L.
Southern magnolia	*Magnolia grandiflora* L.
Sumac	*Rhus* spp.
Sweetgum	*Liquidambar styraciflua* L.
Sycamore	*Platanus* spp.

Common name	Scientific name
Tulip poplar	*Liriodendron tulipifera* L.
Velvet ash	*Fraxinus velutina* Torr.
Victorian box	*Pittosporum undulatum* Vent.
White ash	*Fraxinus americana* L.
Willows	*Salix* spp.
Insects:	
Aphid	*Aphidoidea*
Emerald ash borer	*Agrilus planipennis* Fairmaire
Pathogens:	
Anthracnose	*Glomerella cingulata* (Stoneman) Spauld. & H. Schrenk
Dutch elm disease	*Ophiostoma ulmi* (Buisman) Nannf. and *Ophiostoma novo-ulmi* (Brasier)
Leaf spot	*Sirosporium diffusum* (Heald & F.A. Wolf)
Mistletoe	*Phoradendron flavescens* (Pursh) Nutt
Pitch canker disease	*Fusarium moniliforme* var. *subglutinans* Wollenw. & Reinking
Sudden oak death	*Phytophthora ramorum* (S. Werres, A.W.A.M. deCock & W.A. Man in't Veld)

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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^2)	.0929	Square meters (m^2)
Cubic feet (ft^3)	.0283	Cubic meters (m^3)
Miles (mi)	1.61	Kilometers (km)
Square miles (mi^2)	2.59	Square kilometers (km^2)
Gallons (gal)	.00378	Cubic meters (m^3)
Ounces (oz)	28.4	Grams (g)
Ounces	2.83×10^7	Micrograms (µg)
Pounds (lb)	.454	Kilograms (kg)
Pounds per square foot (lb/ft^2)	4.882	Kilograms per square meter (kg/m^2)
Tons (ton)	.907	Metric tonnes (t)
Thousand British thermal units (kBtu)	1.05	Megajoules (MJ)
Thousand British thermal units	.293	Kilowatt-hours (kWh)
Degrees Fahrenheit (° F)	.556(F-32)	Degrees Celsius

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Appendix 1: Additional Resources

Additional information regarding urban and community forestry program design and implementation can be obtained from the following sources:

Bratkovich 2001. Utilizing municipal trees: ideas from across the country.

Head et al. 2001. Best management practices for community trees: a technical guide to tree conservation in Athens-Clarke County, Georgia.

Miller 1997. Urban forestry: planning and managing urban greenspaces.

Morgan [N.d.] An introductory guide to community and urban forestry in Washington, Oregon, and California.

Morgan 1993. A technical guide to urban and community forestry.

Pokorny 2003. Urban tree risk management: a community guide to program design and implementation.

Swiecki and Bernhardt 2006. A field guide to insects and diseases of California oaks.

For additional information on tree selection, planting, establishment, and care, see the following references:

Alliance for Community Trees: http://actrees.org. (October 9, 2009).

Bedker et al. 1995. How to prune trees. NA-FR-01-95.

California Oak Mortality Task Force: http://www.suddenoakdeath.org. (October 9, 2009).

Center for Urban Forest Research Tree Carbon Calculator: http://www.fs.fed.us/ccrc/topics/urban-forests/ctcc/. (October 13, 2009).

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International Society of Arboriculture: http://www.isa-arbor.com.

National Arbor Day Foundation: http://www.arborday.org. (October 9, 2009).

Sudden Oak Death Best Management Practices: http://www.plantmanagementnetwork.org/php/shared/sod/.

TreeLink: http://www.treelink.org.
Trees for Urban and Suburban Landscapes (Gilman 1997).

Trowbridge and Bassuk 2004. Trees in the urban landscape.

Urban Forest Ecosystems Institute. http://www.ufei.org/Standards&Specs.html. (October 9, 2009).

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These suggested references are only a starting point. Your local cooperative extension agent, CalFire urban forester or landscape professional can provide you with up-to-date and local information.

Appendix 2: Benefit-Cost Information Tables

Information in this appendix can be used to estimate benefits and costs associated with proposed tree plantings. The tables contain data for representative small (camphor), medium (cherry plum), and large (velvet ash) broadleaf trees and a representative conifer (Monterey pine) (see “Common and Scientific Names” section). Data are presented as annual values for each 5-year interval after planting (tables 6 to 17). Annual values incorporate effects of tree loss. Based on the results of our survey, we assume that 45 percent of the trees planted die by the end of the 40-year period.

For the benefits tables (tables 6, 9, 12, and 15), there are two columns for each 5-year interval. In the first column, values describe **resource units** (**RUs**): for example, the amount of air conditioning energy saved in **kilowatt-hours** (**kWh**) per year per tree, air pollutant uptake in pounds per year per tree, and rainfall intercepted in gallons per year per tree. Energy and carbon dioxide (CO_2) benefits for residential yard trees are broken out by tree location to show how shading effects differ among trees opposite west-, south-, and east-facing building walls. The second column for each 5-year interval contains dollar values obtained by multiplying RUs by local prices (e.g., kWh saved [RU] x $/kWh).

In the costs tables (tables 7, 10, 13, and 16), costs are broken down into categories for yard and public trees. Costs for yard trees do not differ by planting location (i.e., east, west, and south walls). Although tree and planting costs occur at year one, we divided this value by 5 years to derive an average annual cost for the first 5-year period. All other costs are the estimated values for each year and not values averaged over 5 years.

Total annual net benefits are calculated by subtracting total costs from total benefits and are presented in tables 8, 11, 14, and 17. Data are presented for a yard tree opposite west-, south-, and east-facing walls, as well as for the public tree.

The last column in each table presents 40-year-average annual values. These numbers were calculated by dividing the total costs and benefits by 40 years.

Table 6—Annual benefits at 5-year intervals and 40-year average for a representative small tree (camphor tree)

Benefits/tree	Year 5 RU	Year 5 Value	Year 10 RU	Year 10 Value	Year 15 RU	Year 15 Value	Year 20 RU	Year 20 Value	Year 25 RU	Year 25 Value	Year 30 RU	Year 30 Value	Year 35 RU	Year 35 Value	Year 40 RU	Year 40 Value	40-year average RU	40-year average Value
		Dollars		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*
Cooling (kWh):																		
Yard: west	17	3.65	34	7.27	57	12.14	94	19.99	131	27.93	165	35.19	195	41.46	221	47.10	114	24.34
Yard: south	13	2.72	26	5.50	44	9.32	74	15.73	104	22.20	132	28.13	159	33.83	183	38.96	92	19.55
Yard: east	13	2.79	26	5.59	43	9.27	71	15.04	98	20.87	123	26.20	144	30.72	163	34.79	85	18.16
Public	12	2.58	24	5.15	40	8.52	65	13.78	90	19.09	112	23.95	131	28.01	149	31.66	78	16.59
Heating (kBtu):																		
Yard: west	28	0.48	55	0.95	86	1.48	122	2.10	158	2.73	191	3.30	219	3.78	245	4.22	138	2.38
Yard: south	27	0.47	53	0.92	80	1.38	101	1.75	123	2.12	142	2.45	146	2.51	149	2.57	103	1.77
Yard: east	-7	-0.13	-14	-0.24	-29	-0.50	-70	-1.20	-111	-1.92	-149	-2.57	-174	-3.00	-196	-3.39	-94	(1.62)
Public	33	0.57	64	1.11	100	1.73	142	2.46	185	3.19	224	3.87	257	4.44	287	4.96	162	2.79
Net energy (kBtu):																		
Yard: west	199	4.13	396	8.22	655	13.62	1,060	22.09	1,468	30.66	1,842	38.49	2,164	45.24	2,454	51.32	1,280	26.72
Yard: south	155	3.19	312	6.42	517	10.70	839	17.47	1,164	24.31	1,462	30.58	1,733	36.34	1,977	41.53	1,020	21.32
Yard: east	124	2.66	248	5.35	406	8.77	636	13.83	868	18.95	1,080	23.63	1,268	27.72	1,436	31.40	758	16.54
Public	154	3.15	306	6.25	500	10.25	789	16.24	1,081	22.29	1,348	27.81	1,572	32.45	1,773	36.62	940	19.38
Net carbon dioxide (lb)																		
Yard: west	16	0.05	32	0.11	52	0.17	84	0.28	116	0.39	146	0.49	175	0.58	202	0.67	103	0.34
Yard: south	13	0.04	26	0.09	43	0.14	68	0.23	94	0.32	119	0.40	143	0.48	166	0.55	84	0.28
Yard: east	9	0.03	19	0.06	30	0.10	46	0.15	63	0.21	79	0.26	96	0.32	113	0.38	57	0.19
Public	13	0.04	26	0.09	43	0.14	67	0.23	92	0.31	116	0.39	139	0.46	160	0.53	82	0.27
Air pollution (lb)[a]:																		
Ozone uptake	0.02232	0.03	0.04884	0.06	0.08061	0.10	0.12420	0.16	0.17155	0.21	0.21904	0.27	0.27742	0.35	0.33580	0.42	0.16	0.20
Nitrous oxide uptake + avoided	0.01801	0.02	0.03780	0.05	0.06200	0.08	0.09586	0.12	0.13154	0.16	0.16600	0.21	0.20345	0.25	0.23972	0.30	0.12	0.15
Sulfur dioxide uptake + avoided	0.00377	0.01	0.00791	0.01	0.01311	0.02	0.02083	0.04	0.02892	0.05	0.03667	0.06	0.04491	0.08	0.05283	0.09	0.03	0.05
Small particulate matter uptake + avoided	0.00648	0.02	0.04505	0.13	0.13152	0.38	0.26337	0.77	0.39912	1.17	0.53367	1.56	0.66537	1.95	0.79389	2.32	0.35	1.04
Volatile organic compounds avoided	0.00072	0.00	0.00144	0.00	0.00236	0.00	0.00375	0.00	0.00516	0.00	0.00645	0.00	0.00757	0.00	0.00858	0.00	0.00	0.00
Biogenic volatile organic compounds released	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00	0.00
Avoided + net uptake	0.051	0.08	0.141	0.25	0.290	0.59	0.508	1.08	0.736	1.60	0.962	2.11	1.199	2.63	1.431	3.14	0.66	1.44
Hydrology (gal rainfall interception)	61	0.34	124	0.68	202	1.11	315	1.73	437	2.40	560	3.08	741	4.07	921	5.07	420	2.31
Aesthetics and other benefits:																		
Yard		9.32		11.95		15.29		18.70		22.13		25.55		28.91		32.16		20.50
Public		10.57		13.56		17.35		21.22		25.12		28.99		32.80		36.49		23.26
Total benefits:																		
Yard: west		13.91		21.21		30.78		43.89		57.18		69.71		81.44		92.36		51.31
Yard: south		12.97		19.40		27.83		39.22		50.77		61.72		72.43		82.44		45.85
Yard: east		12.42		18.29		25.86		35.50		45.30		54.63		63.65		72.14		40.97
Public		14.18		20.84		29.44		40.50		51.71		62.38		72.42		81.85		46.67

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent. RU = resource unit.

[a] Values are the same for yard and public trees.

Table 7—Annual costs (dollars per tree) at 5-year intervals and 40-year average for a representative small tree (camphor tree)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Tree and planting:[a]									
Yard	29.00								3.63
Public	29.00								3.63
Pruning:									
Yard	0.09	0.28	0.27	0.26	5.01	4.84	4.67	4.50	2.04
Public	2.98	5.87	5.66	5.46	17.34	16.67	15.99	15.32	9.62
Remove and dispose:									
Yard	1.00	0.71	0.98	1.26	1.55	1.86	2.17	2.50	1.40
Public	1.50	0.57	0.79	1.02	1.25	1.50	1.75	2.02	1.20
Pest and disease:									
Yard	1.16	1.77	2.36	2.93	3.49	4.03	4.55	5.04	2.94
Public	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Infrastructure repair:									
Yard	0.10	0.15	0.20	0.24	0.29	0.34	0.38	0.42	0.24
Public	0.69	1.05	1.39	1.72	2.04	2.35	2.64	2.91	1.72
Irrigation:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cleanup:									
Yard	0.02	0.03	0.03	0.04	0.05	0.06	0.06	0.07	0.04
Public	0.12	0.18	0.24	0.30	0.35	0.40	0.45	0.50	0.30
Liability and legal:									
Yard	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
Public	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.03
Admin/inspect/other:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.28	0.42	0.56	0.70	0.83	0.95	1.07	1.18	0.70
Total costs:									
Yard	31.37	2.93	3.84	4.74	10.40	11.13	11.84	12.54	10.31
Public	34.58	8.11	8.68	9.23	21.86	21.92	21.96	21.98	17.20

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

[a] Although tree and planting costs occur in year 1, this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table 8—Annual net benefits (dollars per tree) at 5-year intervals and 40-year average for a representative small tree (camphor tree)

Total net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Yard: west	- 17	18	27	39	47	59	70	80	41
Yard: south	- 18	16	24	34	40	51	61	70	36
Yard: east	- 19	15	22	31	35	44	52	60	31
Public	- 20	13	21	31	30	40	50	60	29

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.
See table 6 for annual benefits and table 7 for annual costs.

Table 9—Annual benefits (dollars per tree) at 5-year intervals and 40-year average for a representative medium tree (cherry plum)

Benefits/tree	Year 5 RU	Year 5 Value	Year 10 RU	Year 10 Value	Year 15 RU	Year 15 Value	Year 20 RU	Year 20 Value	Year 25 RU	Year 25 Value	Year 30 RU	Year 30 Value	Year 35 RU	Year 35 Value	Year 40 RU	Year 40 Value	40-year average RU	40-year average Value
		Dollars		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*
Cooling (kWh):																		
Yard: west	26	5.52	60	12.74	97	20.75	134	28.58	168	35.86	188	39.96	206	43.95	222	47.35	138	29.34
Yard: south	21	4.57	47	9.99	75	15.88	101	21.52	126	26.85	142	30.37	159	33.79	172	36.74	105	22.47
Yard: east	22	4.70	47	9.92	72	15.39	96	20.47	118	25.21	131	27.91	143	30.54	154	32.90	98	20.88
Public	21	4.42	44	9.40	68	14.42	89	18.96	109	23.17	119	25.39	129	27.54	138	29.44	90	19.09
Heating (kBtu):																		
Yard: west	43	0.74	85	1.46	124	2.14	157	2.71	188	3.24	206	3.55	223	3.85	237	4.10	158	2.72
Yard: south	43	0.75	86	1.48	123	2.13	153	2.65	181	3.13	198	3.43	215	3.71	229	3.95	154	2.65
Yard: east	4	0.06	-31	-0.54	-87	-1.50	-154	-2.66	-217	-3.74	-255	-4.41	-293	-5.06	-324	-5.59	-170	-2.93
Public	46	0.79	94	1.62	140	2.42	180	3.10	217	3.75	242	4.18	266	4.59	286	4.94	184	3.17
Net energy (kBtu):																		
Yard: west	302	6.25	682	14.20	1,098	22.90	1,498	31.29	1,870	39.10	2,081	43.51	2,285	47.80	2,459	51.44	1,534	32.06
Yard: south	258	5.32	555	11.47	868	18.01	1,163	24.17	1,441	29.98	1,623	33.80	1,801	37.51	1,952	40.69	1,208	25.12
Yard: east	224	4.76	435	9.39	635	13.89	807	17.82	966	21.47	1,054	23.51	1,140	25.49	1,220	27.31	810	17.95
Public	253	5.21	535	11.02	816	16.84	1,069	22.07	1,304	26.92	1,433	29.57	1,558	32.13	1,668	34.38	1,080	22.27
Net carbon dioxide (lb):																		
Yard: west	26	0.09	61	0.20	101	0.34	143	0.48	184	0.61	222	0.74	261	0.87	299	1.00	162	0.54
Yard: south	23	0.08	52	0.18	86	0.29	121	0.40	156	0.52	192	0.64	229	0.76	265	0.89	141	0.47
Yard: east	19	0.06	39	0.13	60	0.20	81	0.27	104	0.35	131	0.44	159	0.53	188	0.63	98	0.33
Public	23	0.08	52	0.17	84	0.28	116	0.39	149	0.50	182	0.61	216	0.72	250	0.83	134	0.45
Air pollution (lb):[a]																		
Ozone uptake	0.02760	0.03	0.06391	0.08	0.10156	0.13	0.13887	0.17	0.17784	0.22	0.21251	0.27	0.24925	0.31	0.28539	0.36	0.16	0.20
Nitrous oxide uptake + avoided	0.02463	0.03	0.05373	0.07	0.08338	0.10	0.11143	0.14	0.13928	0.17	0.16039	0.20	0.18212	0.23	0.20271	0.25	0.12	0.15
Sulfur dioxide uptake + avoided	0.00524	0.01	0.01175	0.02	0.01860	0.03	0.02522	0.04	0.03173	0.06	0.03648	0.06	0.04134	0.07	0.04590	0.08	0.03	0.05
Small particulate matter uptake + avoided	0.01286	0.04	0.05169	0.15	0.10676	0.31	0.16976	0.50	0.22493	0.66	0.22746	0.66	0.22991	0.67	0.23205	0.68	0.16	0.46
Volatile organic compounds avoided	0.00118	0.00	0.00250	0.00	0.00386	0.00	0.00511	0.00	0.00627	0.00	0.00695	0.00	0.00761	0.00	0.00819	0.00	0.01	0.00
Biogenic volatile organic compounds released:	-.00012	0.00	-.00072	0.00	-.00177	0.00	-.00312	0.00	-.00438	0.00	-.00438	0.00	-.00438	0.00	-.00438	0.00	0.00	0.00
Avoided + net uptake	0.071	0.11	0.183	0.32	0.312	0.58	0.447	0.86	0.576	1.11	0.639	1.20	0.706	1.29	0.770	1.37	0.46	0.85
Hydrology (gal rainfall interception)	59	0.33	142	0.78	230	1.27	321	1.76	415	2.29	503	2.76	595	3.27	686	3.77	369	2.03
Aesthetics and other benefits:																		
Yard		29.84		35.61		37.86		38.14		37.55		36.54		35.30		33.94		35.60
Public		33.86		40.41		42.96		43.28		42.61		41.46		40.06		38.51		40.39
Total benefits:																		
Yard: west		36.62		51.11		62.94		72.53		80.67		84.76		88.53		91.53		71.08
Yard: south		35.67		48.36		58.00		65.33		71.45		74.94		78.13		80.66		64.07
Yard: east		35.10		46.23		53.80		58.85		62.76		64.45		65.88		67.02		56.76
Public		39.58		52.70		61.92		68.35		73.42		75.60		77.47		78.88		65.99

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent. RU = resource unit.

[a] Values are the same for yard and public trees.

Table 10—Annual costs (dollars per tree) at 5-year intervals and 40-year average for a representative medium tree (cherry plum)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Tree and planting:[a]									
Yard	29.00								3.63
Public	29.00								3.63
Pruning:									
Yard	0.09	0.28	0.27	5.19	5.01	4.84	0.12	0.11	2.13
Public	2.98	5.87	5.66	18.02	17.34	16.67	30.54	29.25	15.69
Remove and dispose:									
Yard	1.00	0.77	1.14	1.51	1.90	2.30	2.71	3.14	1.68
Public	1.50	0.62	0.92	1.22	1.53	1.85	2.19	2.53	1.43
Pest and disease									
Yard	1.07	1.91	2.73	3.52	4.27	5.00	5.68	6.33	3.51
Public	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Infrastructure repair:									
Yard	0.09	0.16	0.23	0.29	0.36	0.42	0.38	0.53	0.29
Public	0.64	1.13	1.61	2.07	2.50	2.91	3.29	3.65	2.05
Irrigation:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cleanup:									
Yard	0.02	0.03	0.04	0.05	0.06	0.07	0.07	0.09	0.05
Public	0.11	0.19	0.28	0.36	0.43	0.50	0.57	0.63	0.35
Liability and legal:									
Yard	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00
Public	0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.06	0.03
Admin/inspect/other:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.26	0.46	0.65	0.84	1.02	1.18	1.34	1.48	0.83
Total costs:									
Yard	31.27	3.15	4.40	10.56	11.61	12.64	8.96	10.21	11.29
Public	34.49	8.30	9.15	22.54	22.87	23.17	37.98	37.60	24.02

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

[a] Although tree and planting costs occur in year 1; this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table 11—Annual net benefits (dollars per tree) at 5-year intervals and 40-year average for a representative medium tree (cherry plum)

Total net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Yard: west	5	48	59	62	69	72	80	81	60
Yard: south	4	45	54	55	60	62	69	70	53
Yard: east	4	43	49	48	51	52	57	57	45
Public	5	44	53	46	51	52	39	41	42

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

See table 9 for annual benefits and table 10 for annual costs.

Table 12—Annual benefits (dollars per tree) at 5-year intervals and 40-year average for a representative large tree (velvet ash)

	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40-year average	
Benefits/tree	RU	Value	RU	Value	RU	Value	RU	Value	RU	Value	RU	Value	RU	Value	RU	Value	RU	Value
		Dollars		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*
Cooling (kWh):																		
Yard: west	27	5.80	84	17.87	151	32.12	215	45.85	266	56.76	306	65.28	347	73.90	372	79.21	221	47.10
Yard: south	19	4.02	59	12.67	111	23.71	162	34.52	212	45.12	257	54.73	302	64.40	328	69.82	181	38.62
Yard: east	18	3.77	54	11.54	98	20.99	141	30.15	186	39.66	228	48.56	270	57.49	291	62.04	161	34.28
Public	16	3.41	48	10.31	88	18.80	127	27.04	167	35.70	206	43.84	244	52.05	267	56.96	146	31.01
Heating (kBtu):																		
Yard: west	33	0.57	91	1.57	163	2.82	234	4.04	295	5.10	347	5.99	398	6.88	421	7.28	248	4.28
Yard: south	34	0.58	90	1.55	159	2.75	227	3.92	286	4.94	336	5.80	386	6.66	410	7.09	241	4.16
Yard: east	-44	-0.76	-143	-2.47	-189	-3.27	-220	-3.79	-207	-3.58	-173	-2.99	-138	-2.39	-101	-1.75	-152	-2.62
Public	38	0.66	103	1.78	183	3.16	261	4.50	327	5.64	381	6.58	435	7.52	462	7.98	274	4.73
Net energy (kBtu):																		
Yard: west	306	6.38	929	19.44	1,670	34.94	2,385	49.89	2,958	61.86	3,409	71.27	3,865	80.77	4,138	86.48	2,458	51.38
Yard: south	222	4.60	684	14.22	1,272	26.47	1,846	38.43	2,403	50.06	2,904	60.53	3,407	71.07	3,686	76.90	2,053	42.78
Yard: east	133	3.01	398	9.07	796	17.73	1,195	26.36	1,654	36.09	2,105	45.57	2,559	55.11	2,810	60.29	1,456	31.65
Public	198	4.07	587	12.09	1,065	21.96	1,529	31.54	2,001	41.34	2,438	50.41	2,877	59.56	3,134	64.94	1,729	35.74
Net carbon dioxide (lb):																		
Yard: west	24	0.08	73	0.24	132	0.44	189	0.63	240	0.80	282	0.94	327	1.09	363	1.21	204	0.68
Yard: south	19	0.06	57	0.19	106	0.35	154	0.51	203	0.68	249	0.83	296	0.99	333	1.11	177	0.59
Yard: east	9	0.03	26	0.09	56	0.19	88	0.29	128	0.43	170	0.57	214	0.71	249	0.83	118	0.39
Public	18	0.06	51	0.17	93	0.31	135	0.45	179	0.60	221	0.74	264	0.88	299	1.00	158	0.53
Air pollution (lb):[a]																		
Ozone uptake	0.02160	0.03	0.06662	0.08	0.13163	0.16	0.20107	0.25	0.28160	0.35	0.36529	0.46	0.45770	0.57	0.55175	0.69	0.26	0.32
Nitrous oxide uptake + avoided:	0.01906	0.02	0.05757	0.07	0.11063	0.14	0.16501	0.21	0.22301	0.28	0.27967	0.35	0.34001	0.43	0.39103	0.49	0.20	0.25
Sulfur dioxide uptake + avoided:	0.00441	0.01	0.01358	0.02	0.02560	0.05	0.03778	0.07	0.05049	0.09	0.06275	0.11	0.07575	0.13	0.08647	0.15	0.04	0.08
Small particulate matter uptake + avoided	0.00781	0.02	0.05185	0.15	0.14323	0.42	0.27524	0.80	0.40912	1.20	0.54043	1.58	0.66898	1.96	0.79121	2.31	0.36	1.06
Volatile organic compounds avoided	0.00097	0.00	0.00291	0.00	0.00540	0.00	0.00782	0.00	0.01015	0.01	0.01224	0.01	0.01434	0.01	0.01553	0.01	0.01	0.00
Biogenic volatile organic compounds released	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00000	0.00	0.00	0.00
Avoided + net uptake	0.054	0.08	0.193	0.33	0.416	0.77	0.687	1.33	0.974	1.92	1.260	2.50	1.557	3.10	1.836	3.65	0.87	1.71
Hydrology (gal rainfall interception)	59	0.32	192	1.05	360	1.98	535	2.94	734	4.04	940	5.17	1,167	6.42	1,401	7.70	673	3.70
Aesthetics and other benefits:																		
Yard		78.38		73.10		73.53		74.52		76.01		77.98		80.38		83.16		77.13
Public		88.94		82.94		83.44		84.56		86.25		88.48		91.21		94.37		87.52
Total benefits:																		
Yard: west		85.24		94.16		111.67		129.31		144.63		157.86		171.75		182.22		134.61
Yard: south		83.45		88.89		103.10		117.74		132.71		147.01		161.94		172.54		125.92
Yard: east		81.82		83.64		94.20		105.45		118.49		131.79		145.71		155.65		114.59
Public		93.47		96.59		108.47		120.83		134.15		147.31		161.16		171.66		129.20

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent. RU = resource unit.

[a] Values are the same for yard and public trees.

Table 13—Annual costs (dollars per tree) at 5-year intervals and 40-year average for a representative large tree (velvet ash)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Tree and planting:[a]									
Yard	29.00								3.63
Public	29.00								3.63
Pruning:									
Yard	0.09	5.53	5.36	5.19	5.01	0.12	0.12	0.11	3.07
Public	2.98	19.36	18.69	18.02	17.34	31.82	30.54	29.25	19.46
Remove and dispose:									
Yard	1.00	0.84	1.26	1.69	2.14	2.61	3.09	3.61	1.87
Public	1.50	0.68	1.02	1.36	1.72	2.10	2.49	2.91	1.59
Pest and disease:									
Yard	1.11	2.09	3.03	3.93	4.81	5.65	6.48	7.28	3.94
Public	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Infrastructure repair:									
Yard	0.09	0.17	0.25	0.33	0.40	0.47	0.54	0.61	0.33
Public	0.66	1.24	1.79	2.31	2.81	3.29	3.75	4.20	2.30
Irrigation:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cleanup:									
Yard	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10	0.06
Public	0.11	0.21	0.31	0.40	0.48	0.57	0.65	1.69	0.40
Liability and legal:									
Yard	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Public	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.04
Admin/inspect/other:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.27	0.50	0.73	0.94	1.14	1.34	1.52	1.70	0.93
Total costs:									
Yard	31.31	8.67	9.95	11.20	12.43	8.94	10.33	11.73	12.90
Public	34.53	22.02	22.56	23.07	23.56	39.18	39.03	38.86	28.35

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

[a] Although tree and planting costs occur in year 1, this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table 14—Annual net benefits (dollars per tree) at 5-year intervals and 40-year average for a representative large tree (velvet ash)

Total net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Yard: west	54	85	102	118	132	149	161	170	122
Yard: south	52	80	93	107	120	138	152	161	113
Yard: east	51	75	84	94	106	123	135	144	102
Public	59	75	86	98	111	108	122	133	101

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

See table 12 for annual benefits and table 13 for annual costs.

Table 15—Annual benefits (dollars per tree) at 5-year intervals and 40-year average for a representative conifer tree (Monterey pine)

Benefits/tree	Year 5 RU	Year 5 Value	Year 10 RU	Year 10 Value	Year 15 RU	Year 15 Value	Year 20 RU	Year 20 Value	Year 25 RU	Year 25 Value	Year 30 RU	Year 30 Value	Year 35 RU	Year 35 Value	Year 40 RU	Year 40 Value	40-year average RU	40-year average Value
		Dollars		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*		*Dollars*
Cooling (kWh):																		
Yard: west	37	7.82	72	15.42	110	23.42	143	30.58	185	39.46	234	49.86	272	57.93	303	64.49	169	36.12
Yard: south	37	7.82	72	15.42	110	23.42	143	30.58	185	39.46	234	49.86	272	57.93	303	64.49	169	36.12
Yard: east	37	7.82	72	15.42	110	23.42	143	30.58	185	39.46	234	49.86	272	57.93	303	64.49	169	36.12
Public	37	7.82	72	15.42	110	23.42	143	30.58	185	39.46	234	49.86	272	57.93	303	64.49	169	36.12
Heating (kBtu):																		
Yard: west	187	3.23	273	4.71	371	6.41	470	8.11	557	9.61	634	10.94	694	11.99	743	12.84	491	8.48
Yard: south	187	3.23	273	4.71	371	6.41	470	8.11	557	9.61	634	10.94	694	11.99	743	12.84	491	8.48
Yard: east	187	3.23	273	4.71	371	6.41	470	8.11	557	9.61	634	10.94	694	11.99	743	12.84	491	8.48
Public	187	3.23	273	4.71	371	6.41	470	8.11	557	9.61	634	10.94	694	11.99	743	12.84	491	8.48
Net energy (kBtu):																		
Yard: west	554	11.06	996	20.13	1,470	29.84	1,905	38.69	2,408	49.07	2,973	60.80	3,412	69.92	3,769	77.33	2,186	44.60
Yard: south	554	11.06	996	20.13	1,470	29.84	1,905	38.69	2,408	49.07	2,973	60.80	3,412	69.92	3,769	77.33	2,186	44.60
Yard: east	554	11.06	996	20.13	1,470	29.84	1,905	38.69	2,408	49.07	2,973	60.80	3,412	69.92	3,769	77.33	2,186	44.60
Public	554	11.06	996	20.13	1,470	29.84	1,905	38.69	2,408	49.07	2,973	60.80	3,412	69.92	3,769	77.33	2,186	44.60
Net carbon dioxide (lb):																		
Yard: west	50	0.17	93	0.31	142	0.47	192	0.64	247	0.83	308	1.03	363	1.21	413	1.38	226	0.75
Yard: south	50	0.17	93	0.31	142	0.47	192	0.64	247	0.83	308	1.03	363	1.21	413	1.38	226	0.75
Yard: east	50	0.17	93	0.31	142	0.47	192	0.64	247	0.83	308	1.03	363	1.21	413	1.38	226	0.75
Public	50	0.17	93	0.31	142	0.47	192	0.64	247	0.83	308	1.03	363	1.21	413	1.38	226	0.75
Air pollution (lb):[a]																		
Ozone uptake	0.06445	0.08	0.12444	0.16	0.19803	0.25	0.28834	0.36	0.39041	0.49	0.50514	0.63	0.63384	0.79	0.77022	0.96	0.37	0.47
Nitrous oxide uptake + avoided	0.06379	0.08	0.11478	0.14	0.17391	0.22	0.23863	0.30	0.31095	0.39	0.39101	0.49	0.47069	0.59	0.54943	0.69	0.29	0.36
Sulfur dioxide uptake + avoided	0.01055	0.02	0.02052	0.04	0.03192	0.06	0.04423	0.08	0.05861	0.10	0.07504	0.13	0.09119	0.16	0.10705	0.19	0.05	0.10
Small particulate matter uptake + avoided	0.02835	0.08	0.05860	0.17	0.11627	0.34	0.21618	0.63	0.34389	1.01	0.49586	1.45	0.66572	1.95	0.85100	2.49	0.35	1.01
Volatile organic compounds avoided	0.00264	0.00	0.00468	0.00	0.00687	0.00	0.00889	0.00	0.01120	0.01	0.01378	0.01	0.01578	0.01	0.01741	0.01	0.01	0.01
Biogenic volatile organic compounds released	-.00733	0.00	-.05331	-0.03	-.14390	-0.08	-.27063	-0.14	-.39476	-0.21	-.51433	-0.27	-.62917	-0.33	-.73958	-0.39	-0.34	-0.18
Avoided + net uptake	0.162	0.26	0.270	0.48	0.383	0.79	0.526	1.23	0.720	1.78	0.967	2.44	1.248	3.16	1.556	3.95	0.73	1.76
Hydrology (gal rainfall interception)	252	1.38	596	3.28	980	5.39	1,402	7.71	1,840	10.12	2,296	12.63	2,768	15.23	3,250	17.87	1,673	9.20
Aesthetics and other:																		
Yard		104.77		116.82		117.01		112.45		106.53		100.36		94.33		88.60		105.11
Public		118.89		132.55		132.77		127.59		120.88		113.88		107.04		100.53		119.27
Total benefits:																		
Yard: west		117.64		141.02		153.50		160.72		168.33		177.25		183.86		189.13		161.43
Yard: south		117.64		141.02		153.50		160.72		168.33		177.25		183.86		189.13		161.43
Yard: east		117.64		141.02		153.50		160.72		168.33		177.25		183.86		189.13		161.43
Public		131.75		156.76		169.26		175.87		182.68		190.77		196.56		201.06		175.59

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent. RU = resource unit.

[a] Values are the same for yard and public trees.

Table 16—Annual costs (dollars per tree) at 5-year intervals and 40-year average for a representative conifer tree (Monterey pine)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Tree and planting:[a]									
Yard	29.00								3.63
Public	29.00								3.63
Pruning:									
Yard	0.09	5.53	5.36	5.19	0.13	0.12	0.12	0.11	1.70
Public	2.98	19.36	18.69	18.02	33.11	31.82	30.54	29.25	21.57
Remove and dispose:									
Yard	1.00	1.40	2.08	2.75	3.42	4.09	4.75	5.42	2.89
Public	1.50	1.13	1.68	2.22	2.76	3.29	3.83	4.37	2.45
Pest and disease:									
Yard	1.11	3.48	4.99	6.39	7.69	8.87	9.95	10.93	6.23
Public	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01
Infrastructure repair:									
Yard	0.09	0.29	0.42	0.53	0.64	0.74	0.83	0.91	0.52
Public	0.66	2.06	2.95	3.76	4.50	5.17	5.77	6.30	3.65
Irrigation:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cleanup:									
Yard	0.02	0.05	0.07	0.09	0.11	0.13	0.14	0.16	0.09
Public	0.11	0.35	0.51	0.65	0.77	0.89	0.99	1.08	0.63
Liability and legal:									
Yard	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Public	0.01	0.03	0.05	0.06	0.08	0.09	0.10	0.11	0.06
Admin/inspect/other:									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.27	0.44	1.20	1.53	1.83	2.10	2.34	2.55	1.48
Total costs:									
Yard	31.31	10.75	12.92	14.96	11.99	13.95	15.80	17.54	15.06
Public	34.53	23.39	25.07	26.24	43.05	43.37	43.58	43.67	33.47

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

[a] Although tree and planting costs occur in year 1, this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table 17—Annual net benefits (dollars per tree) at 5-year intervals and 40-year average for a representative conifer tree (Monterey pine)

Total net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
					Dollars				
Yard: west	86	130	141	146	156	163	168	172	146
Yard: south	86	130	141	146	156	163	168	172	146
Yard: east	86	130	141	146	156	163	168	172	146
Public	97	133	144	150	140	147	153	157	142

Note: Annual values incorporate effects of tree loss. We assume that 15 percent of trees planted die during the first 5 years, 30 percent during the remaining 35 years, for a total mortality of 45 percent.

See table 15 for annual benefits and table 16 for annual costs.

Appendix 3: Procedures for Estimating Benefits and Costs

Approach

Overview

Because benefits from trees differ owing to regional differences in tree growth, climate, air pollutant concentrations, rainfall patterns, building characteristics, and other factors, we divided the United States into 16 climate zones. A reference city is designated for each climate zone, and intensive data are collected for modeling tree benefits. Criteria for selection as a reference city include:

- Updated inventory of trees by address.
- Detailed information on tree management costs.
- Long-tenured city foresters who can help age trees because they know when they were planted or when different neighborhoods were developed and street trees planted.
- Good contacts within other city departments to obtain data on sidewalk repair costs, trip/fall costs, and litter cleanup costs.
- Capability to provide the resources needed to conduct the study, including an aerial lift truck for 5 days to sample foliar biomass.

The city of Berkeley was selected as the reference city for the Northern California Coast region because it best met these criteria. During 2004, data were collected on tree growth and size for predominant street tree species in Berkeley, and other geographic information was assembled to model tree benefits. A subset of these data is used in this guide, and the entire data set is incorporated into the i-Tree Streets (formerly STRATUM) database for the Northern California Coast region (see www.itreetools.org).

In this study, annual benefits and costs over a 40-year planning horizon were estimated for newly planted trees in three residential yard locations (east, south, and west of the dwelling unit) and a public street-side or park location. Trees in these hypothetical locations are called “yard” and “public” trees, respectively. Prices were assigned to each cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability) and benefit (e.g., heating/cooling, energy savings, air-pollution reduction, stormwater-runoff reduction) through direct estimation and implied valuation of benefits as environmental externalities. This approach made it possible to estimate the net benefits of plantings in “typical” locations with “typical” tree species.

To account for differences in the mature size and growth rates of different tree species, we report results for small (camphor), medium (cherry plum), and large (velvet ash) broadleaf trees and a representative conifer (Monterey pine) (see "Common and Scientific Names" section). The selection of these species was based on data availability, and not intended to endorse their use in large numbers. In fact, the cherry plum has a poor form for a street tree and velvet ash is susceptible to the emerald ash borer (*Agrilus planipennis*), a pest that may threaten all ash in California. Relying on too few species can increase the likelihood of catastrophic loss owing to pests, diseases, or other threats. Results are reported for 5-year intervals for 40 years.

Mature tree height is frequently used to characterize small, medium, and large species because matching tree height to available overhead space is an important design consideration. However, in this analysis, leaf surface area (LSA) and crown diameter were also used to characterize **mature tree size**. These additional measurements are useful indicators for many functional benefits of trees that relate to leaf-atmosphere processes (e.g., interception, transpiration, photosynthesis). Tree growth rates, dimensions, and LSA estimates are based on tree growth modeling.

Growth Modeling

Growth models are based on data collected in Berkeley, California. An inventory of Berkeley's' street trees was provided by the city of Berkeley. The inventory included 36,485 trees representing 279 species.

Tree-growth models developed from Berkeley data were used as the basis for modeling tree growth for this report. Using Berkeley's tree inventory, a stratified random sample of 21 tree species was measured to establish relations among tree age, size, leaf area, and biomass. The species were as follows:

- Black acacia (*Acacia melanoxylon* R. Br.)
- Japanese maple (*Acer palmatum* Thunb.)
- Camphor tree (*Cinnamomum camphora* (L.) J. Presl.)
- Blue gum eucalyptus (*Eucalyptus globulus* Labill.)
- Velvet ash (*Fraxinus velutina* Torr.)
- Ginkgo (*Ginkgo biloba* L.)
- Sweetgum (*Liquidambar styraciflua* L.)
- Tulip poplar (*Liriodendron tulipifera* L.)
- Southern magnolia (*Magnolia grandiflora* L.)
- Chinese pistache (*Pistacia chinensis* Bunge)

- Monterey pine (*Pinus radiata* D. Don)
- Victorian box (*Pittosporum undulatum* Vent.)
- London planetree (*Platanus hybrida* Brot.)
- Cherry plum (*Prunus cerasifera* Ehrh.)
- Callery pear (*Pyrus calleryana* Decne.)
- Evergreen pear (*Pyrus kawakamii* Hayata)
- Coast live oak (*Quercus agrifolia* Née var. *oxyadenia* (Torr.) J.T. Howell)
- Black locust (*Robinia pseudoacacia* L.)
- Coast redwood (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.)
- American elm (*Ulmus americana* L.)
- Chinese elm (*Ulmus parvifolia* Jacq.)

For the growth models, information spanning the life cycle of predominant tree species was collected. The inventory was stratified into the following nine diameter-at-breast-height (**d.b.h.**) classes:

- 0 to 2.9 in
- 3 to 5.9 in
- 6 to 11.9 in
- 12 to 17.9 in
- 18 to 23.9 in
- 24 to 29.9 in
- 30 to 35.9 in
- 36 to 41.9 in
- >42.0 in

Thirty to sixty trees of each species were randomly selected for surveying, along with an equal number of alternative trees. Tree measurements included d.b.h. (to nearest 0.1 cm by sonar measuring device), tree crown and bole height (to nearest 0.5 m by clinometer), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5 m by sonar measuring device), tree condition and location. Replacement trees were sampled when trees from the original sample population could not be located. In total, 701 trees were measured. Field work was conducted in summer 2004.

Crown volume and leaf area were estimated from computer processing of tree-crown images obtained by using a digital camera. The method has shown greater accuracy than other techniques (±20 percent of actual leaf area) in estimating crown volume and leaf area of open-grown trees (Peper and McPherson 2003).

Linear regression was used to fit predictive models with d.b.h. as a function of age for each of the 21 sampled species. Predictions of LSA, crown diameter, and height metrics were modeled as a function of d.b.h. using best-fit models. After inspecting the growth curves for each species, we selected the typical small, medium, large, and conifer tree species for this report.

Reporting Results

Results are reported in terms of annual values per tree planted. However, to make these calculations realistic, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, this analysis assumed that 45 percent of the hypothetical planted trees died over the 40-year period. Annual mortality rates were 3 percent for the first 5 years, and 0.57 percent per year after that. This accounting approach "grows" trees in different locations and uses computer simulation to directly calculate the annual flow of benefits and costs as trees mature and die (McPherson 1992).

Benefits and costs are directly connected with tree-size variables such as trunk d.b.h., tree canopy cover, and LSA. For instance, pruning and removal costs usually increase with tree size, expressed as d.b.h. For some parameters, such as sidewalk repair, costs are negligible for young trees but increase relatively rapidly as tree roots grow large enough to heave pavement. For other parameters, such as air-pollutant uptake and rainfall interception, benefits are related to tree canopy cover and leaf area.

Most benefits occur on an annual basis, but some costs are periodic. For instance, street trees may be pruned on regular cycles but are removed in a less regular fashion (e.g., when they pose a hazard or soon after they die). In this analysis, most costs and benefits are reported for the year in which they occur. However, periodic costs such as pruning, pest and disease control, and infrastructure repair are presented on an average annual basis. Although spreading one-time costs over each year of a maintenance cycle does not alter the 40-year nominal expenditure, it can lead to inaccuracies if future costs are discounted to the present.

Benefit and Cost Valuation

Source of cost estimates—

Frequency and costs of tree management were estimated based on surveys with municipal foresters from Berkeley, Pleasanton, Redwood City, and San Jose. In addition, commercial arborists from Arborwell, Bartlett Tree Experts, Mayne Tree Expert Co., and S.P. McClenahan Co. provided information about tree-management costs on residential properties.

Pricing benefits—

Electricity and natural-gas prices for utilities serving the Northern California Coast region service area were used to quantify energy savings for the region. Costs of preventing or repairing damage from pollution, flooding, or other environmental risks were used to estimate what society is willing 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 gal of treated and controlled runoff to meet minimum standards, then the stormwater runoff mitigation value of a tree that intercepts 1,000 gal of rainfall, eliminating the need for control, should be $10.

Calculating Benefits

Calculating Energy Benefits

The prototypical building used as a basis for the simulations was typical of post-1980 construction practices, and represents approximately one-third of the total single-family residential housing stock in the Northern California Coast region. The house was a one-story, wood-frame, building with a basement and total conditioned floor area of 2,180 ft^2, window area (double-glazed) of 262 ft^2, and wall and ceiling insulation of R11 and R25, respectively. The central cooling system had a **seasonal energy efficiency ratio** (**SEER**) of 10, and the natural-gas furnace had an **annual fuel utilization efficiency (AFUE)** of 78 percent. Building footprints were square, reflecting average impacts for a large number of buildings (McPherson and Simpson 1999). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37 percent and were assumed to be closed when the air conditioner was operating. Summer thermostat settings were 78 °F; winter settings were 68 °F during the day and 60 °F at night. Because the prototype building was larger, but more energy efficient than most other construction types, our projected energy savings can be considered similar to those for older, less thermally efficient, but smaller buildings. The energy simulations relied on typical meteorological data from San Francisco International Airport (Marion and Urban 1995).

Calculating energy savings—

The dollar value of energy savings was based on regional average residential electricity and natural-gas prices of $0.213/**kWh** and $1.73/**therm**, respectively. Electricity and natural-gas prices were for 2006 for Pacific Gas and Electric (PG&E 2006a, 2006b, respectively). Homes were assumed to have central air conditioning and natural-gas heating.

Calculating shade effects—

Residential yard trees were within 60 ft of homes so as to directly shade walls and windows. Shade effects of these trees on building energy use were simulated for small, medium, and large deciduous trees and a conifer at three tree-to-building distances, following methods outlined by McPherson and Simpson (1999). The small tree (camphor) had a visual density of 82 percent during summer and winter. The medium tree (cherry plum) had a density of 80 percent during summer and 40 percent during winter. The large tree (velvet ash) had a visual density of 79 percent during summer and 29 percent during winter, and the conifer (Monterey pine) had a density of 85 percent year round. Crown densities for calculating shade were based on published values where available (Hammond et al. 1980, McPherson 1984).

Foliation periods for deciduous trees were obtained from the literature (Hammond et al. 1980, McPherson 1984) and adjusted for the region's climate based on consultation with the senior forestry supervisor (Koch 2004). Large trees were leafless November 1 through April 1, medium trees November 1 through March 15, and small trees and conifers were evergreen. Results of shade effects for each tree were averaged over distance and weighted by occurrence within each of three distance classes: 28 percent at 10 to 20 ft, 68 percent at 20 to 40 ft, and 4 percent at 40 to 60 ft (McPherson and Simpson 1999). Results are reported for trees shading east-, south-, and west-facing surfaces. The conifer is included as a windbreak tree located greater than 50 ft from the residence so it does not shade the building. Our results for public trees are conservative in that we assumed that they do not provide shading benefits. For example, in Modesto, California, 15 percent of total annual dollar energy savings from street trees was due to shade and 85 percent due to climate effects (McPherson et al. 1999).

Calculating climate effects—

In addition to localized shade effects, which were assumed to accrue only to residential yard trees, lowered air temperatures and windspeeds from increased neighborhood tree cover (referred to as climate effects) produced a net decrease in demand for winter heating and summer cooling (reduced windspeeds by themselves may increase or decrease cooling demand, depending on the circumstances). Climate effects on energy use, air temperature, and windspeed, as a function of neighborhood canopy cover, were estimated from published values (McPherson and Simpson 1999). Existing tree canopy cover for Berkeley was 23 percent, and building cover was estimated to be 25 percent based on Simpson and McPherson (2007). Canopy cover was calculated to increase by 1.9, 2.5, 3.9, and 4.7 percent for 20-year-old small, medium, and large broadleaf trees and the conifer, respectively, based on an effective lot size (actual lot size plus a portion of adjacent street and other rights-of-way) of 10,000 ft^2, and one tree on average was assumed per lot. Climate effects were estimated by simulating effects of air temperature and wind reductions on energy use. Climate effects accrued for both public and yard trees.

Calculating windbreak effects—
Trees near buildings result in additional windspeed reductions beyond those from the aggregate effects of trees throughout the neighborhood. This leads to a small additional reduction in annual heating energy use of about 1 percent per tree for conifers in the Northern California Coast region (McPherson and Simpson 1999). Yard and public conifer trees were assumed to be windbreaks, and therefore located where they did not increase heating loads by obstructing winter sun. Windbreak effects were not attributed to deciduous trees because their crowns are leafless during winter and do not block winds near ground level.

Atmospheric Carbon Dioxide Reduction

Calculating reduction in CO_2 emissions from powerplants—
Conserving energy in buildings can reduce carbon dioxide (CO_2) emissions from powerplants. These emission reductions were calculated as the product of energy savings for heating and cooling based on CO_2 **emission factors** (table 18) and were based on data for the Northern California Coast region where the average fuel mix is 43 percent natural gas, 26 percent hydro/renewable, 23 percent nuclear, 5 percent biomass/other and 3 percent coal (US EPA 2003). The value of $0.003 per lb CO_2 reduction (table 18) was based on the average value in Pearce (2003).

Calculating carbon storage—
Sequestration, the net rate of CO_2 storage in above- and belowground biomass over the course of one growing season, was calculated by using tree height and d.b.h. data with biomass equations (Pillsbury et al. 1998). Volume estimates were converted to green and dry-weight estimates (Markwardt 1930) and divided by 78 percent to incorporate root biomass. Dry-weight biomass was converted to carbon (50 percent), and these values were converted to CO_2. The amount of CO_2 sequestered each year is the annual increment of CO_2 stored as biomass each year.

Calculating CO_2 released by power equipment—
Tree-related emissions of CO_2, based on gasoline and diesel fuel consumption during tree care in our survey cities, were calculated by using the value

Table 18—Emissions factors and implied values for carbon dioxide and criteria air pollutants

Emission factor	Electricity[a]	Natural gas[b]	Implied value[c]
	Pounds per megawatt hour	*Pounds per million British thermal units*	*Dollars per pound*
Carbon dioxide	651.000	11.80000	0.00334
Nitrous oxide	0.445	0.01020	1.25
Sulfur dioxide	0.134	0.00006	1.77
Small particulate matter	0.169	0.00075	2.92
Volatile organic compounds	0.044	0.00054	0.53

[a] US EPA 2003, except Ottinger et al. 1990 for volatile organic compounds.

[b] US EPA 1998.

[c] Carbon dioxide from Pearce 2003. Value for others based on methods of Wang and Santini (1995) using emissions concentrations from US EPA (2003) and population estimates from the U.S. Census Bureau (2003).

0.78 lb CO_2/in d.b.h. This amount may overestimate CO_2 release for less intensively maintained residential yard trees.

Calculating CO_2 released during decomposition—
To calculate CO_2 released through decomposition of dead woody biomass, we conservatively estimated that dead trees were removed and mulched in the year that death occurred, and that 80 percent of their stored carbon was released to the atmosphere as CO_2 in the same year (McPherson and Simpson 1999).

Calculating reduction in air pollutant emissions—
Reductions in building energy use also result in reduced emission of air pollutants from powerplants and space-heating equipment. Volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)—both precursors of ozone (O_3) formation—as well as sulfur dioxide (SO_2) and particulate matter of <10 micron diameter (PM_{10}) were considered. Changes in average annual emissions and their monetary values were calculated in the same way as for CO_2, by using utility-specific emissions factors for electricity and heating fuels (Ottinger et al. 1990, US EPA 1998). The price of emissions savings were derived from models that calculate the marginal damage cost of different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from US EPA (2003), and population estimates from the U.S. Census Bureau (2003).

Calculating pollutant uptake by trees—
Trees also remove pollutants from the atmosphere. The modeling method we applied was developed by Scott et al. (1998). It calculates **hourly pollutant dry deposition** per tree expressed as the product of deposition velocity

($V_d = 1/[R_a + R_b + R_c]$), pollutant concentration (C), canopy-projection area (CP), and a time step, where R_a, $R_{b,}$ and R_c are aerodynamic, boundary layer, and stomatal resistances. Hourly deposition velocities for each pollutant were calculated during the growing season by using estimates for the resistances ($R_a + R_b + R_c$) for each hour throughout the year. Hourly concentrations for 2001 were selected as representative for modeling deposition based on a review of mean PM_{10} and O_3 concentrations for the years 1996–2004. The O_3, NO_2, and SO_2 data were from Oakland and PM_{10} from San Pablo (California Air Resources Board 2004). Hourly air temperature and windspeed data were obtained for Berkeley (CIMIS 2004). To set a value for pollutant uptake by trees, we used the procedure described above for emissions reductions (table 18). The monetary value for NO_2 was used for O_3.

Estimating BVOC emissions from trees—
Annual emissions for biogenic volatile organic compounds (BVOCs) were estimated for the three tree species by using the algorithms of Guenther et al. (1991, 1993). Annual emissions were simulated during the growing season over 40 years. The emission of carbon as isoprene was expressed as a product of the base emission rate (micrograms of carbon per gram of dry foliar biomass per hour), adjusted for sunlight and temperature and the amount of dry, foliar biomass present in the tree. Monoterpene emissions were estimated by using a base emission rate adjusted for temperature. The base emission rates for the four species were based on values reported in the literature (Benjamin and Winer 1998). Hourly emissions were summed to get monthly and annual emissions.

Annual dry foliar biomass was derived from field data collected in Berkeley during the summer of 2004. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data for 2001 described in the pollutant uptake section were used as model inputs.

Calculating net air quality benefits—
Net air quality benefits were calculated by subtracting the costs associated with BVOC emissions from benefits owing to pollutant uptake and avoided powerplant emissions. The O_3 reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from anthropogenic and biogenic sources, were estimated as a function of canopy cover following McPherson and Simpson (1999). They used peak summer air temperature reductions of 0.2 °F for each percentage of increase in canopy cover. Hourly changes in air temperature were calculated by reducing this peak air temperature at every hour based on hourly

maximum and minimum temperatures for that day, as well as maximum and minimum values of total global solar radiation for the year. However, this analysis does not incorporate the effects of lower summer air temperatures on O_3 formation rates owing to atmospheric processes.

Stormwater Benefits

Estimating rainfall interception by tree canopies—
A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 2000). The interception model accounted for water intercepted by the tree, as well as throughfall and **stem flow**. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Rainwater drips from leaf surfaces, flows down the stem surface to the ground, or evaporates. Tree-canopy parameters that affect interception include species, leaf and stem surface areas, **shade coefficient**s (visual density of the crown), foliation periods, and tree dimensions (e.g., tree height, crown height, crown diameter, and d.b.h.). Tree-height data were used to estimate windspeed at different heights above the ground and resulting rates of evaporation.

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree **dripline**), **leaf area indices** (LAI, the ratio of leaf surface area to crown projection area), and the depth of water captured by the canopy surface. Gap fractions, foliation periods, and tree **surface saturation storage capacity** influence the amount of projected throughfall. Tree surface saturation was 0.04 in for all trees. Hourly meteorological and rainfall data for 2005 from the CIMIS (California Irrigation Management Information System) Oakland Foothills Station (Station: ID #149; latitude 37°46' N, longitude 122°10' W) were used for this simulation. Annual precipitation during 2005 was 22.2 in. Storm events less than 0.1 in were assumed to not produce runoff and were dropped from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998, 2000).

Calculating water quality protection and flood control benefit—
Berkeley's Stormwater/Drainage Construction Program was not funded at the time this research was conducted. The benefit of runoff reduction was estimated by using costs associated with collection, conveyance, and treatment—single-family residential sewer service fees ($3.02/**Ccf**/dwelling unit). In Berkeley, the sewer service fee is a conservative proxy for a desired level of service. At $0.004/gal, this fee is below the average price for stormwater runoff reduction ($0.01/gal) assessed in similar studies (Maco et al. 2005).

Aesthetic and Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, wildlife habitat, shade that increases human comfort, sense of place, and well-being are services that are difficult to price. However, the value of some of these benefits may be captured in the property values of the land on which trees stand.

To estimate the value of these "other" benefits, we applied results of research that compared differences in sales prices of houses to statistically quantify the difference associated with trees. All else being equal, the difference in sales price reflects the willingness of buyers to pay for the net benefit associated with trees. This approach has the virtue of capturing in the sales price both the benefits and costs of trees as perceived by the buyers. Limitations to this approach include difficulty determining the value of individual trees on a property, the need to extrapolate results from studies done years ago in the East and South to the Midwest region, and the need to extrapolate results from front-yard trees on residential properties to trees in other locations (e.g., backyards, streets, parks, and nonresidential land).

A large tree adds value to a home—
Anderson and Cordell (1988) surveyed 844 single-family residences in Athens, Georgia, and found that each large front-yard tree was associated with a 0.88-percent increase in the average home sales price. This percentage of sales price was used as an indicator of the additional value a resident in the Northern California Coast region would gain from selling a home with a large tree.

The sales price of residential properties differed widely by location within the region. By averaging the values for several cities, we calculated the average home price for Northern California Coast communities as $631,267 in 2004. Therefore, the value of a large tree that added 0.88 percent to the sales price of such a home was $5,567. To estimate annual benefits, the total added value was divided by the LSA of a 40-year-old velvet ash ($5,567/3,348 ft^2) to yield the base value of LSA, $1.66/$ft^2$. This value was multiplied by the amount of LSA added to the tree during 1 year of growth.

Calculating the aesthetic value of a residential yard tree—
To calculate the base value for a large tree on private residential property, we assumed that a 40-year-old ash in the front yard increased the property sales price by $5,567. Approximately 75 percent of all yard trees, however, are in backyards (Richards et al. 1984). Lacking specific research findings, it was assumed that

backyard trees had 75 percent of the impact on "curb appeal" and sales price compared to front-yard trees. The average annual aesthetic benefit for a tree on private property was estimated as $1.11/ft^2 LSA. To estimate annual benefits, this value was multiplied by the amount of LSA added to the tree during 1 year of growth.

Calculating the base value of a public tree—
The base value of a public tree was calculated in the same way as front-yard trees. However, because street and park trees may be adjacent to land with little value or resale potential, an adjusted value was calculated. A citywide street tree reduction factor (82 percent) was applied to prorate trees' value based on the assumption that public trees adjacent to different land uses make different contributions to property sales prices. For this analysis, the land use factor reflects the proportion of street trees in Berkeley by land use and the reduction factor is the value of a tree in an area of that use relative to single-home residential. Land use and reduction factors, shown respectively, were single-home residential (59 percent, 100 percent), multi-home residential (8 percent, 75 percent), small commercial (12 percent, 66 percent), industrial/institutional/large commercial (6 percent, 50 percent), and park/vacant/other (2 percent, 50 percent) (Gonzales 2004, McPherson 2001).

Although the impact of parks on real estate values has been reported (Hammer et al. 1974, Schroeder 1982, Tyrvainen 1999), to our knowledge, the onsite and external benefits of park trees alone have not been isolated (More et al. 1988). After reviewing the literature and recognizing an absence of data, we made the conservative estimate that park trees have half (50 percent) as much impact on property prices as street trees.

Given these assumptions, typical large street and park trees were estimated to increase property values by $1.36 and $0.83/ft^2 LSA, respectively. Assuming that 80 percent of all municipal trees were on streets and 20 percent in parks, a weighted average benefit of $1.26/ft^2 LSA was calculated for each tree.

Calculating Costs

Tree management costs were estimated based on surveys of municipal foresters and commercial arborists in the region.

Planting

Planting costs include the cost of the tree and the cost for planting, staking, and mulching the tree. Based on our survey of municipal and commercial arborists, planting costs depend on tree size. Costs ranged from $36 for a volunteer-planted tree to $960 for a 36-in box tree. In this analysis, we assumed that a 15 gal tree was planted at a cost of $145.

Pruning

Pruning costs for public trees—

After studying data from municipal forestry programs and their contractors, we assumed that young public trees were inspected and pruned once during the first 5 years after planting, at a cost of $17.50 per tree. After this training period, pruning occurred once every 7 years for public trees. Pruning costs were $50, $165, and $315 for small (<20 ft tall), medium (20 to 40 ft tall), and large trees (>40 ft tall). More expensive equipment and more time was required to prune large trees than small trees. After factoring in pruning frequency, annualized costs were $3.50, $7.14, $23.57, and $45.00 per tree for public young, small, medium, and large trees, respectively.

Pruning costs for yard trees—

Based on findings from our survey of commercial arborists in the region, pruning cycles for yard trees were more frequent than reported for public trees: 3, 4, 5, and 6 years for young, small, medium, and large trees, respectively. However, survey findings indicate that only 20 percent of all private trees are professionally pruned, and the number of professionally pruned trees grows as the trees grow (Summit and McPherson 1998). Accordingly, we assumed that professionals are paid to prune all large trees, 60 percent of the medium trees, and only 6 percent of the small and young trees and conifers. Using these **contract rates**, along with average pruning prices ($25, $100, $250, and $450 for young, small, medium, and large trees, respectively), the average annual costs for pruning a yard tree were $0.10, $0.30, $6.00, and $15.30 for young, small, medium, and large trees, respectively.

Tree and Stump Removal

The costs for tree removal and disposal were $14/in d.b.h. for public trees, and $30/in d.b.h. for yard trees. Stump removal costs were $15/in d.b.h. for public and $6/in d.b.h. for yard trees. Therefore, total costs for removal and disposal of trees and stumps were $29/in d.b.h. for public trees, and $36/in d.b.h. for yard trees.

Pest and Disease Control

Expenditures for pest and disease control in the Northern California Coast region are negligible for public trees but substantial for yard trees. They averaged about

$5 per tree per year or approximately $0.55/in d.b.h. for private trees. Results of our survey indicated that yard trees were most frequently treated for anthracnose, aphids, sudden oak death, and leaf spot.

Irrigation Costs

Rain falls fairly regularly during winter throughout most of the region and additional irrigation is not usually needed after establishment when trees are planted into landscapes with installed irrigation. Frequently, trees are watered for the first summer after planting. We included initial irrigation costs with planting costs in this report.

Other Costs for Public and Yard Trees

Other costs associated with the management of trees include expenditures for infrastructure repair/root pruning, leaf-litter cleanup, litigation/liability, and inspection/administration. Cost data were obtained from the municipal arborist survey and assume that 80 percent of public trees are street trees and 20 percent are park trees. Costs for park trees tend to be lower than for street trees because there are fewer conflicts with infrastructure such as power lines and sidewalks.

Infrastructure conflict costs—

Many Northern California Coast municipalities have a substantial number of large, old trees and deteriorating sidewalks. As trees and sidewalks age, roots can cause damage to sidewalks, curbs, paving, and sewer lines. Sidewalk repair is typically one of the largest expenses for public trees (McPherson and Peper 1995). Infrastructure-related expenditures for public trees in Northern California Coast communities were greater than most other regions, exceeding $20 per tree on an annual basis in some cities. Roots from most trees in residential yards do not damage sidewalks and sewers. Therefore, we did not include this cost for yard trees.

Liability costs—

Urban trees can incur costly payments and legal fees owing to trip-and-fall claims. A survey of Western U.S. cities showed that an average of 8.8 percent of total tree-related expenditures was spent on tree-related liability (McPherson 2000). Communities in our survey report spending on average $0.07 per tree for tree-related liabilities annually.

Litter and storm cleanup costs—

The average annual per-tree cost for litter cleanup (i.e., street sweeping, storm-damage cleanup) was $0.72/tree ($0.06/in d.b.h.). This value was based on average annual litter cleanup costs and storm cleanup, assuming a large storm results in extraordinary costs about once a decade. Because most residential yard trees are not littering the streets with leaves, it was assumed that cleanup costs for yard trees were 10 percent of those for public trees.

Green-waste disposal costs—

Green-waste disposal and recycling costs were minimal for our survey of Northern California Coast communities, where most green waste is recycled as mulch, compost, firewood, or other products. Fees from the sale of these products largely offset the costs of processing, hauling, and tipping. Disposal costs for yard trees were also negligible.

Inspection and administration costs—

Municipal tree programs have administrative costs for salaries of supervisors and clerical staff, operating costs, and overhead. Our survey found that the average annual cost for inspection and administration associated with street- and park-tree management was $1.36 per tree ($0.15/in d.b.h.). Trees on private property do not accrue this expense.

Calculating Net Benefits

Benefits Accrue at Different Scales

When calculating net benefits, it is important to recognize that trees produce benefits that accrue both on- and offsite. Benefits are realized at four scales: parcel, neighborhood, community, and global. For example, property owners with onsite trees not only benefit from increased property values, but they may also directly benefit from improved human health (e.g., reduced exposure to cancer-causing UV radiation) and greater psychological well-being through visual and direct contact with plants. However, on the cost side, increased health care may be incurred because of nearby trees owing to allergies and respiratory ailments related to pollen. We assumed that these intangible benefits and costs were reflected in what we term “aesthetics and other benefits.”

The property owner can obtain additional economic benefits from onsite trees depending on their location and condition. For example, carefully located onsite trees can provide air-conditioning savings by shading windows and walls and cooling building microclimates. This benefit can extend to adjacent neighbors who benefit from shade and air-temperature reductions that lower their cooling costs.

Neighborhood attractiveness and property values can be influenced by the extent of tree canopy cover on individual properties. At the community scale, benefits are realized through cleaner air and water, as well as social, educational, and employment and job training benefits that can reduce costs for health care, welfare, crime prevention, and other social service programs.

Reductions in atmospheric CO_2 concentrations owing to trees are an example of benefits that are realized at the global scale.

Annual benefits (B) are calculated as:

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

where

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

AQ = value of annual air-quality improvement (pollutant uptake, avoided powerplant emissions, and BVOC emissions)

CO_2 = value of annual CO_2 reductions (sequestration, avoided emissions, minus release owing to tree care and decomposition)

H = value of annual stormwater-runoff reductions

A = value of annual aesthetics and other benefits

On the other side of the benefit-cost equation are costs for tree planting and management. Expenditures are borne by property owners (irrigation, pruning, and removal) and the community (pollen and other health care costs). Annual costs (C) equal the costs for residential yard trees (C_Y) and public trees (C_P):

$$C_Y = P + T + R + D + I + S + Cl + L$$

$$C_P = P + T + R + D + I + S + Cl + L + G$$

where

P = cost of tree and planting

T = average annual tree pruning cost

R = annualized tree and stump removal and disposal cost

D = average annual pest- and disease-control cost

I = annual irrigation cost

S = average annual cost to repair/mitigate infrastructure damage

Cl = annual litter and storm cleanup cost

L = average annual cost for litigation and settlements of tree-related claims

G = annual program administration, inspection, and other costs

Net benefits are calculated as the difference between total benefits and costs:

Net benefits = $B - C$

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